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Does an Over-All Modelling Make Any Sense in Automatic Fire Detection?

Abstract

Computer simulation is an important tool in systems design and engineering today. It is used in almost every technical field with considerable success. In this paper the situation in the automatic fire detection case concerning the use of simulation tools and the problem of an associated modelling is discussed. Here an comprehensive "over-all" modelling technique is missing with the consequence that computer simulation is only carried out for parts of the technical problem so far. The existing models cover these parts only and are not designed in a manner that makes an easy combination possible.

An "over-all" modelling is discussed in the paper in very general terms. It shows that there are at least two interfaces existing in this concept which need to be worked out in order to get an comprehensive complete model that could be used for simulation purposes. The "over-all" concept has to take into account the situation in the surroundings of the detector heads (fire as well as not-fire case), the sensor part of the fire detection heads and the "fire-signal"- and data processing part in the detecting system. Such an "over-all" modelling technique is not yet existing. It may also be attractive for large, important and live-safety relevant systems only, because considerable effort has to be put into the solution of this problem. Nevertheless it is attractive from a scientific point of view.

1. Introduction

Model-based simulation is one of the key technologies in science and engineering today. It is applied in very many technical fields as a tool for experimental system design and testing, e.g. in the car & aircraft industry, in the (micro-)electronic circuit design etc. Essentials for a successful application are:

- A more or less complete understanding of the physical backgrounds for all different parts of the system that is under consideration.
- The availability of an appropriate algorithmic model description in combination with large and fast enough computing facilities.

The better and the more complete the physical background of a technical problem is understood the more valuable is the associated mathematical model and the more useful is the computer-simulation based on it. This simple statement is also valid vice versa.

So significant modelling is needed, i.e. modelling that describes reality as exact, complete and in detail as possible. Simulation based on it gives the opportunity to check or to test design draft proposals in a virtual computer world with much lower efforts and costs resp. than in a real laboratory or workshop procedure. The possibility of experimental design is enormously enlarged.

Experimental design associated with performance simulation procedures has been used in automatic fire detection in a very restricted way, i.e. in limited parts of the problem only. The reason for this fact is the absense of an adequate, sufficiently complete modelling in this field of fire safety.

From these considerations it can be concluded that a significant over-all modelling of the automatic fire detection procedure probably makes sense for the following reasons :

- A better understanding of the fire detection procedure in all its details could be achieved, incl. the false alarm problem. To cover this phenomenon too it is necessary that the modelling incorporates the significant not-fire situations as well as the fire situations that may occur.
- Design tools could be developed in order to adapt the actual system design to the individual conditions in the field. These design tools would have to cover the system performance as a whole. They are to be based on a significant modelling but they are working in an artificial computer world.
- Testing procedures probably could be developed that - at least partly - are able to replace much more costly laboratory tests.

The above statements were made out of purely physical and / or technical considerations in the sense of fire detection system improvements. Improvements which probably could be achieved by introducing considerable scientific and technical effort. But it cannot be decided by considerations like these whether or not the development of over-all modelling and associated simulation tools makes sense for the fire detection industry. An answer to this question can only be based on the expectation of improvements that probably can be achieved in combination with the chances to place them in the market.

2. A Fire Detection Over-All Model Concept

Fig. 1 shows an over-all model of the detection procedure in fundamental terms. The model gives no details but it may clarify the different areas in which people work in fire safety with a concern in (early) fire detection. Fig. 2 gives a more technical version of this model.

The "outer world" :	Sensor :	Signal Processing & Decision making part :
Fire source (if present), Temperature Distribution, "Smoke" - Distribution, Flame Radiation, Environmental Parameters (humidity, air pressure and movement etc.)	Physical sensor element	Random sensor output signals, Relevant signal features, Detection parameters (e.g. threshold value)
	"Fire" - Parameters having impact on the sensing element	Sensor output signals
Method of treatment :	Method of treatment :	Method of treatment :
CFD modelling	Physical sensor (performance) model	Random signal modelling, Detection - Algorithms

Fig. 1 Automatic Fire Detection. The over all concept.

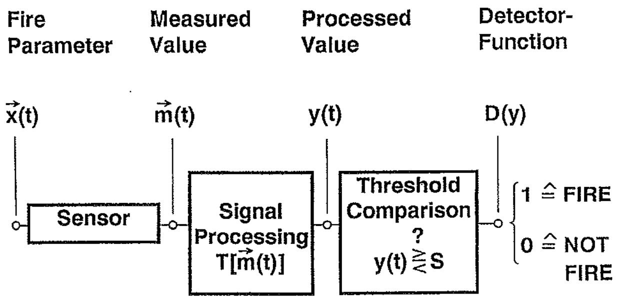

Fig.2 Schematic sketch of the detection procedure

Both figures show that there are - at least - two interfaces that limit the areas between the working fields of different groups who work in the fire safety science and industry. These interfaces are :

- The limit between the "outer world" and the sensor model. The term "outer world" is used because anything that is going on in front of the sensor forms a given situation for the fire detection system. The situation is not influenced by the design of or measures from the detection system.
- The limit between the sensor model and the signal processing & decision making part.

These interfaces are difficult to incorporate in an unique model, because the people working in the different areas normally have different scientific and / or professional backgrounds. One of the consequences is the existence of modelling and simulation methods in each of the three parts in the field which do not work together in a suitable way.

3. The “outer world“

The "outer world" incorporates the fire source and the whole environment of the detector heads. The associated model has to model the fire source, or the false alarm source resp., as well as all (spatial) distribution phenomena, i.e. temperature, smoke, flame radiation and gas components, that may play an significant role. In Fig.2 the “outer world “ is represented by a set of measurable parameters expressed through the vector-valued quantity $\vec{x}(t)$. This set $\vec{x}(t)$ represents the observable part of the "outer world" for the fire detection system. Any physical quantity in the environment of the detector head(s) may have an indirect impact on the set of measured quantities $\vec{m}(t)$, e.g. humidity on the reading of an ionization chamber sensor, but it is not directly observable if it is not incorporated in the set $\vec{x}(t)$. On the other hand the “outer world “-model has to produce a suitable set $\vec{x}(t)$ the elements of which directly can be picked up by suitable models for the sensors applied in the detector head.

A lot of scientific work has already been done in modelling the “outer world “. The existing models are based on thermo-dynamical considerations and are used for CFD (Computational-Fluid-Dynamics) computer simulations, see e.g. [1] where the Fire Research Station's (UK) JASMINE-code was used, or [4] for the flame radiation case.

These models have proofed to be very successful in fire research for calculating temperature- and "smoke-density"-distributions in enclosures in different fire cases [3] but they show the following weak points for the subject discussed here:

- The underlying models do not cover the very first (starting) period of a developing fire which is extremely nonstationary.
- The model output quantities for "smoke-density" measures do not deliver those parameter quantities that are needed for a careful sensor modelling. In the smoke detector case input parameters like particle number concentration N, particle size ditribution $p_D(d)$, where d is the actual particle diameter and D the associated random variable, particle mean value $\bar{d}$, refractive index of the particulate matter etc. as functions of time are necessary for detailed modelling. The assumption that "particle density" will correlate with temperature and that smoke detectors will be activated when the temperature-rise reaches a value of $13\,^0\mathrm{C}$ is not in general satisfied [5]. Smouldering fires are not covered by this assumption at all.
- They are not designed to model the NOT-FIRE case.

A general view on the modelling that exists for the "outer world" is given in [6]. A study of the application of a field model and a two-zone model to flashover fires in a multi room building is carefully described in [7]. Here gas components (CO and CO_2) are also considered. But the application for detection modelling is not directly possible.

4. Sensors

Any fire detector incorporates a sensor element which converts the physical fire phenomenon $\vec{x}(t)$ mostly into electrical signals that can be used for further processing. Sensor properties have a considerable impact on the resulting signal characteristics. The following items have to be known and have to be taken into account if sensor modelling is concerned:

- The really observed physical quantities have to be used for modelling; i.e. the components of $\vec{x}(t)$ are given by the temperature in the gas (fluid),the physical smoke parameters (particle size distribution $p_D(d)$, refractive index of the smoke particles, particle number concentration N, particle shape(?) etc.), the chemical consistency of the particles, the flame radiation quantities in the vicinity of the detector head, gas components reaching the detector location. The time dependance of the relevant quantities is of significant importance.
- The sensor transfer function $\vec{x}(t) \Rightarrow \vec{m}(t)$.
- The environmental quantities in the vicinity of the detector heads that may have an impact on the sensor performance, e.g. humidity, air pressure, air (fluid) movement etc.

Although the performance of most of the sensor elements used in the field is pretty well understood very little has been done so far to incorporate the sensor element into the modelling of fire detection systems. In this context a general sensor element model is needed. Heskestad [8] developed a rather simple generalized model for smoke detectors using a so called characteristic length which in fact is a measure for the time delay that is produced by the procedure of smoke penetrating into the measuring chamber of this kind of detector head (one parameter model). An obviously extended model will be presented by Th. Cleary et al. later this year at the 6. ISFSS in Poitiers/France. Both these models may be useful for an over-all modelling. These are the only attempts known so far. All other descriptions of fire detectors are very closely tied to the physical performance of the sensor element used in the special case and are not directly applicable for over-all modelling.

As an example the reading of an ionization chamber smoke sensor, i.e. the current drop Δi, that is due to the smoke particles in the ionization chamber volume, is considered. It can be linked to the actual aerosol parameters N and $\bar{d}$ in the following way [15]:

$$\frac{\Delta i}{i_0} \cdot \frac{2 - \frac{\Delta i}{i_0}}{1 - \frac{\Delta i}{i_0}} = \text{const.} N \cdot \bar{d}$$

, where i_0 is the current across the ionization chamber without smoke in it. This model description of the ionization chamber can only been used for further modelling if the quantities of N and $\bar{d}$ in the sensor measuring chamber are available as functions of time.

Not very much effort has been put into the development of new sensor elements in the last decades. Almost all newly presented sensors for fire detection purposes are based on the well known principles:

- temperatur measurement by thermocouples or semiconductor elements;
- smoke measurement based on the ionization-chamber method or on optical methods (scattered light, light obscuration);
- radiation measurement with thermo- or semiconductor elements.

The main effort at present is put on the development of low price elements and on the creation of multi-sensor combinations. Some efforts are under way to develop suitable gas sensors for application in fire detection systems. Some progress has been made here [9], but model presentations which are applicable for over-all modelling are missing so far.

5. Detection procedure: Signal processing, decision making

The detection procedure consists of an - as effective as possible - transformation D(y) with $y(t) = T[\vec{m}(t)]$, where D(y) is a simple threshold-comparison decision procedure and $T[\vec{m}(t)]$ is some kind of feature extraction from the set of measured signals $\vec{m}(t)$ (see fig. 2).

The sensor output signals $\vec{m}(t)$ have to be considered as not-stationary random. The random elements in $\vec{m}(t)$ are due to the random behavior of most of the physical parameters in the surroundings of the detector heads in the field and to electronic noise produced during the data-processing in the system. The first may or may not be influenced by a developing fire in the premises to be protected. In any case the modelling has to be based on the modern tools of random signal modelling. Some work has been done in this field already (see [2]) and this part is the one where most of the activities in the fire detection industry are going on at present.

Any relevant signal modelling has to be based on the background of field-measured data. From modern signal processing theory several methods are known to derive signal models form measured data that can be used for computer-simulations (see fig's. 3 and 4). The aim of these techniques is twofold:

- Signal models describing the different situations - fire situations as well as not-fire cases - in the detection procedure can serve as the mathematical background for detection algorithms that can be applied in fire detectors [10, 11].
- Signal models based on measured data in the field may be used as a tool for testing new detection algorithms [12, 13].

The knowledge of the development in modern signal processing methods is necessary in this context. It should also not been ignored that there are problems in connection with data collection in the field. As an alarm or a false alarm situation in the field is a very rare event from the point of view of a single detector head, the total amount of collected data can very soon become tremendous. The only way out of this situation is a so called "selected collection" where data only are recorded in situations that are likely to produce an alarm in the detector. For an realistic simulation procedure it is then necessary to collect data concerning the statistics of inactive period lengths too and include this knowledge into the signal model which is the background for simulation [3, 14].

It should be mentioned in this context that the testing procedure indicated above has nothing to do with the type-testing for approval purposes. It is just a tool for the detector designer who wants to compare a new designed detection algorithm with others having in mind that all algorithms to be compared are based on the same set of sensors or sensor signals (i.e. dedicated detectors [10]).

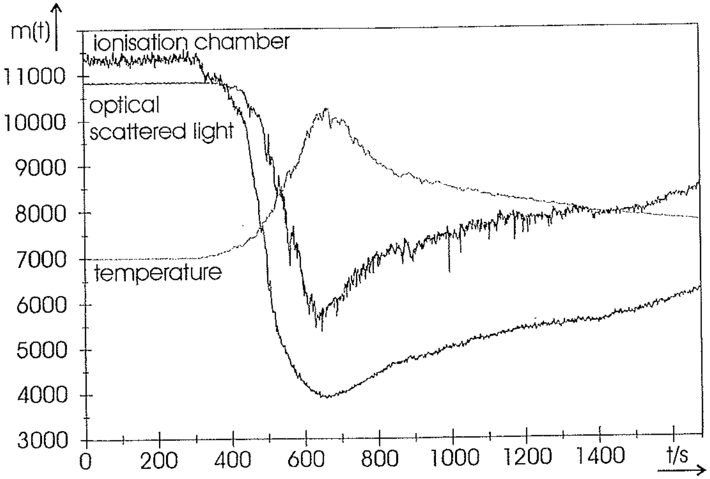

Fig. 3 Output signals m(t) of typical sensors measured in a test fire experiment TF1 according to EN54/9

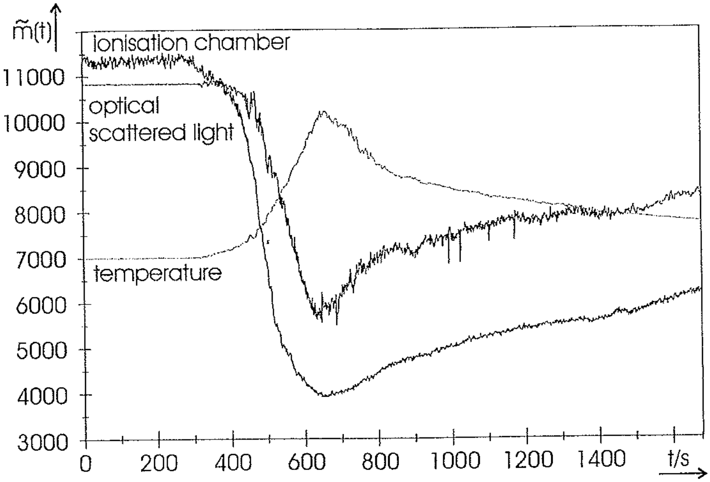

Fig. 4 Simulated output signals m̃(t) for the sensor signals shown in fig. 3

6. Conclusions

The efficiency of automatic fire detection installations is given by their so called detectivity. Detectivity is a two parameter quantity:

(1.) Safely to detect a fire situation, i.e. a high detection probability γ and

(2.) to distinguish this from all not-fire situations, i.e. a low false alarm rate α.

So an over-all modelling / simulation has to produce figures of these quantities for the system under consideration. So the consequences for a meaningful over-all model in automatic fire detection are as follows:

- The model makes sense only for a given combination of the premises to be protected, the detection system and a statistical knowledge about the environmental behavior of the detector heads surroundings.
- The "outer world"- model has to provide the not-fire situations as well as the predetermined fire situations incl. the statistical parameter behavior.
- Some work to model the interface parts in the "over-all" model shown in fig. 1 has to be done. That requires additional scientific and development effort. A comprehensive model is not achievable by just using existing techniques.

From this it can be derived that comprehensive modelling of the automatic fire detection procedure will really be attractive in those cases, where the system to be modeled is big and important enough to put additional effort - compared with the already existing methods - into it, in order to gain more information about the fire detection system's performance in predetermined situations.

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New Approaches to the Interpretation of Signals from Fire Sensors

Abstract

In recent years fire sensors have evolved from threshold devices that sense a single fire signature to multi-mode, multi-criteria sensors that can employ algorithms for decision making. However, these algorithms have so far been based on simple, signal cross-correlation techniques or have employed simple truth tables in an effort to exclude sources of false activations while not rejecting real events. At NIST's Building and Fire Research Laboratory, new research has been initiated to apply our experience with physically based computer models of fire growth and spread in enclosed spaces to the interpretation of signals from fire sensors. Here, data from fire sensors are compared in real time to signals that would be expected from a fire within the protected space. The sensor data is used to adjust unknown variables so that the simulation better matches data. Signals that are inconsistent with the physical laws of fire growth can be questioned and when signals track with projections the system can provide detailed information on current conditions within the space as well as an ability to project future conditions. This latter ability is of considerable interest to fire brigades who could be warned of conditions that may threaten their safety or that of occupants. While in its early stages, the research results are promising.

Background and Current Approaches

Automatic fire detectors are about a hundred years old, and are a crucial component in addressing the life safety goals for the built environment. However, most experts agree that the greatest shortcoming of fire detectors is a high rate of nuisance alarms that limit the detectors credibility with the public. Various schemes have evolved to address this problem; methods to discriminate against conditions that mimic the fire signatures upon which the detectors depend. This paper will discuss the most common of these approaches and will present a new approach under development at the National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory (BFRL).

Nuisance Alarms

Like the "Cry Wolf" story, excessive nuisance alarms limit the credibility of fire alarm systems. Ahrens[1] reports that 69% of people surveyed said that a fire alarm does NOT indicate a fire, but rather some other abnormal condition. Of course, this results in people not starting evacuation until some other fire queue appears, increasing the risk of death or injury.

There are several studies in the literature that quantify nuisance alarm rates in (commercial) fire alarm systems. In the early 1970's Fry[2] reported data from the U.K.

where most systems were connected to fire brigades and reports on every alarm were made. He found nuisance alarm ratios (the ratio of nuisance alarms to real fires detected) for smoke detectors of 14:1. In a 1980 survey of health care facilities in the U.S., Bukowski and Istvan[3] reported nuisance alarm ratios for smoke detectors also at 14:1. In a paper presented at AUBE '95, an officer with the Swiss fire service, Steck[4] reported data from Bern that 77% of alarms received from smoke detectors were false. This translates into a nuisance alarm ratio of about 4:1.

What is striking about these three studies is that they represent three generations of development of smoke detector technology. Fry's data is for detectors in use in the late 1960's, characterized by incandescent lamps and 90 degree scattering optics within highly restrictive chambers, single chamber ionization detectors, and no signal processing beyond alarm at a fixed threshold. The Bukowski and Istvan data is for detectors of the late 1970's that were likely to use LED's and forward scattering optics in chambers designed for much easier smoke entry or dual chamber ionization sensors that were more stable for variations in ambient conditions. The Steck data was for detectors of the 1990's that utilize drift compensation and possibly even early decision algorithms to make the systems "smart." While the evolution of this technology has had some effect on the observed rate of nuisance alarms, the successes have been largely to the problem of alarms from environmental conditions such as temperature, humidity, and high air velocity. What remains is to address unwanted alarms to non-fire aerosols.

The Search for Intelligence

For much of their history fire detectors have been threshold devices - alarm decisions are made when the signal exceeds some fixed threshold level generally referred to as the device's sensitivity. In the language of modern digital electronics this means that the detector is operating on a single bit of information. Some thermal detectors operate on the rate-of-rise principle (alarm when the rate of temperature rise exceeds a fixed value). Even where the thermal detector has dual elements (fixed temperature and rate-of-rise) they indicate an alarm when either element exceeds its threshold, so they are also one bit devices.

One thermal detector, the rate compensation device, operates such that a rapid increase in temperature causes it to decrease the fixed temperature value at which it activates. This could be considered a two-bit criterion since the conditions interact. One light scattering type smoke detector from the 1970's incorporated a circuit that increased the sensitivity (decreased the alarm threshold) if the rate of rise of the smoke signal exceeded a threshold value. While this was primarily done to compensate for an alarm photocell with an excessively long time constant, it represented a two-bit alarm operation.

Another approach to system intelligence was time of day adjustments. Since most nuisance alarms derive from human activities, some systems in the 1970's were given the ability to increase their sensitivity at times when the facility was unoccupied. This was typically done by building in time of day/day of week calendars by which adjustments were automatically made. However, since adjusting sensitivity can represent a compromise of early warning of fires which may be unacceptable to regulator officials and building owners and occupants.

Time delays have been used in detectors to eliminate nuisance alarms to transient phenomena. Here, detectors begin the delay period when the alarm threshold is exceeded and will only alarm if the signal persists for the duration of the delay. A variation on this theme is the alarm verification circuit that resets the smoke detector to determine if it will alarm a second time, after some power down/power up delay. Like the time of day adjustment, the introduction of delays can compromise the early warning aspects of the system response to real fires.

Multiple Sensors

Early attempts at real increases in the intelligence used in alarm decisions involved pattern recognition. In theory, if one could determine a unique pattern in the signal from real fire sources it would be possible to differentiate these from nuisance sources. Signal characteristics examined ranged from simple (temporal variations or rate of change)[5] to complex (particle size distribution)[6] but the general conclusion was that none were sufficiently unique to allow systems to reject nuisance signals without significant risk of also rejecting some actual fires.

The first successes in increased intelligence required the combination of different sensors such as thermal and smoke, ionization and scattering, smoke and gas, in detectors sometimes called multi-mode sensors. Early devices simply combined sensors in an AND configuration. Later more sophisticated signal processing techniques such as signal cross-correlation were applied to produce significant improvements in performance. For example, Qualey et al.[7] describe the development of a cross correlation algorithm for a thermal/smoke combination intended to reduce nuisance alarms without reducing detection performance.

This success can be explained by the prior analogy to digital electronics. It was now possible to base alarm decisions on multiple bits of information. The more bits available on which to base an alarm decision, the better that decision can be made and the lower is the rate of both false positives (nuisance alarms) and false negatives (unwanted fires not detected).

Fuzzy Logic and Neural Networks

A limitation of these early multi sensor approaches was that they could only be combined in AND or OR configurations through typical digital circuits. Digital electronics is 1's and 0's -- on or off, true or false. The development of fuzzy logic in the 1980's changed that. Fuzzy logic can deal with a range -- bigger, smaller, longer, higher. This allowed multi sensors to utilize multiple criteria for example more smoke required less heat to signal an unwanted fire.

Fuzzy logic was an advance, but as the number of sensor inputs increased it became very difficult to think through the logic of their interaction. Neural networks were the next advance where the system is "trained" in how to categorize various patterns of signals. Neural networks are capable of integrating hundreds of sensors and making decisions on large amounts of data (bits of information. Milke[8] describes work to develop a neural network for residential fire detection.

The underlying problem with signal cross correlation, fuzzy logic, and neural networks is that they represent an empirical fit to data. The correlations, logic tables, or training process are developed by exposing the sensors to fires and nuisance sources and determining the coefficients or settings that alarm to all fires and ignore most nuisance sources. Since it is impossible to include all fires and nuisance sources, and because there is no standard set of nuisance sources, the applicability of this approach is somewhat limited to highly controlled applications.

Neural networks can learn "on the job," so when exposed to a pattern that they have not seen before they might assume a fire to be conservative. Later if this was determined to be a nuisance source the system training could be altered and it would no longer signal fire to this pattern. The fear is that a real fire could look sufficiently like a prior nuisance source that the system would ignore it. What is needed is a system that knows enough about fire itself to decide on signal patterns that it has never encountered before.

The NIST Approach

The field of fire science has made great strides in the past two decades, and the increased understanding of fire has been incorporated into computer fire models of ever increasing sophistication. These model are based on the physics and chemistry of fires and as such are valid over a broad range of conditions. Thus, these models represent a method of assessing the validity of an alarm decision against hundreds or even thousands of bits of data. The technology that is beginning to enable such to be done is the increase in processing power and speed of the modern microprocessor and the simultaneous decrease in cost that allows their incorporation into systems.

As sensors become smaller and less expensive, buildings will incorporate more and more such sensors to regulate many aspects of the building such as comfort levels, energy usage, and security. While many of these sensors' primary function will not be fire protection, their response to a fire is predictable. Using the information from all sensors and an understanding of the physics of fires, the heat release rate and other information on the fire might be deciphered. Further, by examination of data from a series of independent sensors for consistency, a confidence level can be established for the alarm decision.

A simple example will illustrate what we mean. If in a single room, a smoke detector gives a large signal but temperature sensors that might be part of the environmental controls do not record any noticeable rise, it is possible that the smoke detector is faulty or a smoldering condition is present. Similarly, if the energy management system records a large electrical fault just before a smoke detector signal, the chances that the fault has initiated a fire are high..

The difference between this approach and previous methods of alarm discrimination is significant in two ways. First, it incorporates all available information to determine what is happening. The realization is that even in the very early stages of a fire, fire is a global phenomena. It has impact throughout a building and as a fire grows that distant information can be used to establish size, rate of increase and other information that can be helpful in fighting the fire. Second, unlike prior methods of reducing false alarms, this does not simply address the decision to alarm but can also be used to assess level of threat and support a tailored response.

Adaptive Modeling

A major part of the NIST approach is adaptive modeling. In this context, adaptive modeling is using the comparison of sensor data with model predictions to determine model inputs appropriate to better match the sensor data over sometime period. Of particular interest is the heat release rate (HRR) input since it is the driving force for most other phenomena. In general this is a complex optimization problem with a goal to minimize the difference between the building sensor data and model predictions. In general, this requires two techniques: 1) a method to quantify the differences between model predictions and measured data, and 2) techniques to determine appropriate model inputs to minimize these differences.

The first tool needed is a quantification of the error between the building sensor data and the model predictions. This is provided through functional analysis and is discussed in the paper by Peacock et. al[9]. The framework of functional analysis allows us to treat time series as if they were vectors and defines appropriate operations on the vectors. Initially, consider a single experimental measure and a model prediction, say the temperature at time t_i. Let E be the experimentally measured value and m be the value calculated by a model. One measure of the error is the relative difference between the two numbers calculated by

$$\frac{|E-m|}{|E|} \tag{1}$$

If instead of being two scalar values E and m where two dimensional vectors we can still define a relative difference. Figure 1 shows the difference between E and m. If we call the length of a vector x the norm and write it as $\|x\|$ then we can define the relative

$$\frac{\|E-m\|}{\|E\|} \tag{2}$$

difference between the two vectors as
The relative difference we will use is directly analogous to the relative difference shown graphically in fig. 1

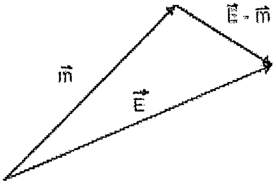

Figure 1

Figure 2 shows the upper layer temperature histories for two CFAST predictions. One is called the experiment the other that has small differences in the HRR is the model. In the present framework the two time temperature curves are treated as vectors which allows us to find the relative difference between the two and the lengths of those vectors using the following equation.

$$\sqrt{\frac{\sum (m_i-E_i)^2}{\sum E_i^2}} \qquad (3)$$

The relative difference between the two curves is 0.0857. This means that the length of the difference between the two curves is 8.57% the length of the experimental curve. This metric will allow the determination of the best fit between model and experiment as well as determining which sensor readings are causing the most error.

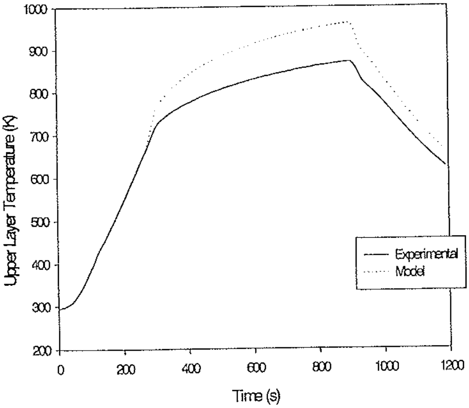

Figure 2

Having a metric to compare model prediction to an experiment is all that is needed in theory to minimize the differences between the model predictions and the experiment. In practice, such a multi-variable optimization can be quite difficult. The problem is a general one in all multi-variable optimization. It is clear that a general method of solving this problem does not meet constraints of reaching a solution in real time. In some cases an enormous number iterations would have to be made before the best fit is established. However if the problem is simplified using knowledge of the physics of a zone fire the problem becomes soluble.

For a simple example consider a single well ventilated room. We can pick a HRR curve that we wish to match using the upper layer temperature of the compartment. A simple procedure gets very close to the actual temperature curve with three model runs is as follows.

Taking a HRR curve of the form

$$at^3 + bt^2 + ct \tag{4}$$

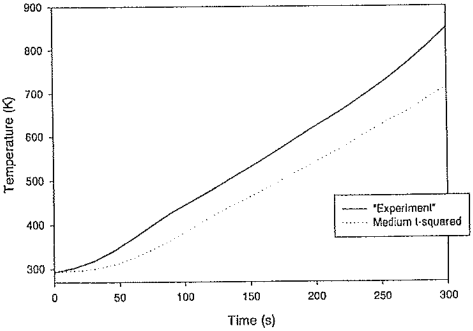

Figure 3

The values that will be used are 4.6436E-06 for *a*, 1.2533E-02 for *b*, and 9.5818E-01 for *c*. This gives an "experimental" HRR curve to attempt to match. A first guess will be to model the experiment as a medium t-squared fire. Figure 3 shows a comparison of the upper layer temperatures for both the "experiment" and the medium t-squared fire. To correct the medium t-squared fire HRR to better predict the upper layer temperature of the experimental fire, the work of McCaffery, Quintiere, and Harkleroad[10] can be used. They found a correlation between upper layer temperature and HRR using the form.

$$\Delta T_U = C\dot{q}^{2/3} \tag{5}$$

Where ΔT_U is the difference in the upper layer over ambient, q is the HRR, and c is the correction due to heat lost to the walls and through the vents. While McCaffery, Quintiere and Harkleroad give the method for calculation of C, for our purposes it is only important that it is independent of HRR and thus constant for a particular building. So using the above correlation gives two equations with four variables.

$$\Delta T_{U,E} = C\dot{q}_E^{2/3} \qquad \Delta T_{U,m} = C\dot{q}_m^{2/3} \tag{6}$$

Where $\Delta T_{U,E}$ is the upper layer temperature for the "experiment", $\Delta T_{U,m}$ is the upper layer temperature for the model prediction, $\dot{q}_E$ and $\dot{q}_m$ are the HRR for the "experiment" and the model respectively. Since the upper layer temperatures for the "experiment" and the model as well as the HRR for the model are all known,we can solve for the HRR of the "experiment" with the equation

$$\dot{q}_E = \left(\frac{\Delta T_{U,E}}{\Delta T_{U,m}}\dot{q}_m^{2/3}\right)^{3/2} = \left(\frac{\Delta T_{U,E}}{\Delta T_{U,m}}\right)^{3/2}\dot{q}_m \tag{7}$$

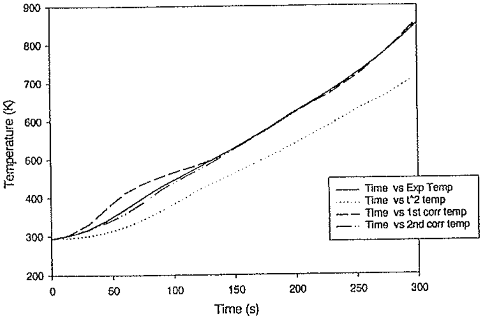

Figure 4

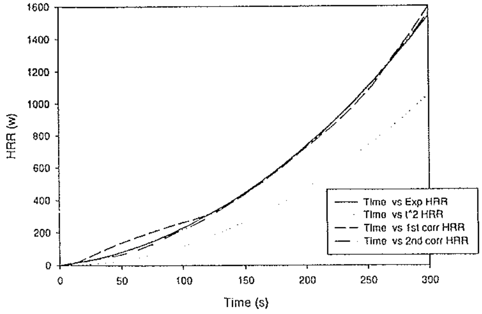

Figure 5

Using the above equation we can generate a new HRR curve from the medium t-squared case. Using the new HRR curve we can make a second model run to calculate a new upper layer temperature to compare to the 'measured' upper layer temperature. If the results are not close enough we can continue repeat the process. Figure 4 shows the "experimental" upper layer temperature with the first three iterations. The relative errors for upper layer temperature for the medium t-squared fire compared to the experiment is approximately 0.134. The first iteration reduces the relative error to 0.029 and the final iteration has a relative error of about

0.009. Figure 5 shows the true HRR used in the "experiment" along with the medium t-squared HRR and the two iterations. Here the relative difference go from 0.338 for the medium t-squared fire to 0.043 for the first iteration to finally 0.01 for the last iteration.

Threat Assessment

The purpose of the adaptive model is to obtain the key characteristics of the fire, primarily the heat release rate (HRR). HRR is widely recognized as the key indicator of the level of threat represented by a fire to occupants, contents, and structure[11]. If the threat posed by a fire can be assessed, it is possible to determine the most appropriate response to that threat.

If a system can report to the fire brigade at dispatch, that the fire has a HRR that is relatively low and is growing slowly the fire brigade may choose to make a limited response. Alternatively, if the HRR is high and rapidly growing toward flashover, the fire brigade my decide to dispatch additional units for the initial response. Such a system could provide a significant improvement in the efficiency of fire brigade operations and improve safety of fire fighters.

Decision Algorithms

Another important purpose of incorporating the model with sensor information is to provide an underlying knowledge of fire that can be used to make better alarm decisions. Here the sensor signals can be evaluated as to whether they are consistent with the physical laws of fire phenomena so that alarm decisions do not require prior experience as do the correlational approaches discussed previously.

Work on multi-mode sensors by Milke [8] and by Gottuk and Williams[12] have shown that simple consistency criteria such as looking for a simultaneous rise in both smoke and CO or CO_2 can substantially improve nuisance alarm discrimination, but does not completely eliminate the problem. The embedded model can provide opportunities for far more detailed consistency tests.

For example, soot yield fractions for specific fuels are relatively constant under fully ventilated conditions. Thus there should be a constant relation between the soot production rate and the HRR while the oxygen concentrations are above about 12% or while the CO/CO_2 ratio is low. Where smoke, gas, and thermal sensor signals are processed through the adaptive model these criteria can be applied to discriminate against non-fire sources that do not demonstrate this phenomenological consistency.

In more sensor rich environments it should be possible to use information from a range of building systems to make decisions. The classical fire signatures of heat, particulates, and gas species could be augmented by pressures, flows, and other conditions produced in spaces containing fire. The more parameters observed that are consistent with the occurrence of fire, the higher the confidence that a fire condition exists. The assignment of a confidence level (low, moderate, or high) to an alarm could be useful information where uncertainties are of concern.

Concluding Remarks

Clearly, the reliability and accuracy of alarm decisions can be improved by increasing the information basis for these decisions. Current correlational methods provide improvements in system performance but may not be able to discriminate against nuisance signals not previously encountered. Modern predictive fire models may be able to impart to systems a sufficient understanding of fire phenomenology that they will be able to make correct interpretation of conditions not previously encountered. Several, major steps will need to be taken for the embedding of an adaptive model into a fire alarm system can be accomplished. NIST is working with a consortium of industry and users toward incorporation of this research into new products and applications. If this is successful, it should open up an entire new line of research into fire safety and many new applications for building owners and the fire service.

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Determination of Characteristic Parameters of Point-type Smoke Detectors

Abstract

Results of the measurement of the characteristic lengths and response thresholds for six point-type smoke detectors are reported. In the tests the flow velocity was varied in the range of 0.2 - 0.8 m/s and the rate of rise of smoke density in the range of 0.1 - 2 dBm^{-1}/s. The characteristic length was found to vary the range of 2 - 9 m indicating a smoke entry time constant in the range of 20 - 90 s at a flow rate of 0.1 m/s typical of smoldering fires. A method of using the results in fire safety engineering calculations is presented.

Introduction

Several countries have already moved and others will soon move to performance-based fire safety regulations. Performance-based fire safety design is becoming popular even regions were the regulations do not explicitly encourage. In performance-based design, emphasis is laid on demonstrating the safety of the whole or part of an appropriate functional part of a building, instead of prescriptive requirements on components. The new approach opens wider market for active measures provided the performance of these can be quantitatively demonstrated [1].

The performance of fire detection systems has been traditionally controlled by requiring minimum performance and different sensitivity classes of detectors. The approach offers very little quantitative information for an engineer having a task to assess the time to detection under a specified design fire scenario with quantitatively defined design fires. The need to develop a dynamic smoke detector model taking into account the sensitivity and the possible time lags of the detectors is evident. In addition, methods need to be developed to predict the flow and smoke density fields carrying the information about the fire to the detector site.

In our earlier work, we showed that one possible way ahead is a simple model based on a conventional diffusion equation including two independent parameters, the characteristic length of the detector L and the static response threshold m_r of the detector [2]. The model parameters were determined on one photoelectric and one ionization detector.

In this work, further measurements were made on six detectors currently on the market. A simple method of applying this model in fire safety engineering is presented.

Response model for smoke detectors

Analogously to the response time index (*RTI*-parameter) defined for heat detectors the concept of characteristic length (*L*-parameter) describing the smoke entry dynamics in smoke detectors has been introduced [3, 4]. The first attempt to actually measure the characteristic length was described in [4]. The same approach is applied in this paper, but considerably larger number of tests were conducted to validate the approach.

The sensitivity of a smoke detector depends both on the sensitivity of the sensor and on the flow of smoke into the detector. The dynamic detector performance can be described by a conventional diffusion equation

$$dm_i / dt = (m_o - m_i) / \tau \tag{1}$$

where t is time, m_i is the smoke density (in units dB/m) inside the detector, m_o smoke density outside the detector, and τ is the time constant describing the lag caused by flow resistance in the smoke entry. It has been postulated [3, 4] that the time constant can be expressed as

$$\tau = L / v \tag{2}$$

where v is the gas flow velocity at the position of the detector and L the characteristic length of the detector.

At the moment of detector response t_r the smoke density outside the detector may be written as follows

$$m_{or} = m_r + \left(\frac{L}{v}\right)\left(\frac{dm_o}{dt}\right)\left\{1 - \exp\left[\frac{-m_{or}v}{L\left(\frac{dm_o}{dt}\right)}\right]\right\} \tag{3}$$

where m_r is the static response threshold. When $dm_o/dt << m_{or}/(L/v)$, equation can be written in the simple form

$$m_{or} = m_r + \left(\frac{L}{v}\right)\left(\frac{dm_o}{dt}\right) \tag{4}$$

The static response threshold depends on the characteristics of the smoke. If the possible dependence on the fluid temperature and flow velocity gradients are neglected here, the characteristic length is a property of the detector structure only.

Test arrangement

In the tests the straight wind tunnel at VTT was applied. The flow velocity was adjusted to a constant value between 0.2 and 0.8 m/s. The test smoke was produced in a controlled way by an aerosol generator described in [5]. The aerosol was fed into the tunnel at a variable rate ranging from 0.1 to 2 (dB/m)/s. The smoke density was measured both with a standard ionization chamber (MIC, measures the smoke density parameter y) [6] and an infrared smoke densitometer (SICK, measures the optical smoke density m) [7]. The aerosol feeding rate was controlled by an HP3497A data aquisition and control unit and a microcomputer. The experimental arrangements are described in more detail in reference [2].

For each detector both the rate of rise of smoke density and the flow velocity were varied. The flow velocities the values used were 0.2, 0.45, 0.6 and 0.8 m/s. The rate of rise of smoke density was changed at small increments spanning the whole available range. The smoke particle size was kept as stable as possible corresponding to a smoldering fire.

Three common ionization smoke detectors and three photoelectric smoke detectors were included in the study. The rate of rise of smoke density was increased up to the detector response keeping the flow velocity constant. Smoke density outside the detector at the moment of detector response was recorded.

Results and discussion

Figures 1 and 2 show examples of the results of measurements. As we can see from equation (3), the slope of the data set is the characteristic length and the intersection with the y-axis the static response threshold.

The characteristic length and the response threshold for each detector were determined from the measured data by least squares fitting. Because the parameter L appears also in the variable on the x-axis, the fitting was done iteratively. The first iteration cycle was done by fitting the data to eq. (4), the results of which are given in table 1.

The subsequent iteration cycles were done using eq. (3), in which the correction of the rate of rise of smoke density was calculated by using the L and m_r obtained from the preceding cycle. Due to convergence problems discovered during subsequent cycles after the second one, a zeroth order regularization method [8] was applied, resulting in stable solutions. The results with their 95 % confidence limits are given in table 2.

By comparing tables 1 and 2 we can see that especially for the photoelectric detectors the second iteration is required. Further iterations would not improve the data significantly due to the inherent scatter in the data.

It can be seen that the validity of the model is good for photoelectric detectors, at least for the type of smoke and the range of flow velocities studied here. In this study the minimum flow velocity was 0.2 m/s. Therefore, the phenomenon observed by Brozovsky et al at WPI, USA was not encountered here. They found that in the case of photoelectric detectors the lag time increases exponentially with decreasing velocities of less than 0.16 m/s yielding very late responses or no response at all, even when obscuration is well above the response threshold [9].

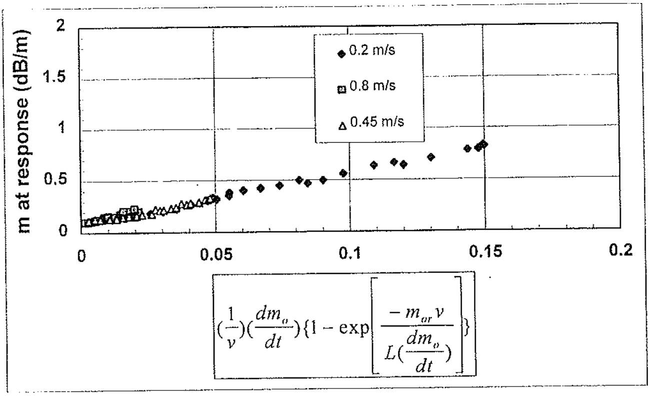

Figure 1. Results of the response threshold measurements for a typical photoelectric smoke detector.

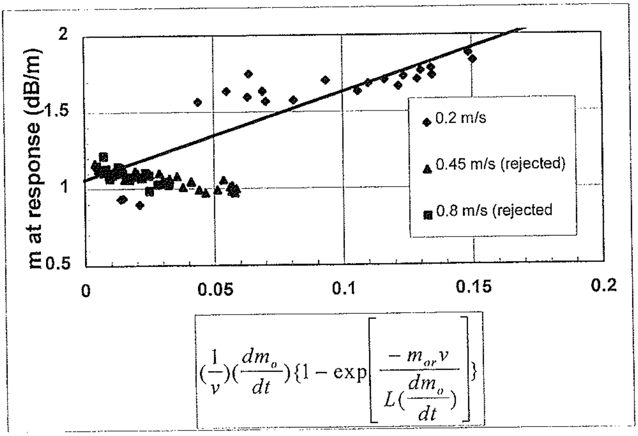

Figure 2. Results of the response threshold measurements for a typical ionization smoke detector.

For ionization detectors the validity of the model is significantly poorer, the reason for which is not quite understood. Increasing the flow velocity appeared to decrease the smoke density at response faster than inversely proportional to the velocity. Another effect was that at the rates of rise of smoke density less than 0.005 (dB/m)/s it seemed that the aerosol reached the chamber much more slowly. The results of the present study are in close agreement with those presented earlier [2]. As discussed by Litton, the effect may be at least partly related to the competition between the recombination of charged smoke particles and the flow of the particles through the chamber [10]. Further insight may be found from the work by Newman [11].

Table 1. Characteristic parameters of smoke detectors determined from the 1st least squares fitting. For the ionization detectors only data points measured at the flow velocity of 0.2 m/s were included in the analysis. In case of the detector D only data points measured at smoke density gradients above 0.005 $(\mathrm{dB/m})\mathrm{s}^{-1}$ were included in the least squares fit.

DETECTOR	**L (m)**	**$\pm\Delta L$ (m)**	**m_r (dB/m)**	**$\pm\Delta m_r$ (dB/m)**
A(photoelectric)	3.24	0.09	0.11	0.01
B(photoelectric)	4.58	0.26	0.14	0.02
C(photoelectric)	5.72	0.68	0.15	0.05
D (ionization)	2.05	0.30	0.92	0.04
E (ionization)	2.21	0.60	1.10	0.08
F (ionization)	4.71	1.28	1.11	0.15

Table 2. Characteristic parameters of the smoke detectors determined from the 2nd least squares fitting. For the ionization detectors only data points measured at the velocity of 0.2 m/s were included in the analysis. In case of the detector D only data points measured at smoke density gradients above 0.005 $(\mathrm{dB/m})\mathrm{s}^{-1}$ were included in the least-squares fit.

DETECTOR	**L (m)**	**$\pm\Delta L$ (m)**	**m_r (dB/m)**	**$\pm\Delta m_r$ (dB/m)**	**r^2**
A(photoelectric	4.82	0.10	0.09	0.01	0.996
B(photoelectric	6.91	0.28	0.11	0.02	0.984
C(photoelectric	9.37	0.69	0.09	0.04	0.952
D (ionization)	2.19	0.31	0.91	0.04	0.858
E (ionization)	2.00	0.62	1.27	0.08	0.834
F (ionization)	5.71	1.17	1.06	0.11	0.845

Application of the model

For the calculation of the response time of thermal detectors methods have existed for over a decade. The best known of the available computer codes is DETACT with its variations [12]. This method is based on analytical correlations available for fires with constant (or semi-stationary) heat release rate and for the t^2-fires [13].

As seen from equations (1) and (2), the time of the smoke detector response can be determined, if the flow velocity and smoke density in the vicinity of the detector are known as a function of time . The flow velocity can be determined as above. A method to determine the smoke density is discussed below.

The smoke density parameters m is proportional to the number density of smoke particles. If heat losses and particle agglomeration are neglected, and if the smoke yield per convective heat output of the fire is assumed constant, it can be postulated [3] that the smoke density parameters are also proportional to the temperature rise T-T_0:

$$m(t) = k\left[T(t) - T_o\right] \tag{5}$$

The coefficient k is different for each type of fire as the smoke yield, the size of the smoke particles and other optical properties of smoke depend on the fuel and the combustion mode (flaming, smoldering).

Figures 3 and 4 show the correlation between smoke density and temperature rise in the standard large-scale smoke detector tests for the effluent from polyurethane and heptane test fires [14]. The values for these fuels are k=0.11 dBm^{-1}/°C and 0.02 dBm^{-1}/°C, respectively. As specified in the test standard, the smoke density is measured at near infrared. Because the smoke density is roughly inversely proportional to the wave length of the light [15], the visible smoke density is some 20 - 25% higher.

By applying equation (5), the derivation of the smoke density distributions as a function of time is straightforward algebra and shall not be discussed here. For the case of a constant heat release rate, i.e. a constant flow velocity and a fixed time constant, one may use the thermal detector model, and simply use the correlation to determine a virtual critical response temperature. However, for a time-dependent fire this is not possible, because the time constant varies with time and the temperature at response is not a constant.

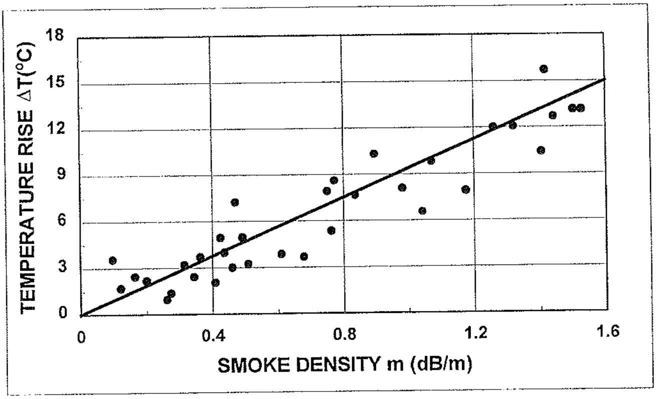

Figure 3. Correlation of the temperature rise and smoke density in the ceiling jet of the polyurethane test fire TF4.

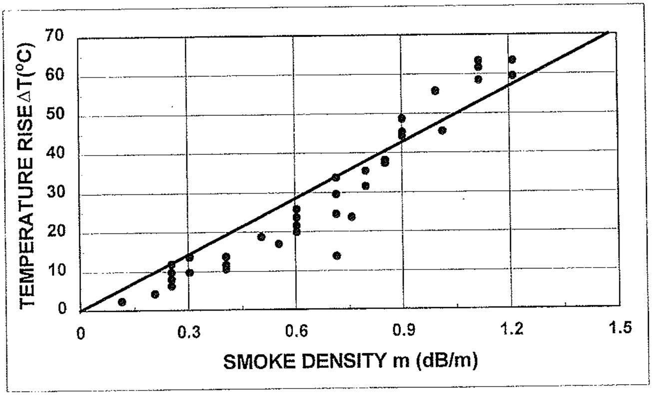

Figure 4. Correlations of the temperature rise and smoke density in the ceiling jet of the n-heptane/butane test fire TF5.

Conclusions

For the needs of fire safety engineering calculations, the dynamic smoke detector model presented here is reasonable. A first (and safe) approximation would be to use a characteristic length of 10 m for point-type smoke detectors. If better accuracy is needed, the parameters can be determined for each detector model by running a sufficient series of wind tunnel tests at different flow velocities and rates of rise of smoke density. The model is not, however, good for the detectors with advanced signal processing, because there response model may not be simplified as described here.

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Smoke Detector Response To Nuisance Aerosols*

Abstract

The worth of a fire detector is determined as much by its ability not to respond to stimuli that are generated from non-threatening sources as to respond in a timely manner to an actual fire. Photo-electric and ionization smoke detectors react to a greater or lesser degree to all particles that enter the sensing chamber, and, by themselves, the detectors cannot distinguish smoke from a nuisance aerosol. The fire-emulator/detector-evaluator (FE/DE) is used to produce smoke and nuisance aerosols representative of what could be present immediately adjacent to an installed detector, and provides a test bed to determine the response of spot-type detectors to physical products (temperature, gases, and smoke) formed in simulated fires, as well as the response to stimuli not associated with a fire threat. The analog output of a multi-sensor detector is measured as a function of aerosol type (peanut oil and clay dust), concentration, and air flow, and is compared to the response of the detector to a flaming fire, and to the extinction of laser light in the FE/DE test section at optical densities up to 0.12 m^{-1}.

Introduction

The ability of a detector to satisfactorily sense the presence of a fire is determined in a series of tests performed by Underwriters Laboratory in reduced and full-scale. UL 217 [1] and UL 268 [2] utilize a 1.7 m long, 0.5 m wide and 0.5 m high test chamber into which "gray" smoke from a cotton lamp wick and "black" smoke from a kerosene lamp are introduced. The detector is mounted at the top of the chamber and a fan causes the smoke-laden air to flow past the detector at about 0.16 m/s. The concentration of smoke is controlled to produce an optical density between 0.003 m^{-1} and 0.2 m^{-1}. A wind tunnel is used for UL 268A [3] to simulate flow through a 0.3 m square duct at speeds between 0.1 m/s and 1.7 m/s. Smoke is created by heating wood sticks on a hot plate and by

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burning a small pool of heptane. Factory Mutual has a smoke detector standard [4] that uses smoldering cotton rope as the smoke source. To pass this test a detector must activate before the obscuration reaches 12%/m.

CEN Technical Committee TC72, the Committee for Fire Detection and Fire Alarm Systems, is revising the current standard, EN 54 [5], that directs how smoke detectors are to be tested in the European Community. According to Northey [6], the fire sensitivity tests previously contained in Part 9 of EN 54 are to be integrated into Part 7, which deals specifically with point detectors using scattered light, transmitted light, or ionizing radiation.

A difficult problem for sensors designed to detect smoke is to discriminate between non-threatening air-borne aerosols and particles originating from an unwanted fire. Road dust entering with the wind through an open door, oil mists generated by moving machinery, soot from an operating Diesel engine, aerosols emitted during cooking, and steam from a shower or clothes dryer are examples of aerosols that may trigger a nuisance response from traditional photo-electric and ionization sensors.

Only one test method deals specifically with air-borne particulates formed from other than flaming or smoldering fires. UL 217 [1] checks the sensitivity to typical aerosols emitted during cooking by exposing the detector to the emissions from animal fat, vegetable oil and beef gravy vaporizing on a hot plate. The smoke detector is not to activate in this situation. At a recent workshop [7], nuisance sources that impact fire detection in telecommunication systems and aircraft cargo areas were discussed, along with possible means to quantify and evaluate detectors exposed to non-fire aerosols. The current paper describes how the NIST fire-emulator/detector-evaluator (FE/DE), first discussed by Grosshandler [8], can be used to examine the response of smoke detectors to different aerosols, including dust, oil, and water, as well as to smoke.

Experimental Facility and Operation

The FE/DE is a flow tunnel designed to reproduce the time-varying speed, temperature and concentration (gas and particulate) expected in the plume above the early stages of a fire. This device, shown schematically in Fig. 1, has a test section 0.3 m high and 0.6 m wide. It has a variable speed fan and heater for velocity and temperature control over ranges of 0.02 m/s to greater than 1 m/s and 20 °C to 80 °C, respectively. A honeycomb flow straightener is placed in the tunnel before the test section.

At the test section, air temperature and velocity are measured. The tunnel has a top-hat mean velocity profile at speeds up to 0.3 m/s, and starts to develop a parabolic profile at higher flows. At the location of the detector opening (20 to 30 mm below the ceiling of the tunnel) the vertical velocity gradient is small. Velocity was measured with a hot-wire anemometer calibrated from 0.05 m/s to 5 m/s. Measurements of flow velocities less than 0.05 m/s are obtained from neutrally buoyant soap bubble trajectories and punk smoke visualization. The expanded uncertainty (95 percent level of confidence) is estimated at ± 10 % of the value for velocities greater than 0.05 m/s using the hot-wire anemometer, and ± 25 % for velocities below 0.05 m/s.

Laser light extinction is measured across the duct at the height of the detector inlet slightly forward of the detector placement and at the mid-height of the duct, as shown in Fig. 2. The laser is reflected off two mirrors inside the tunnel to extend the path length to 1.50 m. A He-Ne laser at 633 nm wavelength is used to measure extinction. The signal-to-noise ratio is approximately 10^4:1 with no aerosol present. The signal is normalized by the pre-test signal level and recorded as a relative intensity ratio at 1 s intervals.

The smoke extinction coefficient (m^{-1}) is 1/e times the optical density, and is related to smoke mass concentration through a constant of proportionality equal to the specific extinction coefficient (m^2/kg). The specific extinction coefficient is a function of the smoke aerosol size distribution and optical properties; it is an intrinsic property and nominally a constant for a given fuel and combustion mode [9]. In the current study, propene/air diffusion burner provides a black smoke source. A portion of the flow from the smoke generator is injected into the air stream ahead of the test section to achieve the desired smoke loading. Step changes in smoke concentration yielding an optical density of up to 0.20 m^{-1} can be achieved. The burner output is stable for at least 30 minutes.

Oil-based aerosols are produced using the NBS aerosol generator [10] and injected into the FE/DE. This generator was designed to simulate a smoke from a smoldering source in terms of the aerosol size and optical properties. Peanut oil is used for the aerosol in the current tests to simulate a nuisance cooking source. Small clay particles (7 μm nominal diameter), representative of a nuisance dust, are added to the air flow using a variable speed screw-feeder fit with a vibrator. A small air jet is passed by

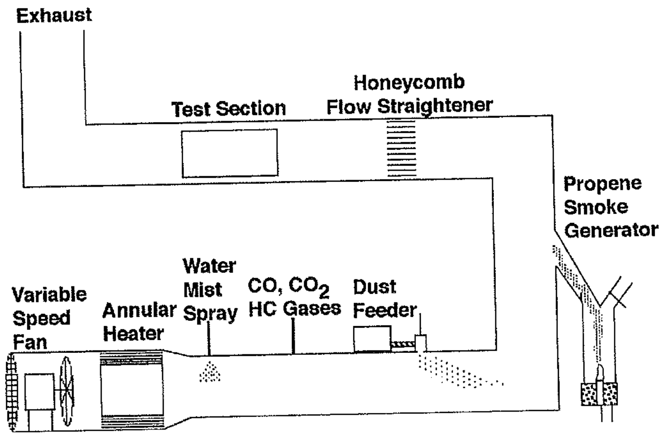

Figure 1. Schematic of fire-emulator/detector-evaluator.

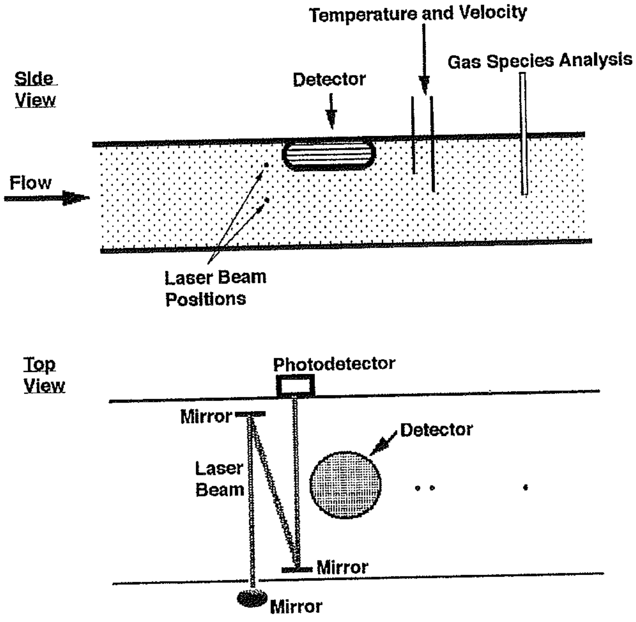

Figure 2. Schematic of FE/DE test section.

the entrance tube to ensure distribution of the dust across the duct. Details of the FE/DE can be found in ref. [11].

The detectors examined in the present study contain photo-electric and ionization sensors and a thermistor. Detector output signals are transmitted about every 3 s as 8 bit binary numbers allowing for a resolution of 1 in 256. Three quarters of the scale (1-192) is used for the output range, with the remaining reserved for zero-drift compensation. The detectors were mounted at the center of the flow tunnel ceiling in the test section. Both ionization and photo-electric detector output were found to be linear functions of optical density for smoke produced by the propene diffusion burner, suggesting that the detector electronics were linearized internally by the manufacturer with respect to optical density.

An experiment in the FE/DE begins by recording for 30 seconds the background signal from the smoke detector and from the laser system with clean air flowing through the test section at the predetermined temperature and velocity. Depending upon the particulate matter desired, either the flow from the smoke generator, the dust feeder, or oil mist generator are initiated. The data are recorded every three seconds during the initial build up of aerosol concentration and for a 60 s steady-state condition. The aerosol flow is then terminated and measurements continued until the reference laser experiences close to full transmission and the detector signals fall to zero.

Results and Analysis

Data were collected in the FE/DE at ambient pressure (100 kPa ± 2 kPa) and temperature (20 °C ± 2 °C), for a range of air speeds between 0.02 m/s and 0.35 m/s. The optical density measured by the attenuation of the reference laser was varied between 0.003 m^{-1} and 0.12 m^{-1} by a combination of increasing the mass loading of the aerosol and decreasing the total air flow.

Figure 3a shows a typical run with smoke from the propene/air diffusion flame for air flowing at 0.20 m/s. The optical density measured with the reference laser is plotted as the solid line (no symbols) on the right-hand vertical axis, versus time on the horizontal axis. The flow of smoke to the wind tunnel begins at 30 s, and can be seen to attenuate the laser light starting 10 s later. By 60 s, the optical density reaches a peak and then oscillates around a mean value of 0.075 m^{-1} for the next 170 s. The flow of smoke is terminated, followed by a rapid drop in optical density back to the initial state.

The output from the detector head is plotted on the left-hand vertical axis. The photo-electric sensor responds first, about 15 s after the smoke is present in the air stream flowing past the detector body. The magnitude of this delay was found previously by Cleary et al. [12] to be a strong function of the air velocity. The internal geometry of the detector also influences the response time of the detector, which can be seen by the significantly longer delay required before the ionization sensor responds. Both particle sensors produce similar output signals at the steady state. The heat sensor is able to track the small increase in temperature (0.5 °C) associated with the smoke.

Figure 3b shows the response of the photo-electric and ionization sensors to the peanut oil aerosol in an air flow of 0.04 m/s. No change in temperature was measured. The general shape of each curve is the same as the corresponding curve in Fig. 3a. The steady-state optical density is less than 1/6 the value measured with smoke, but the detector signals are between 60 % and 75 % as large. The much higher response of the detector sensors to the peanut oil aerosol is hypothesized to be attributable to a higher albedo and smaller size of oil droplets relative to smoke. The photo-electric sensor responds preferentially to light scattering, while the reference laser is sensitive to light absorption. The ionization sensor responds to the total particle number density, which is dominated by smaller particles, but the reference laser is more influenced by the larger end of the size distribution.

The response of the detector sensors to a nuisance dust represented by a clay particle cloud in a stream of air traveling at a speed of 0.35 m/s is plotted in Fig. 3c. There are significant qualitative features different in this figure when compared to Fig. 3a, although the mean value of the optical density measured with the reference laser is of the same order in the two experiments. First, the oscillations of the laser signal occur at a fixed frequency, and the peak-to-peak values are greater than the mean value of the signal. This behavior can be traced to the slowly rotating screw-feeder, which drops a fixed portion of clay dust every 360 degrees. The photo-electric sensor is able to follow these fluctuations, and yields an average signal which is greater than that produced by an equivalent amount of laser light attenuation measured from the smoke in Fig. 3a. The clay particles would be expected to have a higher albedo than the smoke, and while the primary particle size is small, the screw-feeder causes the clay to agglomerate, and the

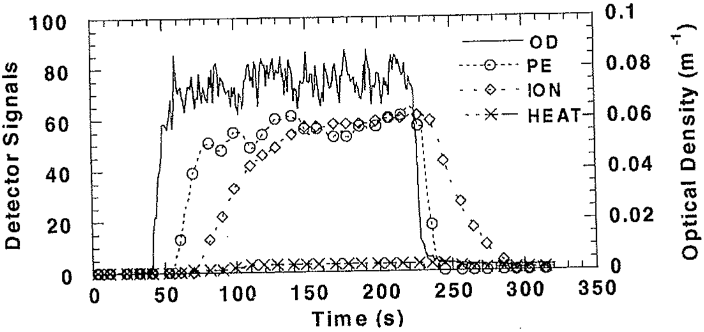

Figure 3a. Detector response to propene smoke ; flow velocity is 0.20 m/s.

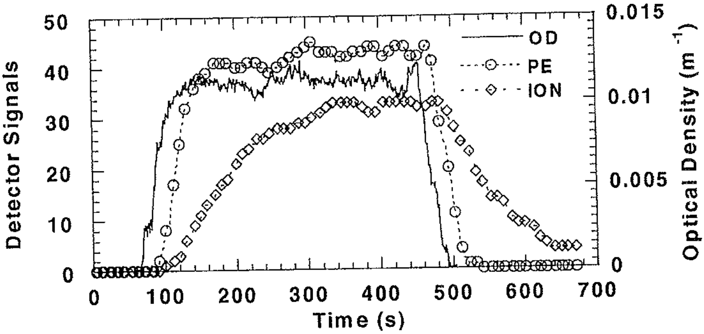

Figure 3b. Detector response to oil aerosol ; flow velocity is 0.04 m/s.

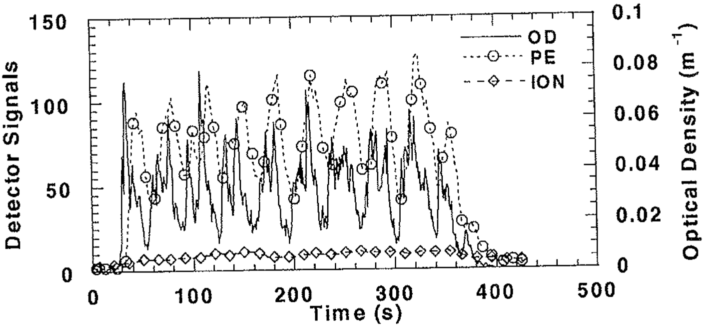

Figure 3c. Detector response to dust aerosol; flow velocity is 0.35 m/s

large particles are more effective scattering centers. This description is consistent with the very low ionization sensor output, which, for a fixed mass loading, is much more sensitive to a large number of small particles than to a small number of large particles.

The steady-state detector signals are plotted in Figs. 4a, 4b, and 4c over the range of optical densities measured by the reference laser. Error bars represent ± one standard deviation. The maximum sensitivity for the detector is stated to be 3.70 % obscuration per 0.305m (1.00 ft). The response from the smoke generator, plotted in Fig. 4a, is linear and about the same for both detectors, with correlation coefficients greater than 0.96. A linear fit also correlates the peanut oil aerosol well, as demonstrated in Fig. 4b. In this case, the slope of the output signal from the photo-electric sensor is almost twice as steep as that from the ionization sensor. Both sensors show a higher sensitivity to the optical density created by the peanut oil than to the propene smoke.

In spite of the large oscillations in clay dust concentration created by the screw feeder, the signal from the photo-electric sensor, Fig. 4c, correlates to the mean optical density with a correlation coefficient of 0.93. The slope of the curve is greater than 2 times steeper than the corresponding curve for smoke. The ionization sensor shows no correlation with the clay dust, and is totally insensitive to the mass loading of the aerosol.

Summary and Conclusions

A modern multi-sensor fire detector was used in this study to demonstrate the utility of the FE/DE for evaluating sensor response to fire and non-fire aerosols. In addition to smoke formed from flaming hydrocarbon combustion, the detector was exposed to clouds of peanut oil and clay dust in air flowing at speeds between 0.03 m/s and 0.20 m/s. This work was illustrative of two types of nuisance aerosols. Future studies will focus on producing steadier and better controlled particle loading in the test section of the FE/DE, expanding the number of nuisance aerosol materials, and characterizing the aerosol size distribution, number density, and optical properties.

Acknowledgements

Melissa Anderson operated the FE/DE and reduced some of the experimental data. We would like to thank Edwards Systems Technology for the use of their equipment.

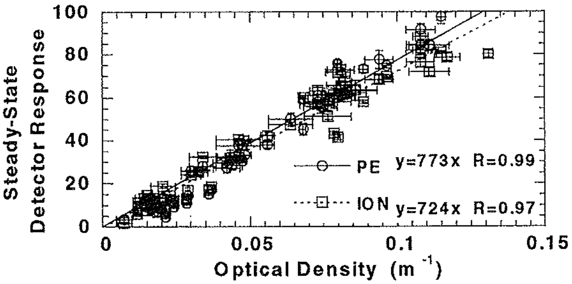

Figure 4a. Steady-state detector response to propene smoke. Equations for best-fit lines through data are given along with correlation coefficients (R).

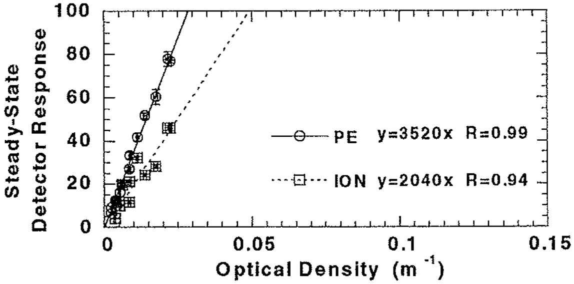

Figure 4b. Steady-state detector response to peanut oil aerosol. Equations for best fit lines through data are given along with correlation coefficients (R).

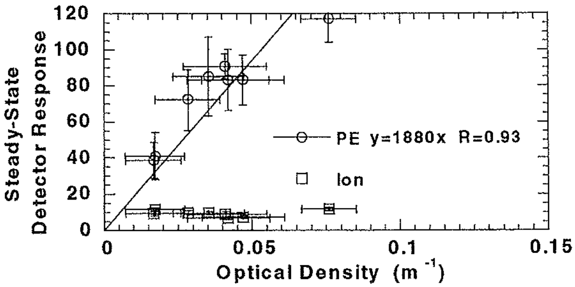

Figure 4c. Steady-state detector response to dust aerosol. Equation for best fit line through photo-electric detector data is given along with correlation coefficient (R).

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Fiber-optic Sensing Measurement and Thermofluid Dynamical Analysis of Temperature Distribution in Utility Tunnels

Abstract

In modern times of highly advanced information-oriented society, safety of communication system as well as stable supply of electrical supply is of extreme importance. The utility tunnel, in which cables associated with these are laid, is regarded as something like the today's lifeline, and prevention of its disasters has been a vital issue.

The present authors have so far carried out fire experiments in model tunnels with varied shapes and sizes for the purpose of early detection and extinction of fires in utility tunnels, confirmed that we can locate the fire source and estimate its thermal energy from temperature distribution measured by means of a fiber-optical sensing system, and proposed this as a fire sensing system.

To establish this procedure, in the present work, the authors calculated the distribution in terms of thermofluid dynamical analysis by using a mathematical model with finite element method, concerning the shape coefficient to calculate calorific value when sensing fire in the utility tunnel with a fiber-optical temperature sensor, and compared it with the result obtained with model fire experiments. The results revealed that we can estimate the calorific value of the fire source by adjusting the coefficient relating to the tunnel shape, and we could verify effectiveness of this fire sensing by means of fiber optics.

1. Introduction

In the present age when the information-oriented society is fast growing, cables for electrical power and information are of existence that may be called the life line, and in the city zone where many utility tunnels have been laid underground, in particular, prevention of this lifeline against disaster has become an important subject[1,2,3]. Though many of these cables laid in the utility tunnel have used flame-resisting sheath material, its combustion energy is, when once ignited, in the same order as coal, causing it extremely difficult to extinguish. Multi-wired cables spread fire with a particularly high speed, and not only work as a medium of expanding fire but also give a danger of yielding much gases to jeopardizing many lives. However, because the fire sensing in such utility tunnels has not so far used sensors but of the spot type, it has hardly grasped location of the fire source or state of its spread, causing delay in extinguishing activity.

The authors has so far made the fire sensing in a vast range possible and studied on the method to detect fire from calorific value of the fire source by means of a temperature measuring device using the fiber-optic temperature sensor[4,5] .

Conducted in this paper are comparison between temperature distribution obtained from thermofluid dynamical analysis of the utility tunnel by means of a mathematical model using finite element method (abbreviated F.E.M. hereafter) and that obtained through the fire experiments using model tunnels, and study on practical application of the fire sensing with the fiber-optical sensor.

2. Basic Equations

In a long and large construction with relatively small cross section like utility tunnel, when the plume rising from the fire source reaches the ceiling face, its thermal airflow once diffuses in all directions, but the flow that moved side wise in the tunnel is blocked by the wall face, and eventually diffuses lengthwise to form a layer of high temperature at upper portion. Thus we determined to carry analysis by regarding the thermal airflow as incompressible fluid and its flow as that in 3-D space. Employed as the basic equations for analyzing thermofluidic features of fire in the utility channel were equation of continuity derived from the law of conservation of mass, equation of motion obtained from the law of conservation of momentum, and energy equation that formulated equilibrium of heat energy, the following (1), (2) and (3), respectively:

$$\nabla \cdot \mathrm{U} = 0 \qquad (1)$$

$$\dot{U}+\frac{1}{\rho}\nabla P+(U\cdot\nabla)U-\nu\nabla^2 U=0 \qquad (2)$$

where, gβ (ΔT) of the buoyancy term was taken into consideration only in the vertical direction.

$$\dot{T}+(U\cdot\nabla)T-\chi\nabla^2 T-\frac{Q}{\rho c_p}=0 \qquad (3)$$

Here, U: flow velocity [m/s], ρ: density [kg/m^3], P: pressure [Pa], ν: kinematic viscosity coefficient [m^2/s], g: gravitational acceleration [m/s^2], β: coefficient of cubical expansion [K^{-1}], T: temperature [K], ΔT: temperature difference from the initial at the fire source part [K], χ: thermal diffusibility [m^2/s], Q: calorific value generated per unit time and unit volume [W/m^3], c_p: specific heat [J/kg·K], and $\dot{T}$ and $\dot{U}$: time derivatives of T and U, respectively.

Dynamic viscosity coefficient ν and thermal diffusibility χ were obtained from Eq. (4) by means of Rayleigh number (abbreviated as Ra hereafter):

$$\chi=\frac{\nu}{Pr}=\sqrt{\frac{g\cdot\beta\cdot\Delta T\cdot L^3}{Ra\cdot Pr}} \qquad (4)$$

where, L: representative length [m] and Pr: Prandtl number.

3. Analytical Conditions

Model tunnels for which analysis was made were of the constant height of 1.8 m and varied widths of 1.35, 1.8, 2.25 and 2.7 m, respectively; and those of the constant width of 1.8 m and varied heights of 1.8, 2.25 and 2.7 m, respectively, all of which had the length of 12.0 m, identical to the fire experiments reported previously.

Fig. 1 shows outline of elemental division when F. E. M. is applied to the utility tunnel of 1.8 m high, 1.8 m wide and 12.0 m long. Divided mesh comprised combination of rectangular parallelepipeds of 15, 20, 25, 50 and 60 cm, each of which consisted of 6 trigonal pyramids so that they are finer in the vicinity of the fire source and larger as going away therefrom. Number of nodal points is 2,624 and number of elements is 11,754.

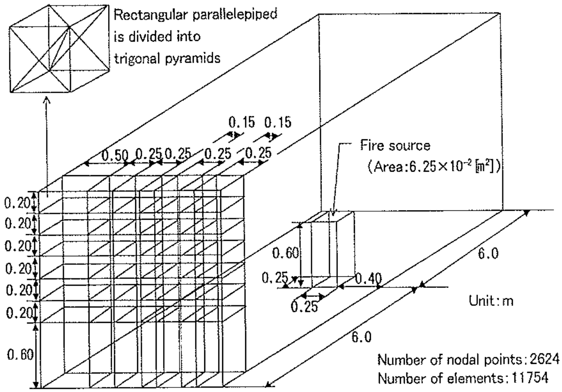


Fig.1. Outline of Analysis using F.E.M.

Boundary conditions are set as adiabatic fixed boundary at ceiling, floor and wall faces, and free boundary at regions open at the both ends. Besides, we assumed that location of the fire source was approximately at the center, similarly to the fire experiment with the model tunnel, 6 m apart from the ends and 0.4 m from the wall face, and that combustion pan was at 0.6 m above the floor and produced a flame of 0.6 m high. The heat source was normal heptane, a liquid fuel, with calorific value of 34.2 kW given at a time step. Table 1 shows initial condition of each coefficient used in the calculation.

Table 1. Initial condition of each coefficient

Specific heat c_p	1.006×10^3	[J/kg·K]
Coefficient of cubical expansion β	3.66×10^{-3}	[1/K]
Density ρ	1.226	[kg/m³]
Environmental temperature	37.8	[°C]
Initial temperature in tunnel	37.8	[°C]

4. Analytical Results

Fig. 2 shows temperature distribution lengthwise along the center line of ceiling 16 seconds after ignition measured by means of C-A thermocouples (0.35 mm dia), in the model tunnel with cross section of 1.8 m square, and calculated results with F. E. M.

using Ra as a parameter. From this result, it is found that the larger Ra, the higher becomes its temperature. This is regarded to be because kinematic viscosity and thermal diffusibility become smaller if Ra gets higher, causing lower viscosity and faster flow speed. In comparison with experimental results measured by means of C-A thermocouples, it is considered most appropriate to use Ra between 10^4~10^6 under the calculating condition at this time. It was the case of Ra: 1.5×10^4, kinematic viscosity: 0.326 m^2/s, and thermal diffusibility: 0.445 m^2/s that the result calculated by using F. E. M. became closest to the experimental value. Accordingly, we determined to use these values in analyses thereafter.

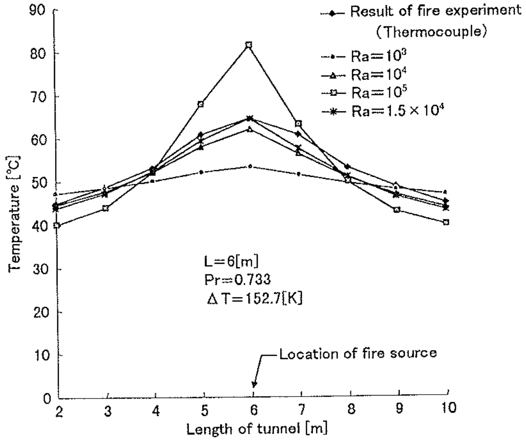
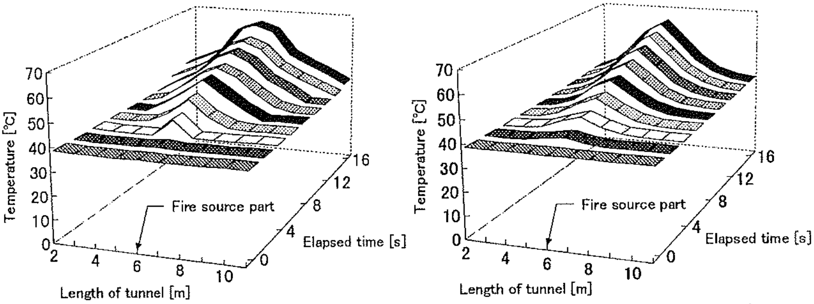


Fig.2. Temperature Distribution Lengthwise in Model Tunnel

Fig. 3 (a) and (b) show calculated values and analytical result of temperature distribution with respect to time elapsed after ignition in the fire experiment in the model tunnel with cross section of 1.8 m square. Found from this is the state that temperature has diffused lengthwise, as time goes on, from its center at the right above the fire source and that temperature rises over the entire region in the utility tunnel as heat transfers. In the fire ignited within the utility tunnel, however, temperature change appeared when 4 seconds elapsed because it takes time to some extent before calorific value is stabilized. Whereas in calculation, temperature change appears at the time of 2 seconds elapsed, showing time difference in the temperature change. This seems to be because the same calorific value has been given, in the analysis, since immediately after the ignition. It has been found however that we can obtain calculated results nearly same as the experimental even in the analysis with F. E. M. of elemental division to this extent.



(a) Experimental result (b) Analytical result (Ra=1.5×10^4)

Fig.3. Variation of Temperature Distribution (Width&Height:1.8[m])

Fig. 4 shows the result that calculated velocity vectors of thermal airflow in the both width and height directions of the cross section, in the model utility tunnel with cross section of 1.8 m square containing the fire source, 16 seconds after the ignition. Found from this is the state that buoyancy has been created in the fluid due to temperature difference between the spot right above the fire source and its periphery, and that thermal airflow has taken place upward and also sidewise centering around the fire source. However, the velocity at the wall face is 0 m/s in the both directions because it was provided as adiabatic and fixed by the boundary condition.

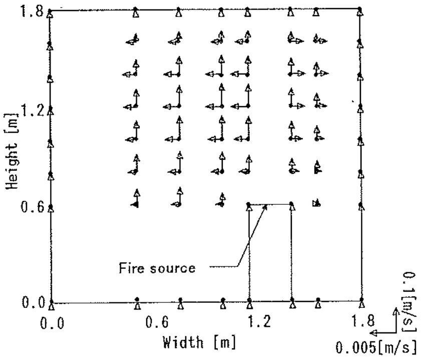
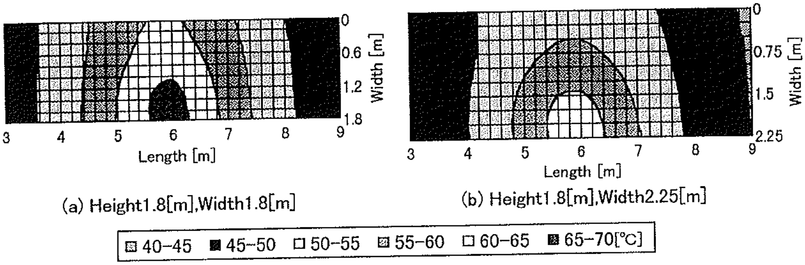


Fig.4. Presentation of Speed in Cross Section of the Model Tunnel (Width&Height:1.8[m])

Fig. 5 shows temperature distributions 16 seconds after ignition at the face of ceiling when the tunnel has the constant height of 1.8 m and varied widths of 1.8 and 2.25 m. Found in the both cases that the state shows so high temperature as above 65°C at the right above the fire source and heat having diffused centering on this vicinity. In comparison of the both, the high temperature portion has been more diffused lengthwise and shows higher temperature in the case of 1.8 m wide than those in the case of 2.25 m wide. This is because the narrower in the width, the smaller in the volume of heat diffusion per unit length.

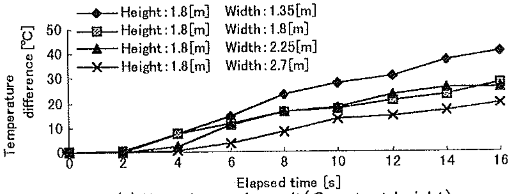


(a) Height1.8[m],Width1.8[m]

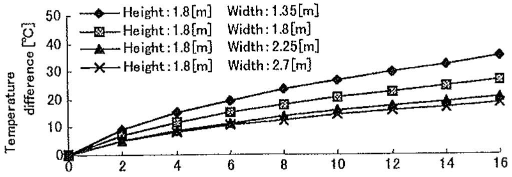
(b) Height1.8[m],Width2.25[m]

Fig.5. Temperature Distribution on Ceiling Face

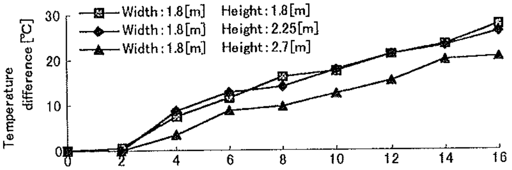
Fig. 6 shows comparison between the experimental result and the analytical using F. E. M. for temperature change at the central portion of the ceiling right above the fire source when the height and width were changed. Both (a) and (b) are results for a constant height, showing that experimental and analytical results are in approximate agreement for widths of 1.35, 1.8 and 2.7 m, and that the larger in the width, the gentler goes the temperature change. This is because, similar to the above-mentioned, the volume of heat diffusion per unit length is smaller when the width is narrower, whereas it goes larger when the width becomes broader. When the width is 2.25 m, it seems that analytical result is correct from the trend of change in the value rather than the experimental result showing the same value as for 1.8 m. Both (c) and (d) are results for a constant width, showing that experimental and analytical results are in approximate agreement for heights of 1.8 and 2.7 m, and that the larger in the height, the smaller goes the temperature change. This is because, similar to the above-mentioned, temperature change becomes gentler because the volume of heat diffusion per unit length is large. It is considered for the height of 2.25 m that the experimental



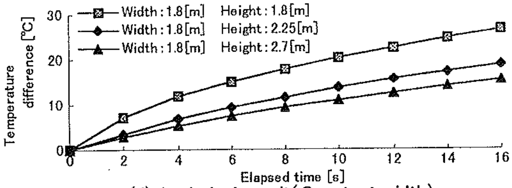
(a) Experimental result(Constant height)



(b) Analytical result(Constant height)



(c) Experimental result(Constant width)



(d) Analytical result(Constant width)

Fig.6. Temperature Variation due to Size of Tunnel

values are more or less higher and the analytical is correct change.

From above results, calculated and measured values showed approximate agreement by putting Ra as 1.5×10^4, and we obtained a prospect that we may calculate out the conversion coefficient α that depends on the shape. By means of this coefficient, it became possible to estimate the calorific value Q [W] with the following formulas we have so far proposed:

$$Q = \frac{\partial E'}{\partial t} = \alpha(H, D, U_W)\frac{\partial \theta_{sum}}{\partial t} \qquad (5)$$

$$\theta_{sum} = \sum_{i=1}^{N_j} (\theta_i - \theta_0) \cdot \Delta Z \qquad (6)$$

Here,

E': Thermal energy

H : tunnel height

D : Width of the high temperature layer

U_W : wind speed

Nj: Nj=(le – ls)/⊿Z, where (le – ls) is the length of the high temperature layer

(θi–θ0): Temperature raise from the ambient temperature [K]

⊿Z: Distance resolution of the temperature measurement

5. Conclusion

As the result of analyzing thermofluid dynamic features in the utility tunnel by applying F. E. M. as stated above, the followings were made evident:

(1) With conditions settled hereunder, use of Rayleigh number between 10^4~10^6 could make it agree with experimental results and the best agreement was obtained for 1.5×10^4.

(2) As for the temperature distribution when the size of utility tunnel was changed, the result of fire experiments showed an approximate agreement with the analytical result using F. E. M., and such a simple method of analysis as this can still be applied to the case with different sizes of the utility tunnel.

(3) Prospect for deriving shape coefficient of the utility tunnel was obtained by means of a mathematical model to which F.E.M. was applied, and it was convinced to practically apply the fire detection based on estimating calorific value by using optical fiber temperature sensor.

As the subject remaining for the future, the followings are listed:

(1) To study so as to make it applicable even when wind blows with a constant speed in the utility tunnel.

(2) To study on application to utility tunnels with thermal features different from the present case such as that with arch type ceiling.

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Ortsbestimmung von Bränden mit Temperatursensorgruppen

Abstract

This paper considers the estimation of the location of a fire in a closed room by use of an array of temperature sensors. Solving this problem enables not only a focused extinguishing in sensible buildings like museums, store houses, shopping malls, computer rooms, etc., but also a better understanding of the cause of the fire and therefore ultimately also for *fire prevention* and *fire detection*. Due to the nonlinear dynamic nature of fire, sophisticated signal processing techniques are required. For this reason, we present an algorithm and a set-up and demonstrate their usefulness by fire experiments.

1 Einführung

Zu den Aufgaben moderner Systeme zur automatischen Brandentdeckung gehört neben der *Branddetektion* auch die *Brandbekämpfung* und vor allem die *Ursachenforschung* zur ständigen Verbesserung bestehender Systeme. In diesem Aufsatz werden wir zu all diesen Aufgaben einen Beitrag leisten. Der Grundgedanke hierzu basiert auf der Fragestellung, ob es mit geringem technischen Aufwand möglich ist, den *Entstehungsort eines Brandes* vor einer Alarmauslösung zuverlässig zu bestimmen. Bei Lösung dieses Problems lassen sich beispielsweise automatische Löschanlagen konstruieren, die eine *gezielte* Löschung des Brandherdes ermöglichen und insofern zu einer drastischen Schadensminderung im Vergleich zu den derzeit großflächig eingesetzten Sprinkleranlagen führen können. Dies gilt in erhöhtem Maße für sensible Umgebungen, wie beispielweise Museen, Lagerhäuser, Kaufhäuser, Rechnerräume, etc.. Neben der Brandbekämpfung erleichtert die Kenntnis des Brandentstehungsortes auch die Ursachenforschung und dient damit letztendlich auch der Prävention. Ferner können die zur Ortsbestimmung verwendeten Kenngrößen, wie z.B. die Strömungsgeschwindigkeit nach *Betrag* und *Richtung*, neben den üblichen Kenn-

größen (Temperatur, Rauchdichte, Gaskonzentrationen) als neue Entscheidunghilfen zur Branddetektion genutzt werden.
Der Aufsatz gliedert sich wie folgt. Im ersten Abschnitt wird die Aufgabenstellung definiert und die Randbedingungen werden angegeben. Darauf folgen die theoretischen Grundlagen und anschließend werden Methoden zur Laufzeitschätzung von Temperaturwellenfronten angegeben. Aus letzteren lassen sich schließlich nicht nur Informationen über den Brandort, sondern auch Strömungseigenschaften bestimmen. Anschließend werden auf den Laufzeitschätzungen basierende Methoden zur Brandortbestimmung abgeleitet und im vierten Abschnitt anhand realer Daten getestet. Mit einem Ausblick und einer Zusammenfassung endet dieser Aufsatz.

2 Aufgabenstellung und Randbedingungen

Betrachten wir einen Brand in einem geschlossenen Raum an dessen Decke mehrere Temperatursensoren (schwarze Punkte) in zunächst willkürlicher Anordnung befestigt sind.

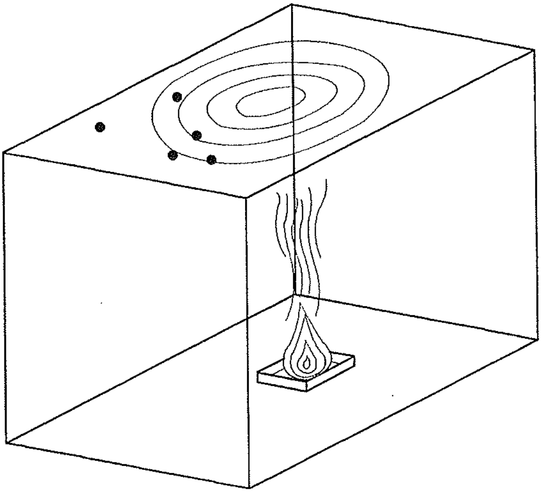

Bild 1: Brand in einem geschlossenem Raum

Zur eindeutigen Aufgabenbeschreibung wird stets von folgenden Annahmen ausgegangen.

- Die Decke ist hinreichend glatt mit geringer Wärmeleitfähigkeit.

- Die Strömungsgeschwindigkeit $|\vec{v}|$ der Verbrennungsgase ist unterhalb der Decke in dem zur Ortsbestimmung genutzten Zeitraum näherungsweise konstant.
- Die Wände sind von gleicher Temperatur.
- Der Brandort ist nicht in Wandnähe, aber in Bodennähe.
- Die neben den durch den Brand verursachten Strömungen sind vernachlässigbar. Hierzu zählen beispielsweise Strömungen bedingt durch Heizungen, Klimaanlagen etc..

Aufgrund dieser Annahmen ist die Ausbreitung der Verbrennungsgase unterhalb der Decke in guter Näherung radial, so daß die Kurven gleicher Temperatur, die als *Temperaturwellenfronten* bezeichnet werden, *im zeitlichen Mittel Kreise* sind (siehe Bild 1). Der in Ausbreitungsrichtung zeigende Strömungsgeschwindigkeitsvektor steht demzufolge immer senkrecht zur Temperaturwellenfront.
Wir werden uns nun der Aufgabe widmen, einen Brand in geringer Zeit unter den angegebenen Randbedingungen genau zu lokalisieren. Zu dieser Problematik existieren schon einige Lösungsansätze. Beispielsweise wird in [7] die gesamte Decke äquidistant mit einer großen Zahl an Temperatursensoren versehen. Der Brandort ist dann durch den Sensor mit dem maximalen Temperaturwert einfach bestimmbar. Nachteilig ist der für eine hinreichend genaue Lokalisierung notwendige hohe technische Aufwand. In [6] wird dieser Aufwand deutlich reduziert. Dabei werden mit Hilfe von *Rechnersimulationen* die Alarmierungszeitpunkte von N Temperaturmeldern für möglichst viele Brandorte ausgerechnet und in einer Datenbank abgelegt. Die im *realen Brandfall* gemessenen $N-1$ Differenzen der Alarmierungszeitpunkte werden dann mit denen in der Datenbank abgelegten nach dem Kriterium des kleinsten mittleren quadratischen Fehlers verglichen, und der Brandort kann somit bestimmt werden. Obwohl in der Praxis nur 5 Melder für eine hinreichend genaue Ortsbestimmung notwendig sind, weist diese Methode zwei prinzipielle Nachteile auf. Zum einen erfordert eine geringfügige Änderung der Raumgeometrie stets eine Neuberechnung sämtlicher Alarmierungszeitpunkte. Zum anderen ist eine Ortsbestimmung erst dann möglich, wenn auch der vom Brandort *am weitesten* entfernte Melder alarmiert hat. In diesem Aufsatz ist hingegen die Zielstellung, *vor* der Alarmierung des dem Brandort *am nächsten* befindlichen Melders den Ort schon bestimmt zu haben.
Durch die Annahme, daß sich das Feuer in Bodennähe entzündet, reduziert sich die Ortsbestimmung von einem dreidimensionalen auf ein zweidimensionales Problem (Bild 2). Zu bestimmen sind der *Radius R*, der *Winkel* α und - da die Sensorsig-

nale eine Funktion der *Zeit* sind - die die Orts- und Zeitparameter verknüpfende *Strömungsgeschwindigkeit* $|\vec{v}|$.

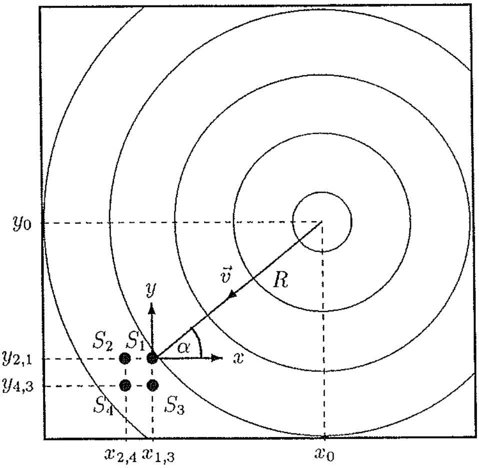

Bild 2: Quadratische Sensorgruppe zur Ortsbestimmung

Wir werden im folgenden stets eine Temperatursensorgruppe bestehend aus 4 Sensoren betrachten. Die Sensoren befinden sich an den Eckpunkten (x_n, y_n), $n = 1(1)4$ eines Quadrates mit der Kantenlänge d = 10cm und sind in einem Abstand von 4cm unterhalb der Decke montiert. Als Sensoren wurden moderne keramische NTC-Widerstände (auch Heißleiter oder Thermistoren genannt) aus folgenden Gründen gewählt. Thermistoren sind kostengünstig; sie sind für den in der Brandentdeckung notwendigen Temperaturbereich (0° – 200° Celsius) erhältlich; sie sind auch mit sehr kleinen Ansprechzeiten ($\approx$ 0.2s) verfügbar und sind mit geringer Bauteiltoleranz lieferbar, welches die Verwendung in einer Sensorgruppe erfordert. Weitere technische Daten sind in [4] nachzulesen.

In ersten Versuchen zur Ortsbestimmung wurden anstelle der hier gewählten quadratischen Anordnung auch andere Geometrien untersucht (siehe [3]). Beispielsweise wurden die Sensoren entlang einer Geraden äquidistant mit einem Abstand von 25cm befestigt. Als wesentliche Erkenntnis ergab sich, daß die in einem solch großen Abstand gemessenen Sensorsignale nur gering korreliert waren und damit eine genaue Ortsbestimmung aussichtslos war. Aus diesem Grunde sollte die Sensorgruppe also von kleiner räumlicher Ausdehnung sein. Jedoch bedingt eine zu kleine räumliche Ausdehnung den Verlust der Radiusinformation, da die an sich kreisförmige Temperaturwellenfront dann innerhalb der Sensorgruppe als *quasiplanar* erscheint. Insofern

stellt die gewählte Kantenlänge $d = 10\text{cm}$ einen Kompromiß dar. Ferner bietet die quadratische Anordnung neben einer einfacheren mathematischen Behandlungsweise auch auf Plausibilität leicht zu prüfende Meßergebnisse.
Auch wenn obige Annahmen vollständig erfüllt sind, verbleiben zur Ortsbestimmung von Bränden noch zahlreiche Probleme. Zum einen sollte die Meßdauer nicht zu lange sein - nicht nur um den Brand möglichst frühzeitig zu lokalisieren, sondern vor allem weil sich die Strömungsverhältnisse im Laufe der Zeit durch Rückwirkungen der begrenzenden Wände deutlich ändern können. Hingegen sollte die Meßdauer auch nicht zu kurz sein, da gerade zu Beginn des Feuers nur geringe, nicht durch das Feuer verursachte Strömungen schon eine Vorzugsrichtung für die Temperaturwellenfront bedeuten können und diesselbe insofern im zeitlichen Mittel keinesfalls kreisförmig sein muß. Aus dieser Diskussion folgt die Frage, ob die Ortsbestimmung von Bränden mit dem hier gewählten Ansatz überhaupt prinzipiell möglich ist.

3 Theoretische Grundlagen

Wir betrachten das sich ausbreitende Temperaturfeld $T(x, y, t)$ als stochastisches Wellenfeld mit der Eigenschaft

$$\mathrm{E}\left\{T(x,y,t)\right\}\big|_{(x-x_0)^2+(y-y_0)^2=c} = f(t), \quad c \in \mathbb{R}, \tag{1}$$

wobei (x_0, y_0) der Brandort und $\mathrm{E}\{X\}$ der Erwartungswert der Zufallsvariablen X ist. Gleichung (1) beschreibt die sich um das Zentrum (x_0, y_0) ausbreitende *kreisförmige* Temperaturwellenfront und verdeutlicht die aus $f(t)$ folgende Instationarität der gemessenen Sensorsignale. Hierbei ist anzumerken, daß die Instationarität durch die in der Regel langsam ansteigende Temperatur nur schwach ausgeprägt ist, so daß in einem zeitlich beschränkten Intervall durchaus noch statistisch nutzbare Kenngrößen durch zeitliche Mittelung gewonnen werden können.
Der $n-te$ Temperatursensor tastet dieses stochastische Wellenfeld räumlich an der Stelle (x_n, y_n), $n = 1(1)4$ ab und liefert das *analoge* Temperatursignal $\tilde{T}_n(t) = T(x_n, y_n, t)$. Dieses analoge Signal wird nun mit einer Frequenz von $f_A = 500\text{Hz}$ abgetastet und das *zeitdiskrete* Temperatursignal $T_n(k) = \tilde{T}_n(k/f_A)$, $k \in \mathbb{Z}$ steht somit zur weiteren Signalverarbeitung zur Verfügung. Obwohl die wesentlichen Frequenzen eines Feuers nur in dem Bereich bis 10Hz liegen [2], wurde die Abtastfrequenz deutlich größer gewählt um die nachfolgende Signalverarbeitung zur Ortsbestimmung zu erleichtern. Wir werden im folgenden diesen Aspekt nochmals aufgreifen.
Für das zeitdiskrete Temperatursignal $T_n(k)$ wird das folgende Signalmodell

$$T_n(k) = S_n(k) + N_n(k), \quad n = 1(1)4,\ k \in \mathbb{Z} \tag{2}$$

angenommen, wobei $S_n(k)$ der in $T_n(k)$ enthaltene deterministische, jedoch unbekannte Anteil ist. $N_n(k)$ ist ein additives beliebig verteiltes Rauschen. Bedingt durch die zeitlich fortschreitende Temperaturwellenfront sind die deterministischen Anteile $S_n(k)$ und $S_m(k)$ nur zeitlich zueinander um k_{nm}, $k_{nm} \in \mathrm{Z}$ verschoben und eventuell gedämpft, so daß wir das vorherige Signalmodell wie folgt modifizieren können

$$T_n(k) = \alpha_n\, S(k - k_{1n}) + N_n(k), \quad n = 1(1)4,\ k_{nn} = 0, \tag{3}$$

wobei ohne Beschränkung der Allgemeinheit Sensor 1 als Referenzsensor gewählt wurde und somit $S_1(k) = S(k)$ und $\alpha_1 = 1$ gilt. Zur Schätzung der gesuchten Parameter werden im ersten Schritt sämtliche Zeitdifferenzen k_{nm}, welche im weiteren auch als *Laufzeiten* bezeichnet werden, zwischen den Temperatursensorsignalen geschätzt. Sodann können bei gegebener Strömungsgeschwindigkeit $|\vec{v}|$ die Ortskenngrößen R, α bestimmt werden.

Wir haben hier vereinfachend k_{nm} als ganzzahlig angenommen, welches in der Praxis im allgemeinen nicht erfüllt ist. Um den dadurch entstehenden Fehler so gering wie möglich zu halten, wurden die Signale wie schon erwähnt deutlich überabgetastet. Diese Vorgehensweise ermöglicht die Verwendung einer Vielzahl bekannter Verfahren [1] zur Zeitdifferenzschätzung. Wird hingegen auf obige Annahme verzichtet, so ist eine zusätzliche Interpolation der Abtastwerte notwendig (siehe [5], S. 322), die in diesen ersten prinzipiellen Untersuchungen zur Ortsbestimmung von Bränden die Signalverarbeitung nur unnötig komplizieren würde.

Offenbar ist es völlig ausreichend, ein Verfahren zur Schätzung der Zeitdifferenz nur zwischen dem Sensor 1 und *einem* beliebigen anderen Sensor zu entwickeln. Sämtliche verbleibende Zeitdifferenzen können dann durch entsprechende Indexvertauschungen berechnet werden. Wir betrachten daher nur die beiden Gleichungen

$$\begin{aligned} T_1(k) &= S(k) + N_1(k) && (4)\\ T_n(k) &= S(k - k_{1n}) + N_n(k), n \neq 1. && (5) \end{aligned}$$

Bei diesem Modell ist nun zu entscheiden, ob $S(k)$ bekannt oder unbekannt ist oder ob zumindest statistische Eigenschaften bekannt sind, ob $N_1(k)$ unkorreliert oder auch unabhängig von $N_n(k)$ ist, ob $N_n(k)$, $n = 1(1)4$, unkorreliert ist, oder ob die Rauschprozesse gaußverteilt oder nichtgaußverteilt sind. Anhand dieser a-priori-Informationen können entsprechend geeignete Verfahren zur Bestimmung von k_{1n} ausgewählt werden. Nun ist bei der hier gestellten Aufgabe aufgrund der nichtlinearen dynamischen Natur des Feuers irgendeine a-priori Annahme nur schwerlich möglich. Beispielsweise ist $S(k)$ im allgemeinen Brandfall bis auf einen im relevanten Zeitintervall stets ansteigenden Verlauf völlig unbekannt. Auch die bekannte Eigenschaft des Flammenflackerns mit einer typisch dominanten Frequenz von ca. 3Hz [2] läßt sich nicht ausnutzen, da der Transportweg der heissen Verbrennungsgase unterhalb der Decke einen ausgeprägten Tiefpaßcharakter hat, der die Flackerfrequenz schon in geringer Entfernung von (x_0, y_0) deutlich dämpft. Hingegen können bedingt durch lokale Turbulenzen in Sensornähe die beiden Rauschprozesse $N_1(k)$ und $N_n(k)$ in erster Näherung als unabhängig oder zumindest unkorreliert angenommen werden. Diese Sichtweise motiviert auch die Unabhängigkeit von $S(k)$ von jedem Rauschprozeß $N_n(k)$, $n = 1(1)4$. Da der zeitlich langsame Anstieg in $S(k)$ enthalten ist, kann der zeitliche Mittelwert der Rauschprozesse vernachlässigt werden, so daß $\mathrm{E}\{N_n(k)\} = 0$ approximativ gilt. Die Verteilung der Rauschprozesse ist zunächst als nichtgaußverteilt zu betrachten, da die Temperatur innerhalb der Flamme an sich schon nicht gaußverteilt ist [2]. Genauere Untersuchungen können jedoch den Einsatz von Verfahren basierend auf sogenannten *Statistiken höherer Ordnung* (siehe [5], S. 322) motivieren.

In dieser ersten Untersuchung haben wir uns für einen bewährten Algorithmus - die sogenannte *Kreuzkorrelationsmethode* - entschieden, der im folgenden kurz erläutert wird. Die Kreuzkorrelation von $T_1(k)$ mit $T_n(k)$ ergibt sich zu

$$\begin{aligned} R_{1n}(\kappa) &= \mathrm{E}\{T_1(k)\,T_n(k+\kappa)\}\,, \quad n = 2(1)4 \\ &= \mathrm{E}\{S(k)S(k-k_{1n}+\kappa)\}\,, \end{aligned} \tag{6}$$

wobei die Unabhängigkeit der angenommenen Prozesse und $\mathrm{E}\{N_n(k)\} = 0$, $\forall n = 1(1)4$ ausgenutzt wurde. Offenbar ist $R_{1n}(k_{1n})$ das Maximum von $R_{1n}(\kappa)$, da dann im Argument des Erwartungswertes für beliebiges k stets der positive Wert $S^2(k)$ steht. Zur Bestimmung von k_{1n} ist also lediglich $R_{1n}(\kappa)$ aus den gemessenen Signalen zu schätzen und das Maximum zu suchen. Der entsprechende Abszissenwert ist dann gleich der gesuchten Zeitdifferenz k_{1n}. Eine übliche Schätzung $\hat{R}_{1n}(\kappa, k)$ der Kreuzkorrelationsfunktion $R_{1n}(\kappa)$ ergibt sich bei jeweils K gemessenen Signalwerten $T_1(k)$, $T_n(k)$, $k = 0(1)K$ durch Ersetzen des Erwartungswertes durch den Zeitmittelwert

$$\begin{aligned} \hat{R}_{1n}(\kappa, k) &= \frac{1}{L}\sum_{l=m}^{L+m-1} T_1(l)\,T_n(l+\kappa), \quad n = 2(1)4,\ k = \frac{m}{M} \\ & \qquad m = 0(M)K-L, \quad M \in \mathbb{Z}, \quad \kappa = -\kappa_{\max}(1)\kappa_{\max}, \end{aligned} \tag{7}$$

wobei der Instationarität der Signale durch die Zeitabhängigkeit $k = m/M$ von $\hat{R}_{1n}(\kappa, k)$ Rechnung getragen wird. Die gemessenen Temperatursignale werden also in Blöcke der Länge L aufgeteilt und über das Produkt derselben wird zeitlich gemittelt. Um den Rechenaufwand zu reduzieren wird die Kreuzkorrelationsfunktion nur zu jedem M-ten Zeitpunkt geschätzt. Zudem sollte $\kappa_{\max}$ nicht unnötig groß gewählt werden. Eine detaillierte Diskussion dieses Algorithmus und die Wahl von

L, M und $\kappa_{\max}$ würde den Rahmen dieses Aufsatzes deutlich überschreiten. Für weiterführende Informationen wird daher auf [4], [8] verwiesen.

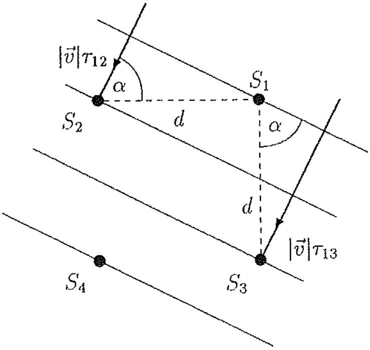

Bild 3: Quasiplanare Wellenfront

Nachdem nun die Laufzeiten bestimmt werden können, ist ein Zusammenhang zu den gesuchten Parametern R, α, $|\vec{v}|$ abzuleiten. Dazu betrachten wir zunächst den vereinfachten Fall eines sehr weit entfernten Brandortes $R \gg d$ (Bild 3) und damit einer näherungsweise *ebenen* (oder auch *planaren*) Wellenfront in der Umgebung der Sensorgruppe, wobei $\tau_{nm} = k_{nm}/f_A$ gilt. Da der Strömungsvektor senkrecht zur Wellenfront steht, gelten die Beziehungen

$$|\vec{v}|\,\frac{k_{12}}{f_A} = d\cos\alpha \tag{8}$$

$$|\vec{v}|\,\frac{k_{13}}{f_A} = d\sin\alpha, \tag{9}$$

und folglich

$$\alpha = \arctan\left(\frac{k_{13}}{k_{12}}\right) \tag{10}$$

$$|\vec{v}| = f_A\,\frac{d\cos\alpha}{k_{12}}. \tag{11}$$

Ist also die Brandquelle weit von der Sensorgruppe entfernt, so können Einfallswinkel und Strömungsgeschwindigkeit nach der Laufzeitschätzung mit (10), (11) einfach bestimmt werden. Wird zusätzlich noch ein vierter Sensor verwendet, so gilt neben den Gleichungen (8), (9) auch

$$|\vec{v}|\,\frac{k_{14}}{f_A} = \sqrt{2}\,d\cos(\alpha - \pi/4) \tag{12}$$

$$|\vec{v}|\,\frac{k_{23}}{f_A} = \sqrt{2}\,d\sin(\alpha-\pi/4) \tag{13}$$

$$|\vec{v}|\,\frac{k_{24}}{f_A} = d\sin\alpha \tag{14}$$

$$|\vec{v}|\,\frac{k_{34}}{f_A} = d\cos\alpha. \tag{15}$$

Obige Gleichungen können zur *robusten* Schätzung der gesuchten Parameter mitverwendet werden. Da das so entstandene Gleichungssystem (8),(9),(12)-(15) nichtlinear ist und aus Aufwandgründen auf Optimierungsverfahren verzichtet werden soll, hat sich

$$\hat{\alpha} = \frac{1}{3}\left(\arctan(\frac{\hat{k}_{13}}{\hat{k}_{12}}) + \arctan(\frac{\hat{k}_{23}}{\hat{k}_{14}}) + \arctan(\frac{\hat{k}_{24}}{\hat{k}_{34}}) + \frac{\pi}{4}\right)$$

$$|\hat{\vec{v}}| = f_A d\,\mathrm{median}\left(\frac{\sin\hat{\alpha}}{\hat{k}_{13}};\frac{\cos\hat{\alpha}}{\hat{k}_{12}};\frac{\sin\hat{\alpha}}{\hat{k}_{24}};\frac{\cos\hat{\alpha}}{\hat{k}_{34}};\frac{\sqrt{2}\sin(\hat{\alpha}-\pi/4)}{\hat{k}_{23}};\frac{\sqrt{2}\cos(\hat{\alpha}-\pi/4)}{\hat{k}_{14}}\right)$$

zur Schätzung bewährt. Die Verwendung des *Medians*[1] zur Bestimmung der Geschwindigkeit hat sich als genauer erwiesen als der üblich verwendete Mittelwert, da durchaus Laufzeitschätzungen mit dem Wert Null auftreten und sich folglich sehr ungenaue Geschwindigkeitsschätzungen ergeben können. Durch den Median werden solche Ausreisser nahezu unbedeutend.

Nach dieser robusten Methode zur Bestimmung der Geschwindigkeit und des Winkels verbleibt die Radiusbestimmung. Hierzu kann mit einer zweiten, von der ersten deutlich entfernten Sensorgruppe ein zweiter Einfallswinkel bestimmt werden. Der Schnittpunkt beider Geraden liefert dann den Brandort (Bild 4).

Der technische Aufwand für diesen Lösungansatz ist zwar verdoppelt, jedoch ist der Signalverarbeitungsaufwand gering. Zudem wird die Ortsbestimmung ab einem kritischen Radius bei Verwendung von zwei Sensorgruppen deutlich genauer, da die Varianz der Winkelschätzung unabhängig vom Radius ist, wohingegen die Varianz der Radiusschätzung bei Verwendung *einer* Gruppe und Annahme einer *kreisförmigen* Ausbreitung proportional zur *vierten* Potenz des Radius ist (siehe [1], S. 252). Große Entfernungen mit einer kleinen Sensorgruppe zu schätzen, ist also extrem schwierig. Wir haben nun eine neue Methode zur Ortsbestimmung vorgestellt und werden im folgenden Abschnitt deren Funktionsweise anhand realer Daten prüfen.

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[1] Die Daten werden der Größe nach sortiert und der Median liefert dann den in der Mitte liegenden Wert.

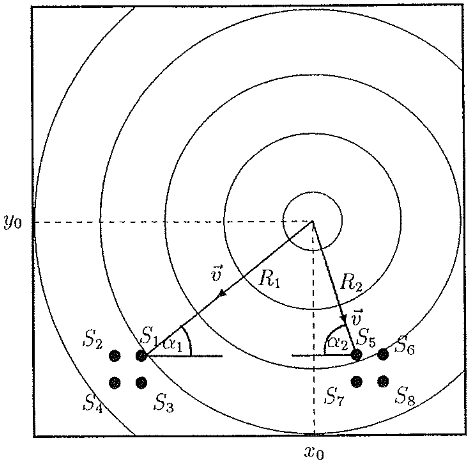

Bild 4: Zwei Sensorgruppen zur robusten Ortsbestimmung

4 Ortsbestimmung mit realen Daten

In dieser Grundlagenuntersuchung wurden zunächst zwei Spiritusfeuer in dem Brandentdeckungslabor der Gerhard-Mercator-Universität Duisburg durchgeführt. Das Labor hat eine Grundfläche von $10,5\text{m} \times 9\text{m}$ und verfügt über eine auf $3,40\text{m}$ eingestellte höhenvariierbare Decke. Es wurden jeweils 800g Spiritus in einer in der Raummitte befindlichen quadratischen Schale mit der Kantenlänge $43,7\text{cm}$ entzündet, wobei Sensor 1 und Sensor 5 in einem Abstand von $3,39\text{m}$ von der über dem Brandort liegenden Deckenmitte befestigt waren. Die theoretischen Werte betragen also $\alpha_1 = 45°$, $\alpha_2 = 45°$, $R_1 = 2,40\text{m}$, $R_2 = 2,40\text{m}$.

Die folgenden Bilder (Bild 5a,b) zeigen beispielhaft die Signalverläufe von Sensor 1 und Sensor 2 für beide Messungen. Dabei kennzeichnen die hochgestellten Indizes das Experiment und die tiefgestellten Indizes den Sensor. Offenbar sind sich die Signale in jedem Experiment sehr ähnlich, weshalb, wie im folgenden zu sehen sein wird, auch die Kreuzkorrelation recht hohe Werte annimmt. Hingegen ist die Zeitverschiebung zwischen den Signalen von Sensor 1 und Sensor 2, die in der Größenordnung von $< 1\text{s}$ liegt, nicht zu erkennen. Das Feuer beginnt im ersten Experiment nach ca. 40 Sekunden. Da nach der europäischen Norm für Wärmemelder der Klasse A1 die Alarmauslösung bei einer Erhöhung der Raumtemperatur um 29° Celsius erfolgen soll, ist hier die Auslösetemperatur ca. 52.5° Celsius und der Auslösezeitpunkt im ersten Experiment ca. 90s nach Brandbeginn. Diese Zeit steht also zur Ortsbestim-

mung zur Verfügung. Im zweiten Experiment beginnt das Feuer nach ca. 60s und wiederum stehen ca. 90s zur Ortsbestimmung zur Verfügung.
Nach einigen Untersuchungen über die Wahl der Parameter L, M, $\kappa_{\max}$ (siehe [4], [8]) ergaben sich die Einstellungen $L = 20000$, $M = 1000$, $\kappa_{\max} = 500$ als sinnvoll. Die gesuchten Ortsparameter wurden durch Lösung des unter (8),(9),(12)-(15) angegebenen nichtlinearen Gleichungssystems bestimmt.

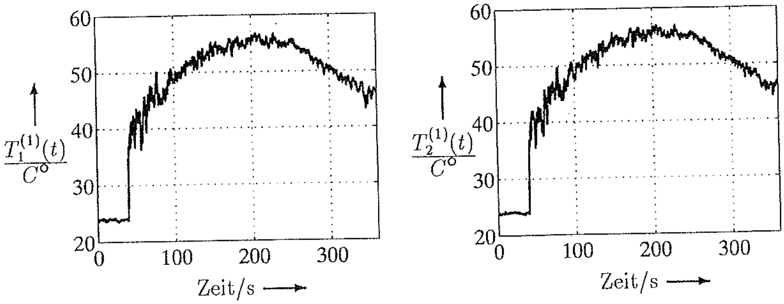

Bild 5a: $T_1^{(1)}(t)$ und $T_2^{(1)}(t)$ im ersten Experiment

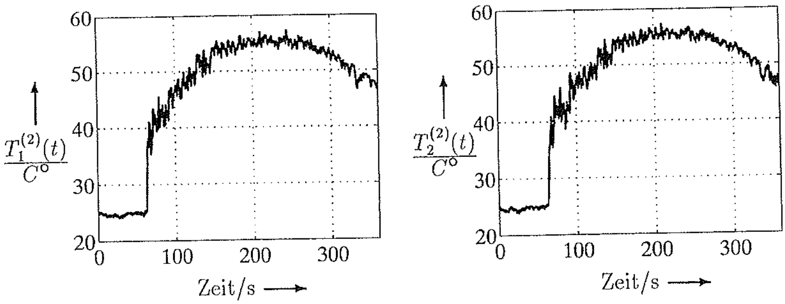

Bild 5b: $T_1^{(2)}(t)$ und $T_2^{(2)}(t)$ im zweiten Experiment

In den nachfolgenden Bildern wird der Ortsfehler

$$\Delta r(k) = \sqrt{(x_0 - \hat{x}_0(k))^2 + (y_0 - \hat{y}_0(k))^2} \tag{16}$$

mit den geschätzten Koordinaten

$$\hat{x}_0(k) = D\,\frac{\tan\hat{\alpha}_2(k)}{\tan\hat{\alpha}_1(k) + \tan\hat{\alpha}_2(k)}, \qquad \hat{y}_0(k) = D\,\frac{\tan\hat{\alpha}_1(k)\,\tan\hat{\alpha}_2(k)}{\tan\hat{\alpha}_1(k) + \tan\hat{\alpha}_2(k)}$$

als Funktion der diskreten Zeit k und die geschätzten Brandorte in den für die

Brandentdeckung relevanten Zeitbereichen dargestellt. Ferner ist der Mittelwert

$$\bar{\hat{R}}^{N}_{\max}(k) = \frac{1}{12}\left(\sum_{i=1}^{4}\sum_{\substack{j=2\\ j<i}}^{4} \max_{\kappa} \hat{R}^{N}_{ij}(\kappa,k) + \sum_{i=5}^{8}\sum_{\substack{j=6\\ j<i}}^{8} \max_{\kappa} \hat{R}^{N}_{ij}(\kappa,k)\right) \tag{17}$$

sämtlicher Maxima der geschätzten *normierten* Kreuzkorrelationsfunktionen

$$\hat{R}^{N}_{ij}(\kappa,k) = \frac{\hat{R}_{ij}(\kappa,k)}{\frac{1}{L}\sqrt{\sum\limits_{l=m}^{L+m-1} T_i^2(l) \sum\limits_{l=m}^{L+m-1} T_j^2(l)}} \tag{18}$$

abgebildet. Vorteilhaft an der Normierung ist der nunmehr auf das Intervall $[-1,1]$ begrenzte Wertebereich von $\hat{R}^{N}_{ij}(\kappa,k)$, so daß beispielsweise bei einem normierten Kreuzkorrelationswert von 1 die Signale bis auf einen positiven Faktor identisch sind. Alle im folgenden dargestellten Ergebnisse sind im Internet unter `http://fb9nt.uni-duisburg.de/mitarbeiter/kaiser/aube.99/aube.html` erhältlich.

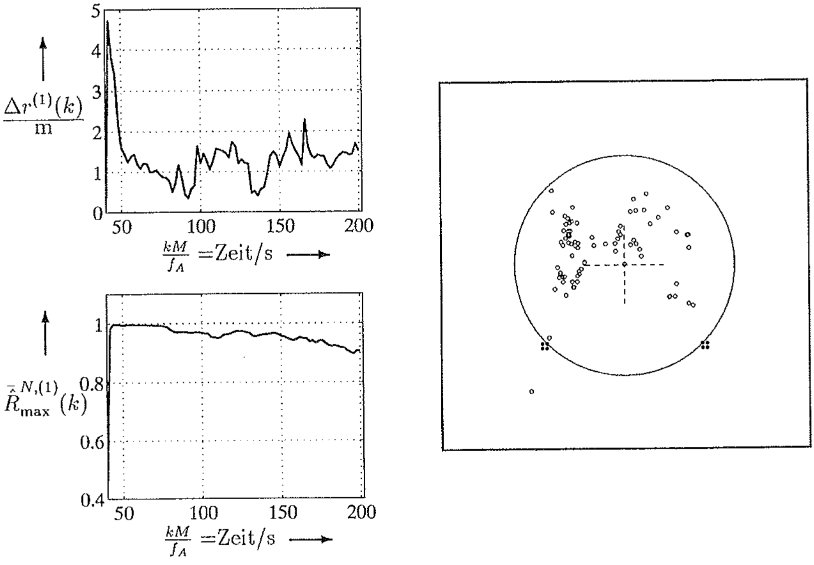

Bild 6a: Ortsfehler, maximaler mittlerer Kreuzkorrelationswert und die geschätzten Brandorte im ersten Experiment

Beim ersten Experiment (Bild 6a) nimmt die Korrelationsfunktion zu Beginn des Feuers (ca. 40 Sekunden nach Beginn der Aufzeichnung) drastisch zu und der Ortsfehler langsam ab. Die anfänglich schlechten Schätzungen mit einem Ortsfehler von sogar 4,80m liegen schon 20 Sekunden nach Brandbeginn bei einem Meter. Ungefähr 40 – 50 Sekunden nach Brandbeginn ist der Ortsfehler in der Größenordnung einer Schalengröße (43,7cm) und damit hinreichend genau. Anschließend steigt der Ortsfehler wieder langsam an. Fraglich ist nun wie der Zeitpunkt bestimmt werden kann bei dem der Ortsfehler am kleinsten ist. Zur Lösung dieser Aufgabe ist es zunächst einsichtig, daß der Ortsfehler mit steigender Messzeit aufgrund des "Herausmittelns" von zufälligen Strömungsänderungen immer geringer werden sollte. Ab einem gewissen Zeitpunkt jedoch werden die durch die Wände verursachten Rückwirkungen die Strömungsverhältnisse zur Ortsbestimmung ungünstig ändern. Es wird dann also nicht nur die näherungsweise radiale Temperaturwellenfront des Feuers auf die Sensorgruppe treffen, sondern auch Strömungen aus anderen Richtungen. Die sich daraus ergebenden Turbulenzen sollten auf merkbar unkorreliertere Sensorsignale führen. Genau dies ist anhand von $\bar{\hat{R}}^N_{\max}(k)$ zu erkennen. Ungefähr 40 Sekunden nach Brandbeginn nimmt die Korrelation von dem beinahe idealen Wert 1 deutlich ab und fällt von da an langsam mit wachsender Zeit. Als erster Ansatz zur Ermittlung des Zeitpunktes zur Ortsbestimmung ist also einfach ein Schwellenwert von $\bar{\hat{R}}^N_{\max}(k)$ zu wählen. Zur Bestätigung dieser Erkenntnis betrachten wir nun die Ergebnisse beim zweiten Experiment (Bild 6b).

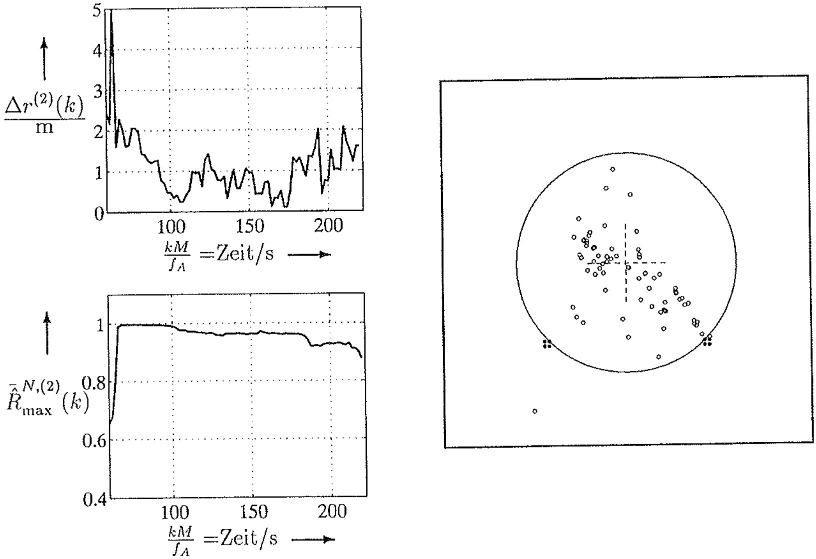

Bild 6b: Ortsfehler, maximaler mittlerer Kreuzkorrelationswert und die geschätzten Brandorte im zweiten Experiment

Das Feuer wurde ca. 60 Sekunden nach Aufzeichnungsbeginn entzündet und wiederum steigt der maximale mittlere Korrelationswert schnell an, während der Ortsfehler wieder mit kurzer Verzögerung kleiner wird. Es bestätigt sich jedoch die obige, zur zuverlässigen Ortsbestimmung wichtige Erkenntnis, daß der Ortsfehler dann am geringsten ist, wenn der maximale mittlere Korrelationswert schnell von ≈ 1 abfällt. Dies wäre wiederum $40 - 50$ Sekunden nach Brandbeginn der Fall.

5 Zusammenfassung und Ausblick

Wir haben in diesem Aufsatz eine Methode zur Ortsbestimmung von Bränden vorgestellt und deren Funktionsweise anhand zweier Experimente geprüft. *Es ergab sich, daß der Brandort mit einer Genauigkeit von etwa einer Schalengröße (43,7cm) deutlich vor einer Alarmierung bestimmbar ist.* Damit ist die grundlegende Fragestellung, ob es überhaupt möglich ist, den Brandort mit einer geringen Anzahl von Sensoren vor einer Alarmauslösung zu bestimmen, durchweg zu bejahen.

Neben der Ortsbestimmung liefert der vorgestellte Ansatz auch *neue Kriterien* für eine zuverlässigere *Branddetektion*. Beispielsweise ist die *Strömungsgeschwindigkeit*, auf die wegen Platzmangels nicht näher eingegangen werden konnte, für das Eindringverhalten in Rauchmeldern von Bedeutung. Zudem sollte bei einem Feuer stets auch eine *dominante Strömungsrichtung* vorliegen, welche eine *hohe Kreuzkorrelation* und eine sich nur *langsam ändernde Ortsschätzung* im Brandfall bewirkt.

Nach dieser Grundlagenuntersuchung verbleiben noch viele offene Fragen. Zum einen sind die gewonnenen Erkenntnisse anhand weiterer vor allem andersartiger Feuer zu prüfen. Zudem ist der Einfluß von Störungen, bedingt beispielsweise durch einen Heizkörper, unterschiedlich kalte Wände, offene Türen, Fenster, Klimaanlagen etc., zu untersuchen. Ist beispielsweise eine Wand in dem geschlossenen Raum deutlich kälter als die anderen, so sind die Temperaturwellenfronten eher von elliptischer Form und somit steht der Strömungsgeschwindigkeitsvektor nicht länger senkrecht zur Wellenfront. Dies erfordert eine aufwendige analytische Lösung, um weiterhin aus den Laufzeitschätzungen den Ort zu bestimmen. Auch sind die optimale Anordnung der Sensoren, die optimale Kantenlänge, die optimale Sensoranzahl und der optimale Abstand zur Decke zu ermitteln. Ferner sind die Laufzeitschätzungen mit modernen Signalverarbeitungsmethoden eventuell noch deutlich zu verbessern. Interessant ist auch die Radiusschätzung mit nur einer Sensorgruppe und die Bestimmung des kritischen Radius, ab dem die 2-Gruppen-Lösung vorzuziehen ist. Zudem ist die Verwendung anderer Temperatursensoren, beispielsweise gegenüber Umwelteinflüssen äußerst robuste pyroelektrische Sensoren, in Betracht zu ziehen. Abschließend verbleibt der Bau eines Prototypen basierend auf einem herkömmlichen Brandmelder, an dessen Unterseite eine kleine Temperatursensorgruppe befestigt wird.

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Photoacoustic Gas Detection for Fire Warning

Abstract

A detector for measuring the gas concentration of carbon dioxide based on an infrared photoacoustic principle is presented. Many molecules and particles in the atmosphere cause extinction of an incident beam of infrared radiation due to absorption and scattering processes. The absorption occurs at wavelengths which are very specific for each molecule. In the miniaturized gas detector presented the ambient gas enters a small cell (approx. $1 cm^3$) via a diffusion membrane. The gas is irradiated with pulsed infrared light at the specific absorption wavelength for carbon dioxide. The absorption of the radiation energy by the gas molecules causes slight variations of the pressure inside the measuring cell which can be detected with a commercial microphone. The amplified and subsequently linearized microphone signal is proportional to the gas concentration present. The applicability of the photoacoustic principle for the detection of combustion gases is discussed.

1. Introduction

Conventional fire detectors are based on sensing techniques which measure the physical effects of a fire such as the increase in temperature and particle density, i.e. smoke, in the air. The particle density and the temperature resulting from a fire largely depends on the type of combustion process. For example, in the complete combustion of alcohol no smoke particles are released, whereas the temperature increase is significant. Smouldering, slowly burning fires with oxygen deficiency only release a small number of smoke particles and even the increase in temperature is sometimes not significant enough to clearly detect a fire. The measurement of one or more physical parameters is not always sufficient for an early and reliable fire detection. Therefore, some years ago the idea emerged of detecting the gases released in the chemical reactions during the combustion process to enhance detection efficiency for fires which are hardly detectable when measuring only physical parameters [1,2]. Since reliable detection techniques for specific gases are more complicated than for the measurement of temperature and smoke density, no appropriate gas sensing elements have so far been available on the market at a price level required for fire detection units. Gas detection, therefore, was not a serious topic for fire detection for several years.

During recent years gas sensing techniques have been developed further and it has now become an area of major interest for fire detection [3,4]. The gases related to combustion processes which mainly apply for fire warning are carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxides (NO_x). Other gases such as methane (CH_4), hydrogen (H_2), amines ($-NH_2$) and water (H_2O) are currently being investigated for their applicability, too.

The technical requirements for the sensing of combustion gases are quite different to those for industrial needs for the monitoring of toxic and explosive concentrations of gases in air. The power consumption of the devices for industrial gas detection, for example, is not of major importance, since the areas to be protected by gas warning systems are clearly defined and limited. For the detection of combustion gases for early fire warning, on the other hand, the number of detectors needed to protect areas and buildings can easily exceed 1000 sensors and, therefore, the power consumption and also the price of the devices plays a most significant role in the applicability of a system.

In the following, a gas detection technique will be presented which is based on an infrared photoacoustic principle which has already been used with great success for industrial gas detection and in building automation for air quality monitoring. The use of this technique for fire warning and fire prevention is discussed.

2. Infrared photoacoustic principle for gas detection

Many molecules and particles in the atmosphere cause extinction of an incident beam of infrared radiation due to absorption and scattering processes. The absorption occurs at wavelengths which are very specific to each molecule. This physical effect allows the spectroscopic analysis of an unknown mixture of different gas molecules. In general, a certain volume of the gas to be measured is irradiated by an infrared beam at the molecule-specific wavelength and the extinction of the beam is measured by a photodiode. This direct measurement of the absorption makes high demands on the light source and the electronics and a continuous reference signal is also needed. In the gas sensing principle presented, the measurement of the absorption of the incident radiation energy is done by the photoacoustic [5,6] effect which allows a much simpler realization of a gas detector than the direct measurement and, therefore, it can be produced at low cost.

The main applications for the photoacoustic detector (PAD) are the measurement of carbon dioxide (CO_2) and hydrocarbons (HC), such as methane (CH_4), in the range from a few ppm to some % V/V.

2.1. Theory

The gas to be measured is irradiated with pulsed radiation having the specific wavelength corresponding to the resonance vibrational frequency of its molecules (IR). The frequency depends on the mass distribution of the individual atoms in the molecule and the strength of their mutual attraction. The amplitude of the absorption line grows with the possible dipole momentum change in the direction of oscillation (hence the CO_2 molecule shows strong absorption lines in the IR (λ=4.25μm), whereas N_2 does not respond although its vibrational frequencies are almost the same). Due to the numerous collisions between the gas molecules a fast relaxation takes place after a few microseconds where the vibrational energy is transformed into translational energy, i.e. heat. In the closed volume of a measuring cell, the heat released causes an increase in pressure during the time of the radiation pulse. These very small pressure changes (in the order of a few micro Pascal) can be detected with a commercial microphone.

The incident modulated beam with the intensity *I(t)* can be expressed as

$$I(t) = I_0 \cdot [1 + m \cdot \sin(\omega t)],$$

where ω and *m* denote the modulation frequency and depth, respectively. The beam at the specific resonant wavelength propagates in the gas cell along the way *x* according to the Lambert-Beer law

$$I = I_0 \cdot \exp(-\alpha c x)$$

with α and *c* being the absorption coefficient and concentration of the gas to be measured. In good approximation the absorbed intensity in a cell of length *l* can then be expressed as

$$\Delta I = I_0 \cdot [1 - \exp(-\alpha c l)] \ .$$

For the induced pressure change *Δp* within the cell a simplified expression can be derived

$$\Delta p = \frac{1}{V} \cdot a \cdot \frac{1}{\sqrt{\lambda^2 + \omega^2}} \cdot \Delta I \ ,$$

where *V* denotes the volume of the cell, *a* stands for the thermodynamical properties of the gas and λ is a constant which describes the heat conduction and diffusion in the cell. For small concentrations and small cell lengths, where ($\alpha c l << 1$), the expression is further simplified and we obtain for the signal *S* in the microphone with sensitivity *Q*

$$S = Q \cdot \frac{1}{V} \cdot a \cdot \frac{I_0 \cdot \alpha c l}{\sqrt{\lambda^2 + \omega^2}} \ .$$

Obviously, the signal is linearly dependant on the gas concentration.

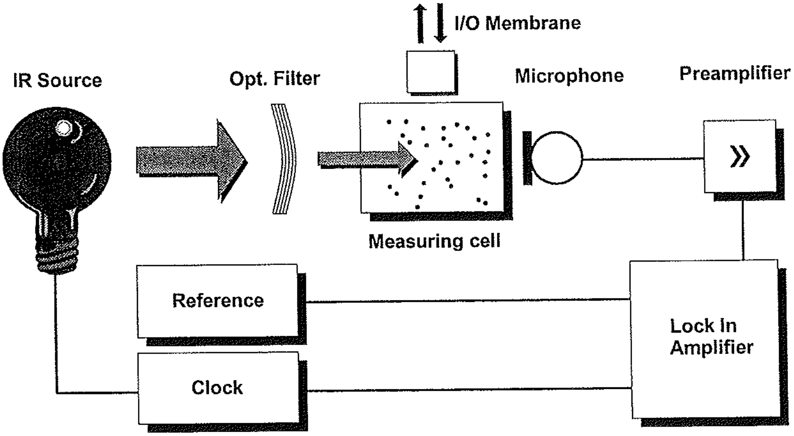

Figure 1: Schematic view of the photoacoustic detector.

2.2. Technical realisation of the photoacoustic detector (PAD)

The IR-source of a PAD can be an open incandescent filament similar to devices based on absorption. But these filaments are subject to oxidation or evaporation of the metal and react rather slowly. Another solution is the use of an evacuated bulb (figure 1), sometimes supplied with special IR-transitive windows as sapphire glass. If quartz glass is used, some of the intensity is lost due to absorption. The advantage of a fast responding source is its ability to be pulsed electrically, so chopper-wheels and motors can be omitted. For reliable sensors the stability of the IR-source is of utmost importance. This is achieved by measuring the lamp temperature or brightness of each pulse and regulating the pulse width, in order to keep it constant. A narrow-band interference filter is used as optical filter, which only transmits a specific electromagnetic wavelength. The pulse repetition rate is usually in the order of 10 to 20 Hz. This is a compromise between the stronger signal with increasing ω and the decrease of Q for most microphones below 10 Hz. In contrast to other methods, for the PAD a closed chamber is used to measure the acoustic pressure which can be realised with a gas permeable membrane at low cost.

The main advantages compared to other methods are: high stability, which means low offset drifts, practically no cross-sensitivities to other gases (for CO_2), low influences of pressure and temperature and a probable lifetime of 5 to 10 years. The detector can be used for other gases by just changing the optical filter (choosing another wavelength). For example, hydrocarbons can be detected non-selectively at 3.4μm. If the absorption lines of the measured gas coincide with those of water vapour, which is often present, these errors have to be taken into account. The detection of CO, for example, is therefore almost impossible with the simple arrangement discussed above.

Figure 2 shows a test measurement of the CO_2 concentration in a heavy traffic highway tunnel made with a gas detector based on the photoacoustic principle. The difference between the weekends and the weekdays with the two rush hours can be clearly seen.

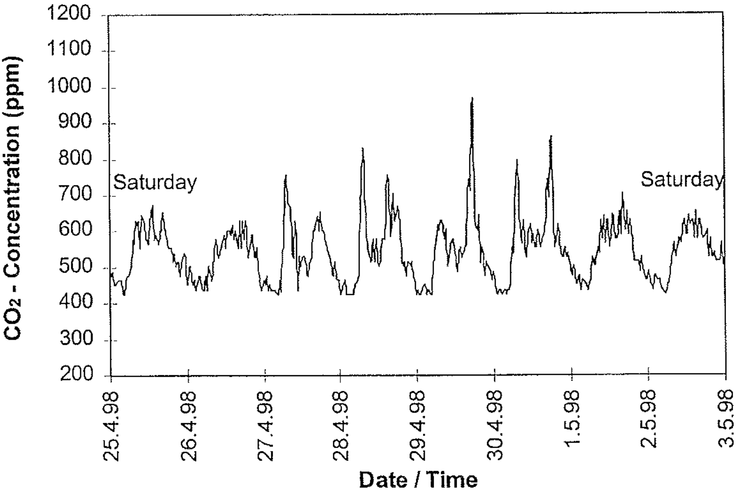

Figure 2: Photoacoustic measurement of CO_2 concentration in heavy traffic highway tunnel in the vicinity of Zurich.

3. Application of photoacoustics for fire detection and fire prevention

The main advantage of gas detection based on an infrared photoacoustic principle is the possibility of producing a cheap detector. This is especially important for cost-sensitive applications such as, for example, air quality measurement for ventilation control systems, where photoacoustic detectors have already been used for many years for CO_2 measurement. The potential of a photoacoustic detector for fire detection and fire prevention is discussed below.

3.1. Fire Detection

As mentioned in the introduction, gas detection for fire warning has become an area of major interest in the last few years especially for the early detection of slowly-burning smouldering fires. A photoacoustic detector can be used to detect carbon dioxide or hydrocarbons such as methane. In case of carbon dioxide there is almost no cross interference with other gases which might

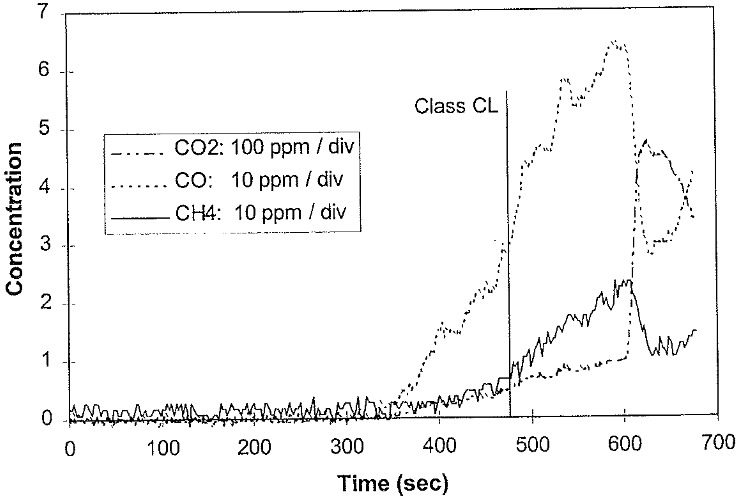

Figure 3: Measurements of gas concentrations in a standard EN54 TF2 test fire [2].

cause false alarms. Figure 3 shows the carbon monoxide, carbon dioxide and methane concentrations in a standard TF2 test fire using smouldering wood.

The increase of the CO_2 concentration in the TF2 test fire is not significant until the flashover, whereas the concentration of methane shows a clear increase up to a maximum of approximately 20ppm. On the other hand, there is a clear change in the CO_2 concentration in a TF1 test fire (open burning wood), whereas only a small amount of methane is released.

3.2. Fire Prevention

Gas detectors are widely used for the measurement of flammable gases and vapours in many industries for protection against explosion. In the case of a leakage of flammable liquids, the amount of liquid released, before there is a risk of explosion, is quite high. Nevertheless, only a small amount of uncontrolled flammable liquid causes a serious danger of a fire. Flammable liquids with high vapour pressure can be easily detected by measuring the

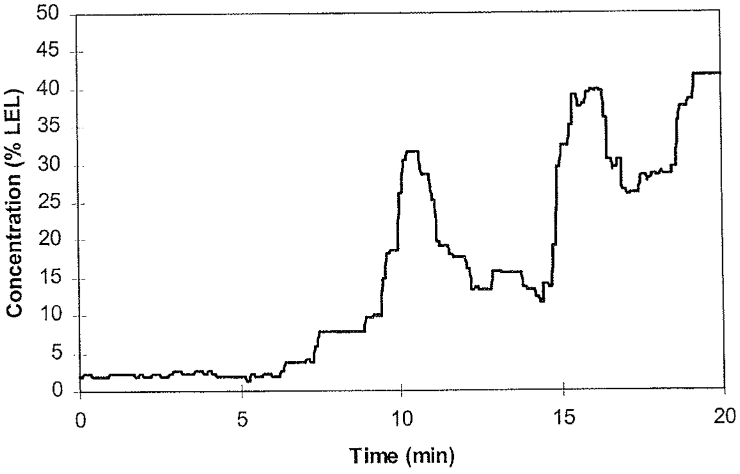

Figure 4: 200 litres of heptane released in a tub with a surface of $25m^2$. Measurement of the heptane concentration with a photoacoustic detector.

concentrations of hydrocarbons in the air. The use of an infrared photoacoustic detector is one possibility for reliably measuring these hydrocarbons. Therefore, the photoacoustic detector can also be used for fire prevention.

Figure 4 shows a leakage of heptane measured with a photoacoustic detector. 200 litres of liquid heptane were slowly released in a tub with a surface of $25m^2$ resulting in a layer of flammable liquid of 8mm deep. The detector was mounted on a floating platform with a space of 4cm between the surface of the liquid and the detector. The concentration is given in units of the lower explosion limit (LEL) of hexane (100% LEL = 1.1% V/V). There is a clear increase in signal detector up to 40% LEL and an early warning can be transmitted to prevent fire or explosion.

4. Conclusion

The use of a photoacoustic device is an additional means of detection and preventing fire and it can be realised at low cost. However, the power consumption of such a detector is between 0.5 W and 2 W which causes a problem for the power supply in large systems with many detectors. The main problem for the power consumption of the detector is the infrared light source. Future development are aimed at producing cheap and low power consumption semiconductor lasers which offer huge potential for the further development of photoacoustic detectors: Not only will power consumption be less than today, but the range of the detectable gases will also be greatly extended by using

Molecule	Formula	Wavelength (nm)
nitrogen dioxide	NO_2	800
ammonia	NH_3	1500
hydrogen cyanide	HCN	1540
carbon monoxide	CO	1567
methane	CH_4	1651
nitrogen oxide	NO	1800
carbon dioxide	CO_2	2004

Table 1: NIR detectable gases at higher harmonic absorption frequencies (wavelengths) for some fire related gases [7].

higher harmonics of the absorption frequencies. Table1 shows other detectable gases at higher harmonic absorption frequencies for some fire-related gases.

So far, the infrared photoacoustic principle for the detection of gases can only be used in special applications and the development of new radiation sources will show the future potential of infrared spectroscopic methods for the detection of fire-related gases.

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Detection of Glow Spots and Overheated Break at a Lignite Conveyor System by a Gas Sensor Array

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Fast Response Gas Sensor System

Within brown coal briquette factories the grinded coal is moved using encapsulated conveyors. In case of a defect in a coal powder producing mill it is possible that particles of glowing metal fall onto the coal and give birth to a small nest of smouldering coal. When in a sequential line of conveyors the coal powder drops to a second belt it is possible that the nest acts as an ignition source and the dust explodes. Only a few seconds are available to detect the nest on the first belt. Therefore, the fire detecting system must have a low response time

Because there is a lot of dust inside of the encapsulation, ionisation- or optical- smoke-detectors which detect smoke aerosols, are not able to operate. Sometimes the temperature of the transported coal changes, because a dryer apparatus does not work with constant efficiency. So it is not possible to detect the glow spot by a temperature increase. However, it can be identified by its emitting gases. These are H_2, CO, CO_2, CH_4 and also higher saturated and unsaturated hydrocarbons, aldehydes, alcohols, and organic acids in lower concentrations. After the gas has reached the sensor, there are only a few seconds remaing before the glow nest appears at the end of the band. Therefore the gas sensor response time has to be low enough to stop the belt and to prevent the nest falling onto the conveyor belt below. A span of less than 10 seconds remains to stop the conveyor. The coal dust in the air above the band is sucked through tubes to filter units. The airflow of 23 m/s effects a high dilution of the combustion products. Problems during the measurement are high temperature, vibrations, dust, humidity and the difficult access to the gas sensor system after installation (Figure 1).

A gas sensor system was developed to operate under the described conditions. It is composed of two sensors, a microcontroller (Siemens/Intel 80C537), digital potentiometers and heating regulators (Figure 2). Tindioxide semiconductor gas sensor elements are optimized to have a fast response time by doping with appropriate catalysts and by using the optimal operating temperature. One sensor responds to carbon monoxide (CO), the other sensor element is selected to respond to hydrogen (H_2). The sensor elements are protected by a cap of sintered metal, which keeps the dust off. Carbon monoxide and hydrogen reach the sensor elements by diffusion (IP 64 proofed). The heater regulators of the sensor elements and the measuring voltage across the sensitive surface of the sensor elements are controlled by digital potentiometers, which are connected to the microcontroller by an IIC-bus. During the start up routine, the microcontroller sets the digital potentiometers to the right values which are read from the non volatile storage (EEPROM). The resistance of the sensor elements is taken every 0,5 second by the controller. In the system the M-Bus is used to transfer measured values and functional conditions such as alarms and malfunctions from the gas sensor heads to a central computer. There they are recorded and the data of each sensor head can be displayed online on the monitor as diagrams. Thereby it is possible to recognize critical events which disturb signal processing.

Tests with Glow Spots on Conveyors

Because it is too dangerous to work with glow spots in an active plant, tests were performed in two stages. At first it was tested, if the gas concentrations expected for the case of a glow spot transported on the conveyor, are detectable online: in Rheinbraun briquette plant "Fortuna-Nord" it was measured under typical operating conditions (Figure 1). Figure 3 shows a sketch of the coal mill, the conveyor, and the tube on which the system was mounted, with its sensor head intruding into the interior. Figure 4 shows the sensor signals after injections of hydrogen and carbon monoxide, respectively. Each sensor responds to its destination gas. The gas sensor system was in operation for 3 weeks in this factory and the sensor data were recorded during this time. After completion of this first part of the investigation, Rheinbraun decided to employ the relevant parts of the coal transport system in the research centre "Sibylla" which realises nearly the same conditions as in the briquette plant but allows to work with real glow spots. A coal dryer and an original encapsulated conveyer with a length of 7 meters were installed (Figure 5). At this site it was possible to get sensor signals from real glow spots on top of freshly dried coal on the conveyor. A glow spot of 5cm x 5cm causes maximum peak levels of about 1 ppm hydrogen and 10 ppm carbon monoxide (Figure 6). On base of these measurement data and those of Fortuna Nord a smart signal evaluation was developed to detect glow spots without producing false alarms by using a peak shape recognition algorithm.

Detection of an Overheated Break in Niederaußem Power Plant

The research and development of the new gas sensor fire detection unit (hence GSFDU) was a cooperation of RWE Energie and Gießen University. RWE Energie operates lignite-fired power plants in the vicinity of the open-cast lignite mines in the area of Cologne. One of RWE's largest power plants is located in Niederaußem. Most of the tests with the new GSFDUs were conducted there. Eight central alarm systems with 2,800 fire detectors are deployed for the prevention and early detection of smouldering fires of lignite dust.

For those readers unfamiliar with power plants, we will give a quick introduction how the lignite transportation inside a power plant is handled and why GSFDUs are required. Niederaußem power plant has an aggregate capacity of 2,800 MW and generates enough electricity for about three million people. Approximately 70,000 tonnes of lignite are combusted per day. In order to take over this amount of lignite, a train with 600 freight cars and a length of 12 km would be needed. The lignite is transported on conveyor belts from the ditch-type bunker to the boiler house. The conveyor belts are approximately 1,200 m long. They are mounted on tilted bridges as shown in figure 7. Despite weekly cleanings, all surfaces on the tilted bridges are covered permanently with a thick layer of lignite dust. Lignite dust is easily inflammable. Overheated conveyor belt rollers, welding works or stray sparks have caused a smouldering fires in the past. On March, 23, 1991, a short circuit caused a smouldering fire that developed into an extended fire in Niederaußem power plant. The repair costs and loss of production due to the damage of both the tilted bridge and the distributing station amounted to 6.4 million DM.

On June, 4, 1995, there was a smouldering fire in the distributing station, marked by an "A" in figure 8. The cause was a jammed conveyor belt brake. As can be seen on the graphs, shown in figures 9 to 11, the emitted combustion gases reached also the rooms below the conveyor belt. Since the measured gas concentrations are traced for any desired time on the central PC, it is often possible to learn about the cause of incidents once an alarm has been triggered. In the graph of figure 9 you can inspect the sensor values of a developing smouldering fire for

- S1: H_2,
- S2: solvent gases and NO_x
- S3: CO

of GSFD no. 87.2 . Section 1 shows clearly a slightly increased CO concentration between 4 pm an 5 pm. However, this is not sufficient to trigger an alarm. Section 2 shows the gas concentration from 5.30 pm to 6.30 pm. During that interval the conveyor belt was in operation with jammed brakes. The friction heat increased the emission of H_2 in addition to CO. This additional H_2 emission is used as a precondition to trigger a fire alarm. The combustion gases have spread from the conveyor belt room to the floors and into the lower staircase. At approximately 4 pm the GSFDUs 87.2-87.4 are beginning to detect the increasing CO concentration. After about 5.45 pm the GSFDUs 87.5 and 88.1 are also picking up the CO emission (figure 10). It should be remarked that the curves' progression, concentration and speed of concentration increase are practically identical. The graph in figure 11 shows the H_2 concentration. At 4 pm, there's no measurable quantity of H_2. From 5.45pm on, increasing emission of H_2 is observed. This is due to the increasing friction heat of the brake material. The GSFDUs 87.2-87.5 are installed in the same room. Therefore they are measuring the same concentration of H_2. Since there are two floors between the source of the H_2 emission and GSFDU 88.1, the combustion gas concentration measured by that sensor is noticeably lower. This is, of course, the reason why the concentraion of both H_2 and CO measured by GSFDU 88.1 is below the critical values, i.e., a fire alarm is not triggered by that GFSDU. By this example it is shown that the GSFDU detects reliably smouldering fires up to distances of 30 m. This fire alarm system has been in use in Niederaußem power plant since spring 1995.

Further Development

To realize lower power consumption, to simplify the handling, and to reduce the price, a second generation L 03 was developed by GTE and introduced into the market by Siemens. It is equipped with an internal DC-DC voltage converter, so it can be powered by 12 to 40V DC. New smaller sensor chips, heating regulators working with pulse width modulation and a low power microcontroller reduce the power consumption to 2W. 24V DC power supply lines for conventional fire detectors are standard in power plants.

Further, highly specific Bioensors [3, 4] for characteristic organic gas components from smouldering fires are investigated in a common project of the institute of applied physics, the institute of phytopathology, both in Gießen, and the ISI institute of the KFA Jülich. This project is funded by the German ministery of research (BMBF)

Acknowledgements: Parts of the fundamental sensor research work relevant to the development of the applications described above were funded in the frame of the BMBF projects Kombisens and Nosebox.

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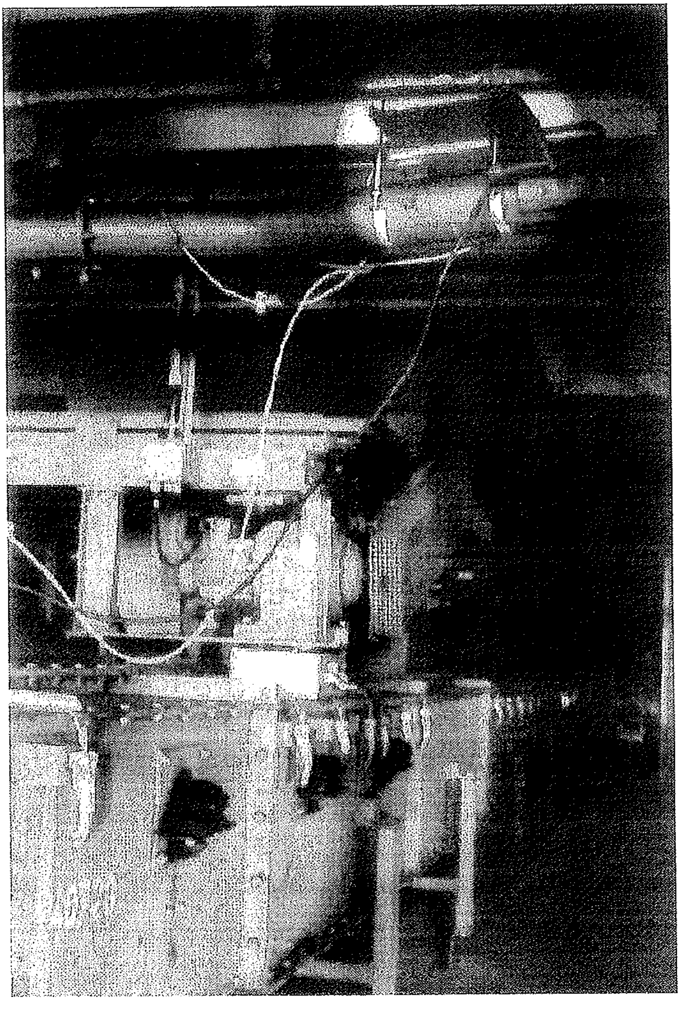

Figure 1:
Gas sensor system installed in Rheinbraun briquette plant "Fortuna-Nord".

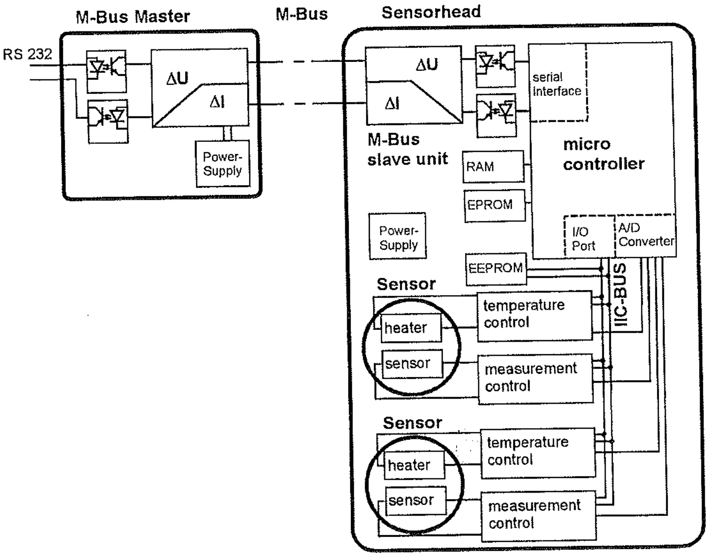

Figure 2:
Architecture of the Gas Sensor Fire Detection Unit.

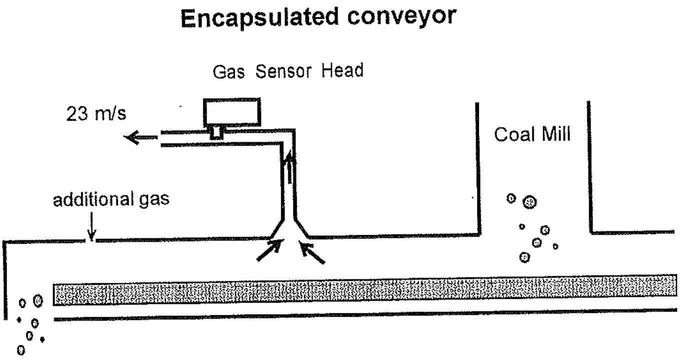

Figure 3:
Sketch of gas sensorsystem at the tube of encapsulated conveyor in "Fortuna Nord".

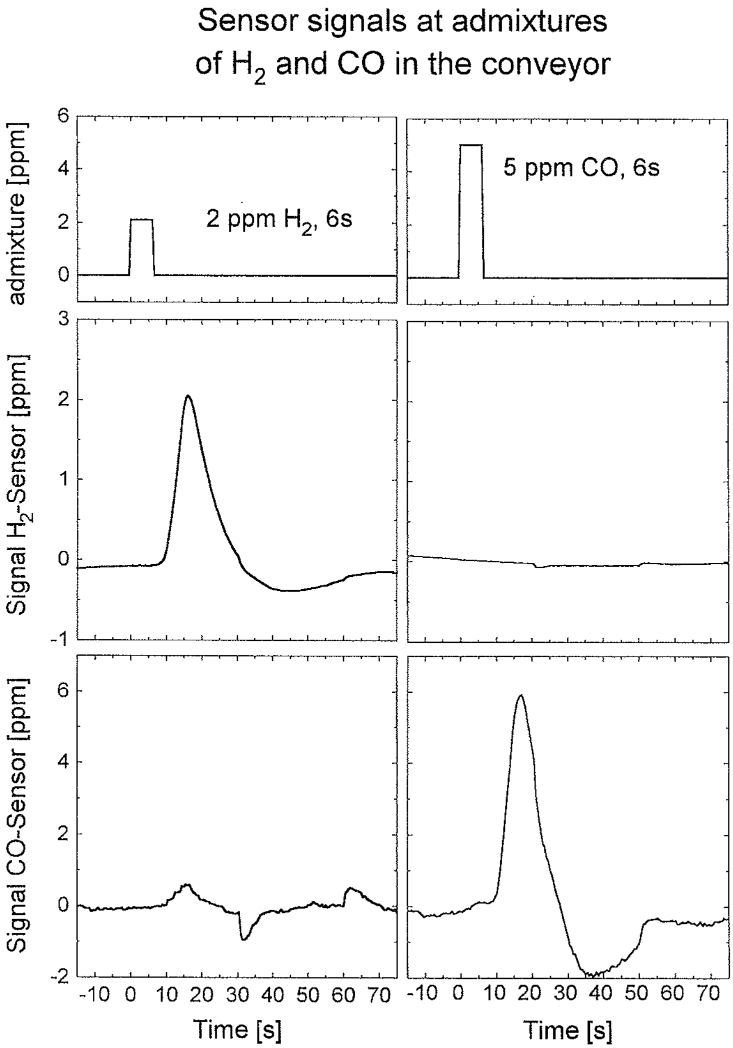

Figure 4:
Sensor signals at admixtures of hydrogen and Carbon monoxide.

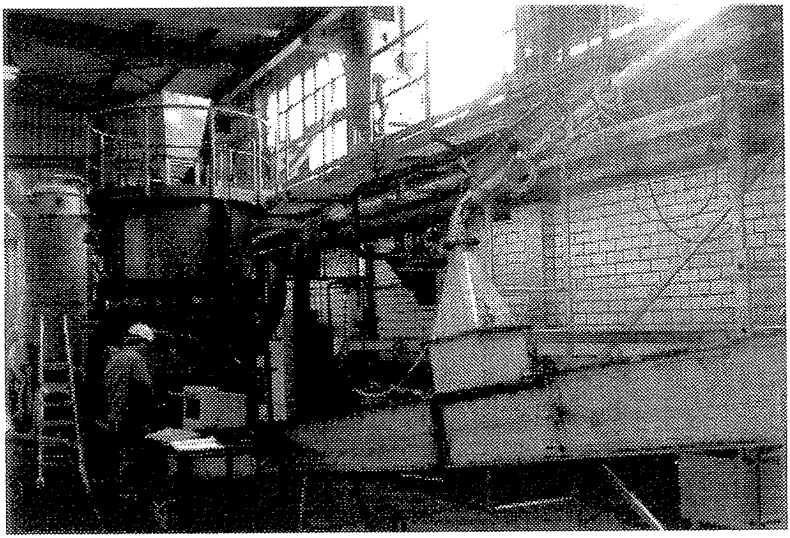

Figure 5:
Conveyor in research centre "Sibylla" for tests with real glow spots.

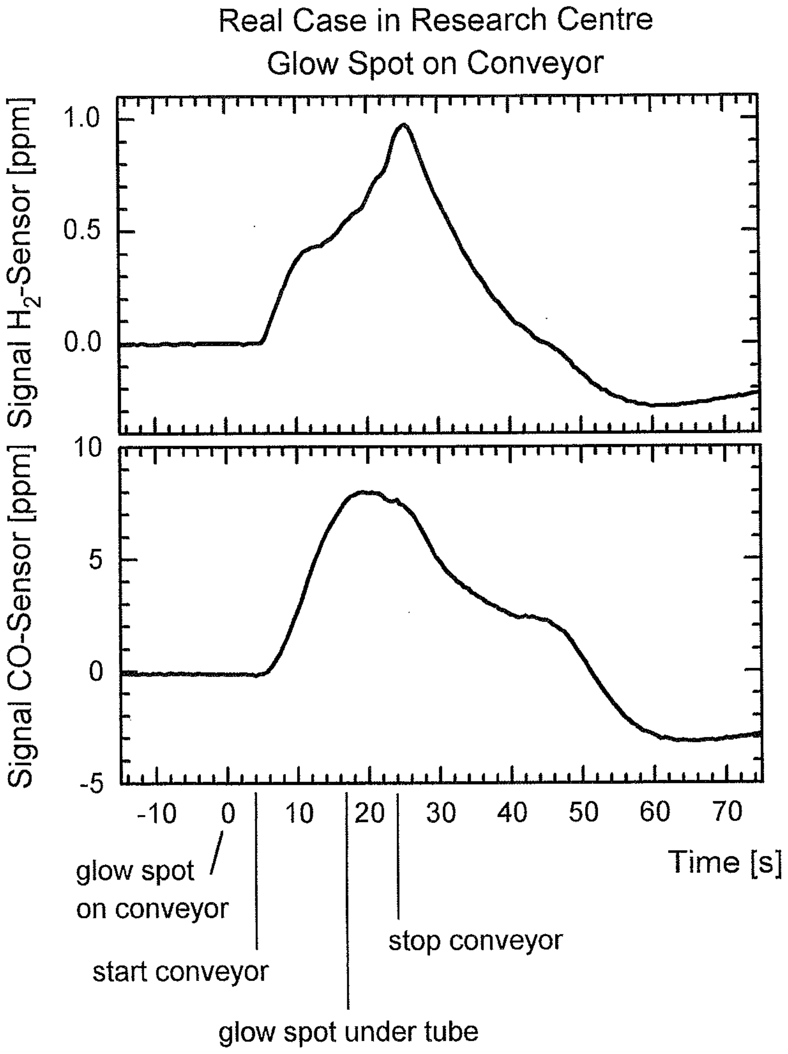

Figure 6:
A glow spot of 5 cm x 5 cm hole area causes maximum peak levels of 1 ppm hydrogen and 10 ppm Carbon monoxide.

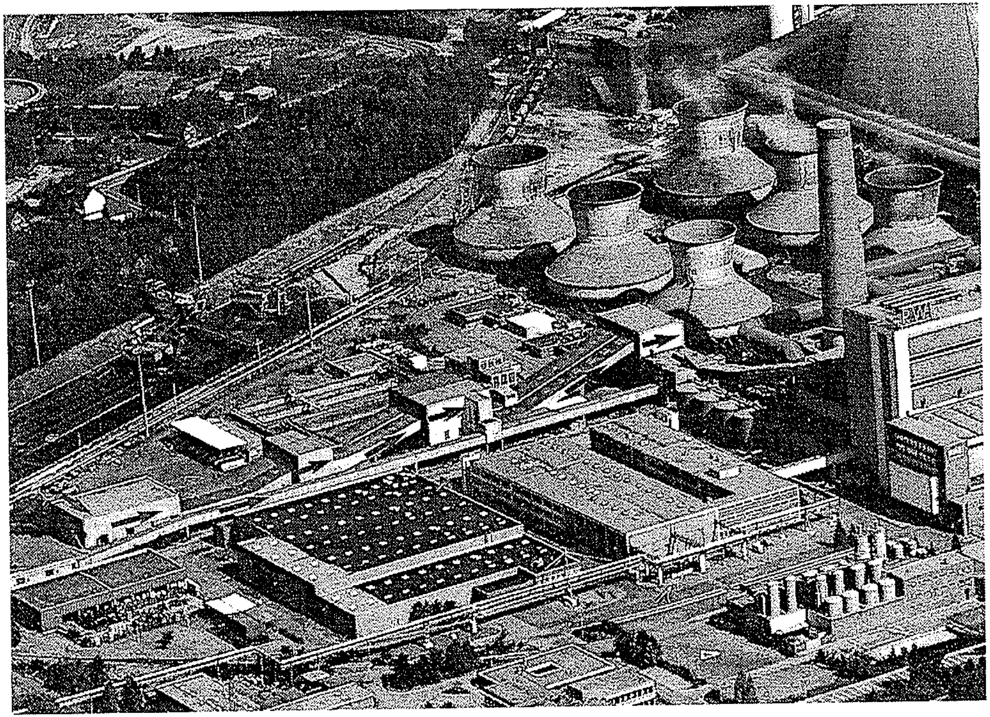

Figure 7:
The lignite is transported on conveyor belts from the ditch-type bunker to the boiler house. The conveyor belts are approximately 1,200 m long. They are mounted on tilted bridges.

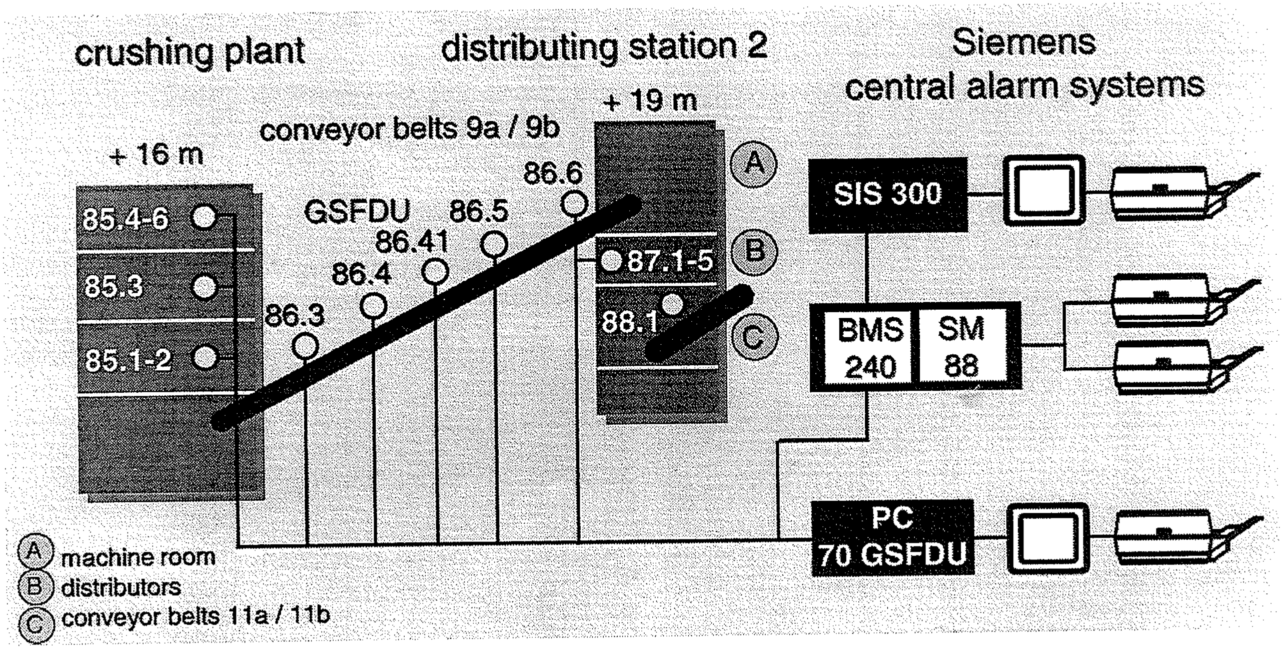

Figure 8:
A part of the lignite transportation with the GSFDUs.

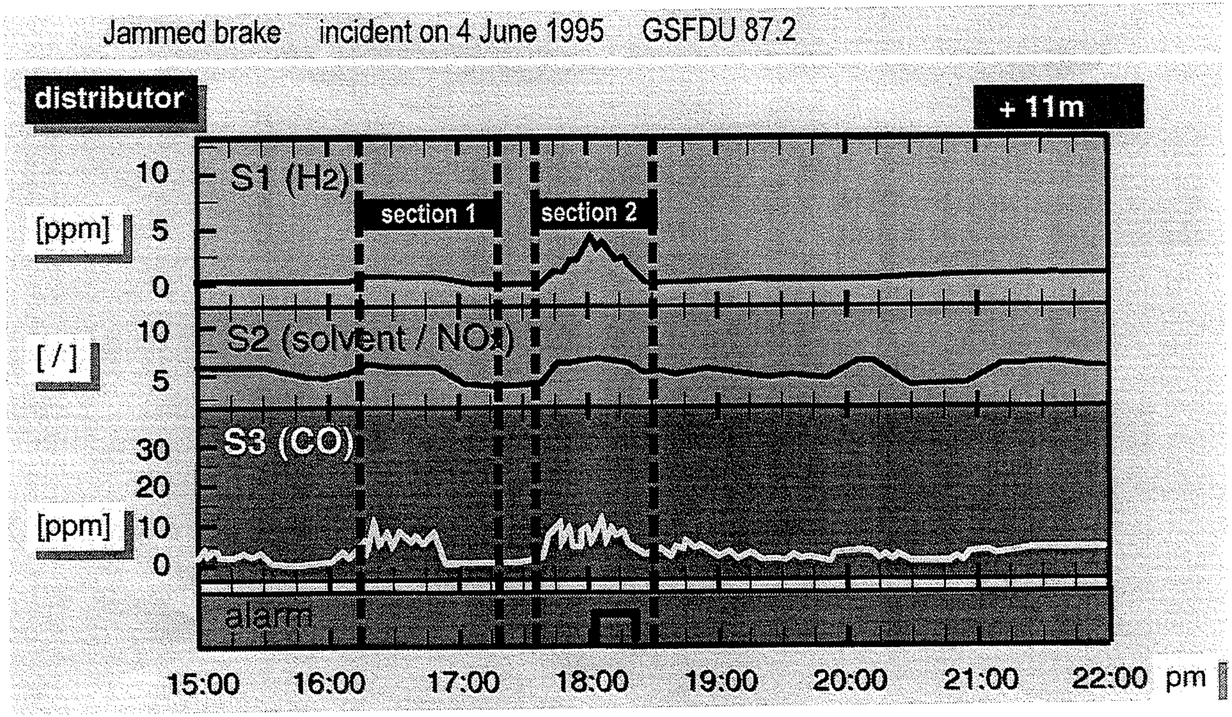

Figure 9:
Sensor curves of a developing smouldering fire.

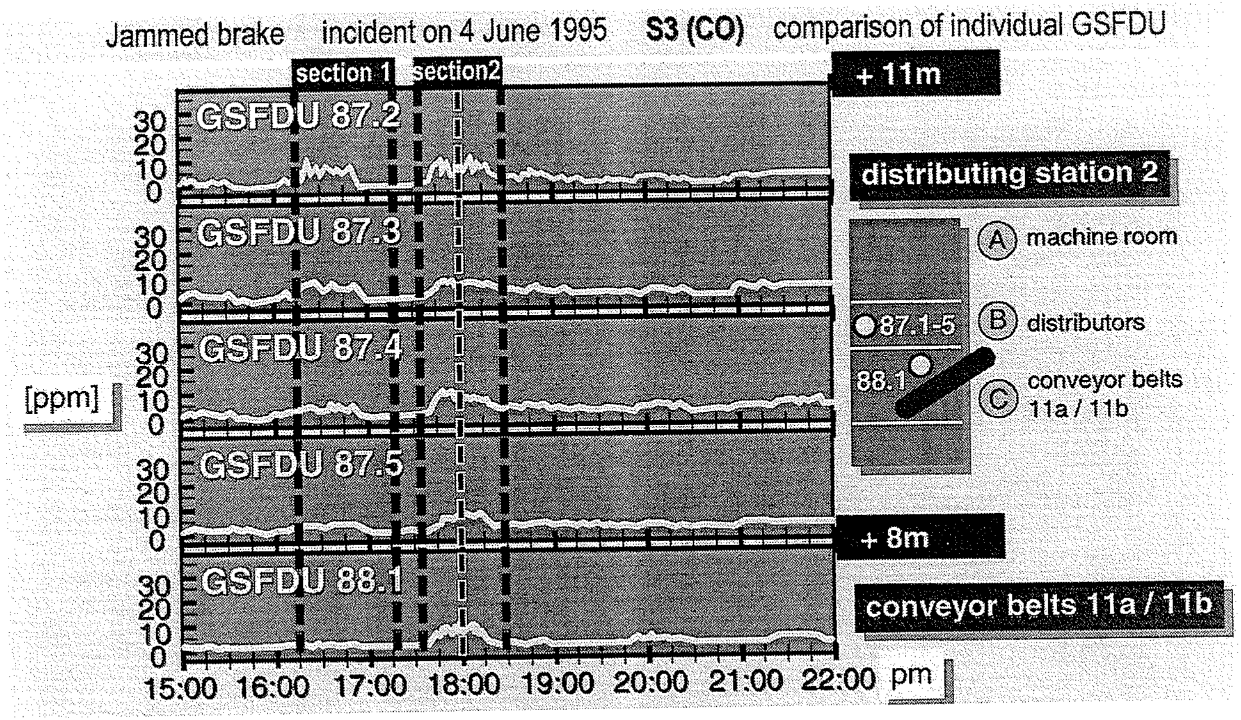

Figure 10:
The combustion gases have spread from the conveyor belt room to the rooms below (carbon monoxide).

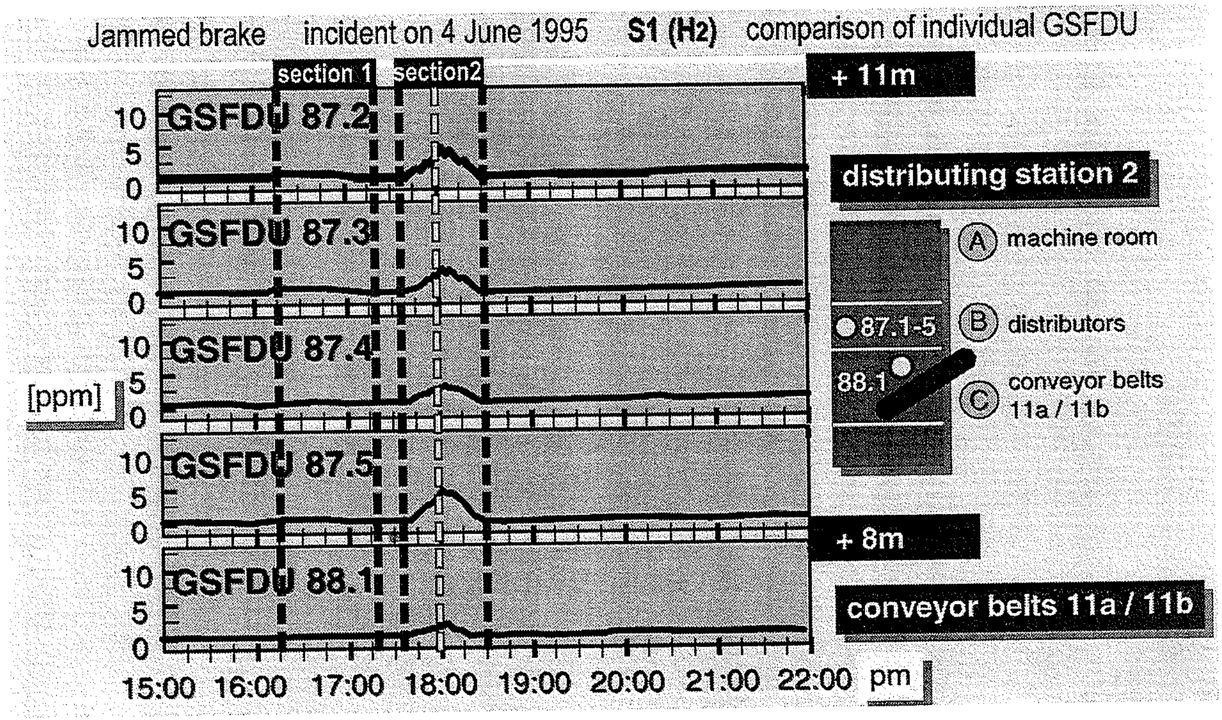

Figure 11:
The combustin gases have spread from the conveyor belt room to the rooms below (hydrogen).

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Multigassensoren auf optoelektronischer Basis und deren Einsatz für die Branderkennung

Abstract
This paper presents a new technique to measure gas concentration in the air, based on a chemical „key/lock" process. The sensing element uses simple optical circuits to measure the gas sensitive phenomena. The sensor can be miniaturized and formed as an array to detect multiple gases. The detector has minimal cross-sensitivity against other than the leading gas. Because there is no heating element required, the resulting power consumption is ideally suitable for fire detectors.

1. Einleitung

Bei jedem Brand entstehen neben der Asche, die am Brandherd verbleibt, Rußpartikel, Aerosole und Gase. Aufgrund verschiedener physikalischer Prozesse und Turbulenzen in der Luft entstehen Rauchpartikel. Sie werden von optischen Rauchmeldern und Ionisationsmeldern detektiert. Die beim Brand freigesetzte Energie führt zu einer Temperaturerhöhung und zu einer Strahlungsemission durch die Flammen, die von Wärmemeldern und Flammenmeldern erkannt wird.

In der Anfangsphase von Bränden entstehen aufgrund unvollständiger Verbrennung CO, gesättigte und ungesättigte Kohlenwasserstoffe, Alkohole und Säuren. In der Regel verbrennen organisch Stoffe, dann fallen vorwiegend CO, CO_2, H_2O als Oxide an. Ab rund 200^0 C entstehen beim Brand NO_x aus dem in der Luft befindlichen Sauerstoff und Stickstoff. Ein Nachweissystem für die beim Brand entstehenden Gase wurde bis heute in der konventionellen Brandmeldetechnik noch nicht eingesetzt. Gründe dafür waren der große Strombedarf, die Querempfindlichkeit, die unzureichende Langzeitstabilität und der hohe Preis der am Markt verfügbaren Gassensoren.

Seit einigen Jahren untersucht Bosch die Einsatzmöglichkeiten von Gassensoren in der Brandmeldetechnik. Hierbei stellte sich heraus, daß der Nachweis von Gasen u. a. aufgrund der schnellen Diffusion in vielen Fällen bereits zu einem früheren Zeitpunkt möglich ist als der von Rauchpartikeln. Darüber hinaus lassen sich Täuschungsgrößen von Bränden aufgrund der unterschiedlichen Konzentration und Verhältnisse der Gase zueinander unterscheiden.

2. Neue Verfahren und Erkenntnisse der Gasmeßtechnik

An Gassensoren für Brandmelder wird gefordert die Reproduzierbarkeit des Meßergebnisses, Kalibrationsfreiheit, Vorauswahl des Meßbereiches, hohes Auflösungsvermögen, Langzeitstabilität und niedrige Leistungsaufnahme. In Zusammenarbeit mit dem Centre for Chemicals Sensors der ETH Zürich ist es Bosch gelungen ein Gassensorprinzip zu entwicklen, das sich im Gegensatz zu Metalloxidsensoren durch eine hohe Seketivität, lange Lebensdauer und geringen Energieverbrauch auszeichnet.

Durch den Einsatz einer Sensormembran, die ihre Absorptionseigenschaften aufgrund einer in ihr enthaltenen Indikatorsubstanz durch zumindest einen indirekten Kontakt mit einem Gas und/ oder Gasgemisch ändert (Abb.1), ist es in einfacher Weise möglich, miniaturisierte Gassensoren, sogenannte Optoden, herzustellen. Da nur geringste Substanzmengen zur Detektion benötigt werden, ist eine Miniaturisierung besonders einfach. Mit Hilfe einfacher optischer Vorrichtungen können Gase in Konzentrationen von einigen ppb bis zu einigen % ohne Querempfindlichkeit bestimmt werden.

Mit diesem Gassensorprinzip ist es erstmals möglich die Anforderungen der Brandmeldetechnik für den konventionellen Einsatz zu erfüllen.

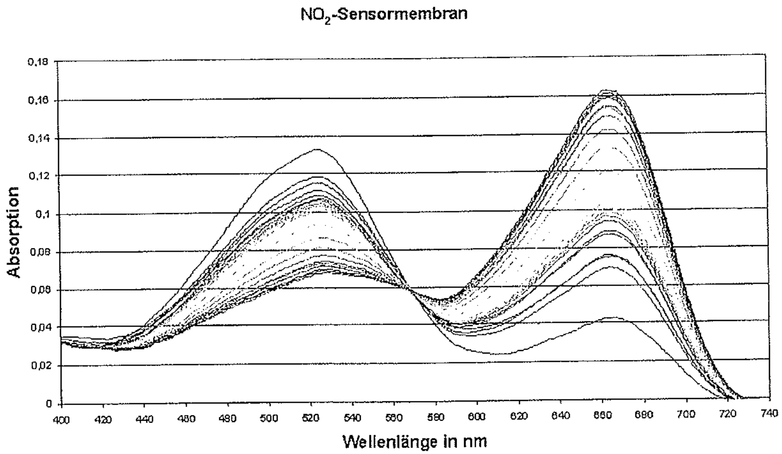

Abb. 1: Transmissionsmessung mit Spektrometer

Die Nachweisgrenze und Ansprechgeschwindigkeit kann durch die Variation von Schichtdicke und Schichtzusammensetzung der Sensormembran bedarfsgerecht eingestellt werden.

Im Nachfolgenden wird auf die Zusammensetzung der für den Einsatz in Brandmeldern geeigneten Membranen NOx und CO_2 und deren Ansprechverhalten eingegangen.

NOx –Sensormembran

Die NOx –Sensormembran besteht aus einem NOx-selektiven Rezeptor
(Co-haltiger Komplex (Cyanoaqua-cobyrinsäure –heptakisalkylester),
und einem gasdurchlässigen Polymer. Je nach Anwendung wird als polymere Matrix für die sensitiven Akzeptoren ein mit Dioctylsebacat weichgemachtes Polyvinylchlorid, Polybutadiene oder Polyisopren verwendet. Das so erstellte Polymer erlaubt das Eindringen des Gases in die Membran und damit die Reaktion mit dem Akzeptor.

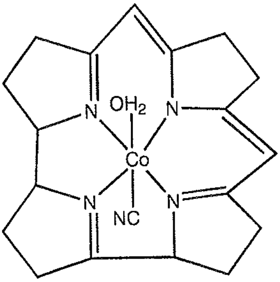

Abb. 2: Kern des Co-Komplexeseinem pH-sensitiven Farbstoff (Nilblau-Derivat)

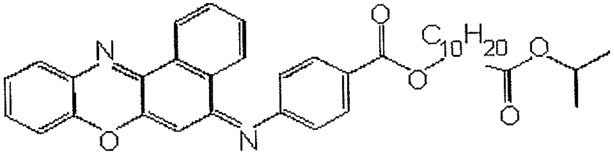

Abb. 3: Kern des Farbstoffes

Der Reaktionsmechanismus der NO_2-Membran ist noch nicht abschließend geklärt. Vermutlich löst sich NOx an der Oberfläche der Membran im Wasserfilm. Das enstehende Nitrit NO_2- diffundiert gleichzeitig mit dem bei der Reaktion enstandenem Proton in die Polymermembran.

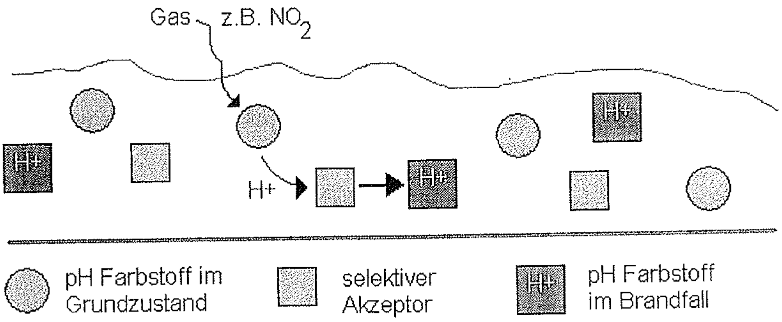

Abb. 4: Reaktionsmechanismus

Dort wird das NOx selektiv vom Corbyrinderivat gebunden. Damit die Elektroneutralität der Membran erhalten bleibt, muß mit jedem Nitrit ein Proton mitabsorbiert werden. Das Proton reagiert mit dem Farbstoff unter Änderung des Farbstoffes. Die Selektivität der Sensormembran wird durch die hohe Selektivität des Corbyrins bestimmt.

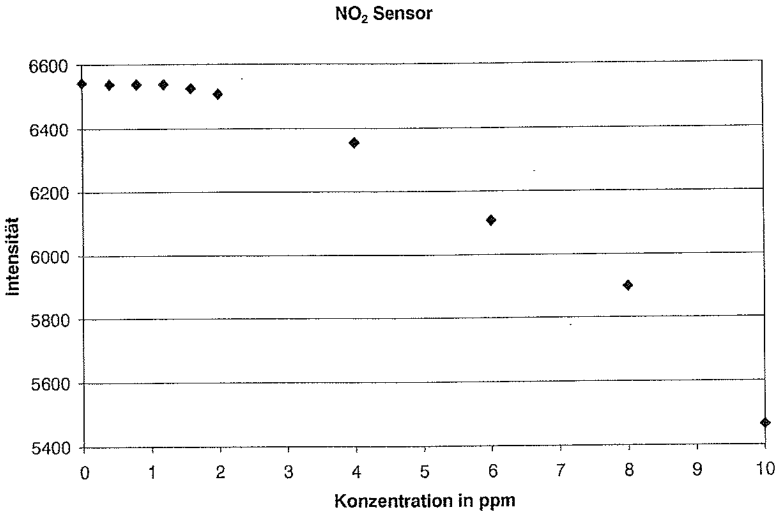

Abb. 5: Kennlinie NO_2-Sensor zwischen 0 und 10 ppm Gaskonzentration

CO_2-Sensormembran

Der Kohlendioxid-(CO_2)-Sensor besteht aus

- einem pH-sensitiven Farbstoff (Stilben-Azofarbstoff Brilliantgelb) mit einem Farbumschlag in den pH-Bereichen 2 und 9,
- einer organischen Base (Phosphazen) mit einer gute Empfindlichkeit für CO_2. Diese Basen sind vollständig kompatibel zu Siloxanen und anderen hydrophoben Polymeren.
- und einem gasdurchlässigen Polymer.

Für CO_2–Sensoren eignet sich insbesondere Polydimethylsiloxan. Dieses Polymer erlaubt aufgrund seines niedrigen Glaspunktes bzw. der hohen Beweglichkeit der einzelnen Polymersegmente ein sehr schnelles Ansprechverhalten, genügt aber nicht den Stabilitätskritärien, die für den Einsatz in der Brandmeldetechnik erforderlich sind. Problematisch ist hier der Restgehalt an freien OH-Gruppen (Kieselsäuregruppen). Diese sind gegenüber Basen empfindlich, bzw. reagieren mit Basen. Die Reaktion mit Tetraoctylammoniumhydroxid ist verlangsamt, da die Komponenten eine Microphasenseparation aufzeigen. Bei der Verwendung von vollständig methylierten Polysiloxan findet keine Nebenreaktion statt. Allerdings sind hier nur Polymere mit geringer Viskosität erhältlich, d.h. im höheren Einsatzbereich von Brandmelder könnte es hier zu Problemen kommen.

Alternativ wurden hier Polybutadiene eingesetzt. Diese zeigen eine etwas geringere CO_2-Permeabilität als Siloxane, erfüllen jedoch die Stäbilitätskriterien um in einem Brandmelder eingesetzt werden zu können.

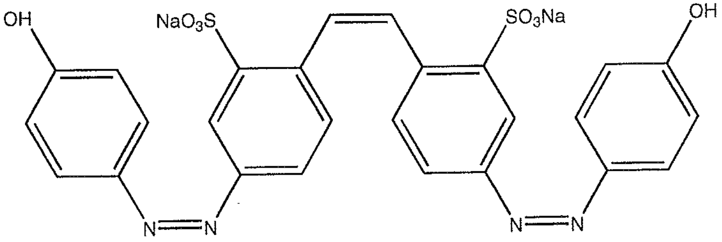

Abb. 6: Brilliantgelb

Bei der Reaktion der CO_2 –Membran setzt die organische Base (Tetraoctylammoniumhydroxid) die Säureform HI des Indikators in die Basenform I- um. Durch einen Überschuß an Base werden basische Bedingungen im Polymer eingestellt. In der Luft vorhandenes Kohlendioxid CO_2 reagiert mit der Base und dem Restwassergehalt in der Membran zu Hydroxylionen H_3O+ und Hydrogencarbonat HCO_3-. Die Hydroxylionen H_3O+ reagieren mit der Basenform I- des Indikators, wobei ein

Wechsel des pH-Wertes auftritt. Dieser pH-Wechsel ist mit einem Farbwechsel des Indikators von blau nach gelb verbunden.

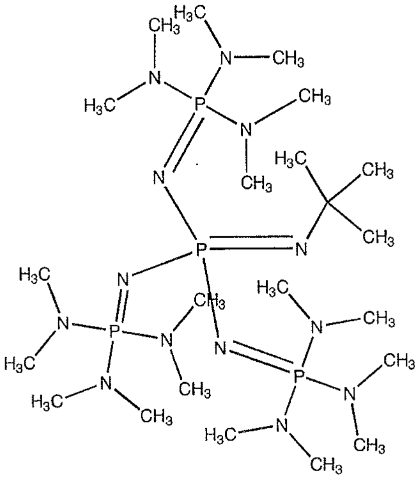

Abb.7: P4-t-Bu-Phosphazenbase

Die Abbildungen 8-10 zeigen das Ansprechverhalten der CO_2 Sensormembran und den Einfluß der Luftfeuchte.

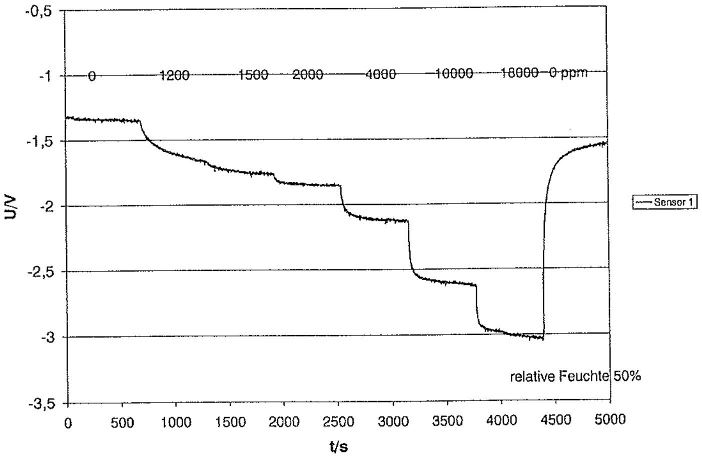

Abb. 8: CO_2-Sensor Gaskonzentration zwischen 0 und 18 000 ppm

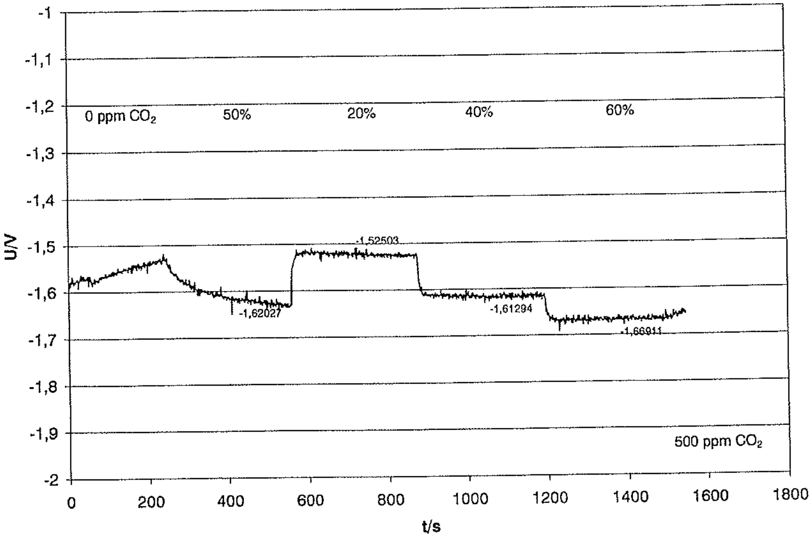

Abb. 9: CO_2-Sensormembran Änderung der relativen Luftfeuchte zwischen 20 und 60%

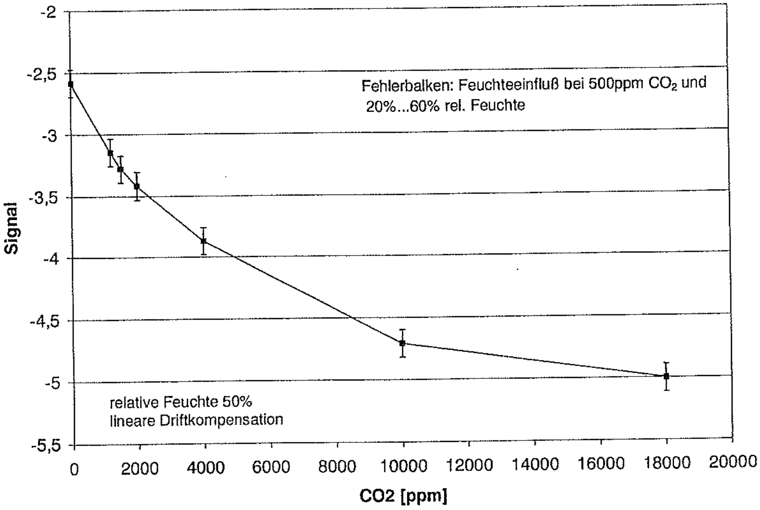

Abb. 10: Kennlinie CO_2-Sensormembran Gaskonzentration zwischen 0 und 18.000 ppm

Nachfolgend wird ein optoelektronischer Gassensor auf der Basis von Optoden dargestellt, bei dem in oder auf einem Halbleitersubstrat 4 monolitische voneinander getrennte Photodioden und ein mittig dazwischen liegender Lichtsender integriert sind (Abb.11). Mit dieser Ausführung können drei unterschiedlich gassensitive Optoden und eine Referenzstrecke zur Kompensation von Umwelt- und Temperatureinflüssen realisiert werden. Der optoelektronische Gassensor wird mit einem Filter gegen Insekten, Fremdlicht und gegebenenfalls Schadgas geschützt.

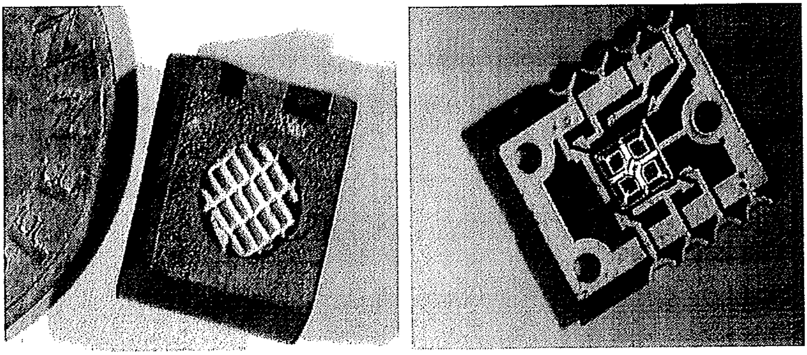

Abb. 11: Optisches Gassensorarray.

Die Nachweisgrenzen einzelner Gase liegen bei rund 100 ppb und die Stromaufnahme unter 20 μA (Leistungsaufnahme < 50 μW).

3. Meßergebnisse

Zum Nachweis der Eignung von Gassensoren für die Erkennung von Bränden hat Bosch neben den durch die EN54 vorgeschriebenen Testbrände eine Vielzahl von Brand- und Störversuchen durchgeführt. Die Signale der Referenzmeßeinrichtung, der Temperturaufnehmer, der Waage, Gasmeßsystem (Bestimmung der Brandgase und deren Konzentration) und der Prüflinge werden mit einem vollautomatischen Meßsystem erfaßt.

Bei jedem Brand ist eine der Refernzmeßeinrichtungen (Ionsisationskammer, optische Meßstrecke, Temperaturfühler) dominant; ihr Meßwert erreicht den durch die Norm vorgegebenen Maximalwert zuerst. Als Brandende eines Testfeuers ist laut EN 54 der Zeitpunkt zu betrachten, zu dem einer der drei festgelegten Maximalwerte m= 2 db/m, y= 6 oder ΔT = 60 K erreicht ist.

Um Hinweise über die Eignung eines Brandmelders zu erhalten sieht die EN 54 eine Klassifizierung der Empfindlichkeit vor, wobei die Eignung eines Melders für jede Brandart einzeln festgelegt wird. Die Alarmpunkte aller untersuchten Melder eines Typs müssen innerhalb der Anforderungen einer Klasse liegen, um in dieser Klasse zugeordnet zu werden.

Folgende Grenzwerte legt die EN 54 fest:

Klasse A	ΔT = 15 K	m = 0,5 db/m	y = 1,5
Klasse B	ΔT = 30 K	m = 1,0 db/m	y = 3
Klasse C	ΔT = 60 K	m = 2,0 db/m	y = 6

Tabelle 1: Grenzwerte für die Klassen nach EN 54/9

Mit den in der EN 54 festgelegten Testfeuern 1 bis 5 werden Rauchpartikel unterschiedlicher Größe und Farbe erzeugt, um die Funktion von Rauchmeldern nachzuweisen. Testfeuer 6 wird von Rauchmelder nicht erkannt.

Abbildung 12 und 13 der Testfeuer 2 und 3 nach EN 54, sowie die Ergebnisse einer Vielzahl von Brandversuchen je Testfeuer, zeigen, daß durch den Einsatz von Gassensoren grundsätzlich eine Reduzierung der Detektionszeiten im Vergleich zu konventionellen Brandmeldern erreicht wird.

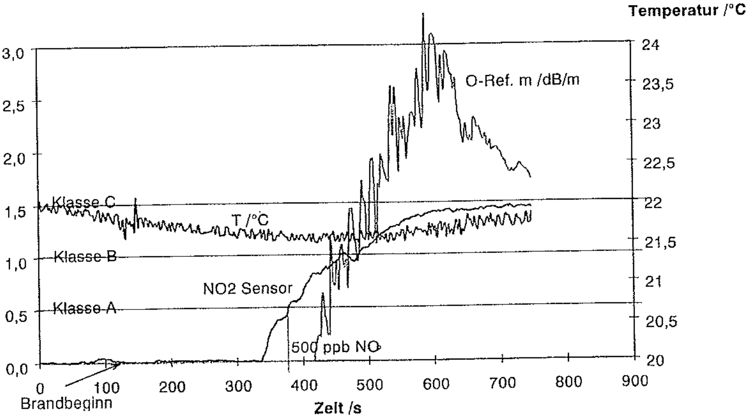

Abb. 12: Testfeuer 2 nach EN 54 Buchenholzschwelbrand

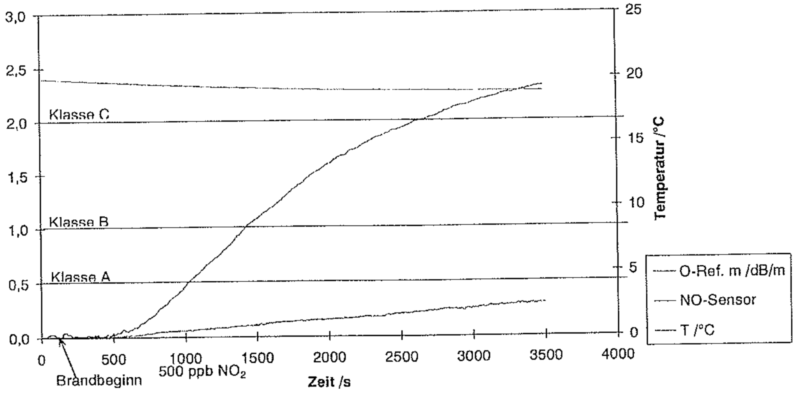

Abb. 13: Testfeuer 3 nach EN 54 Glimm-Schwelbrand

In dem hier gewählten Beispiel, einer NO$_2$-Sensormembran, wurde als Alarmzeitpunkt der Anstieg der Gaskonzentration um 0,5 ppm in einem definierten Zeitfenster gegenüber umweltbedingter Belastung festgesetzt. Lange bevor die optische Referenzmeßstrecke Rauchpartikel detektiert, werden die von den Schwelbränden erzeugten Brandgase von den Brandgassensoren nachgewiesen. Abbildung 14 zeigt das Ansprechverhalten des NOx-Sensors im Vergleich zur Referenz (Klasse A) des jeweiligen Testfeuers.

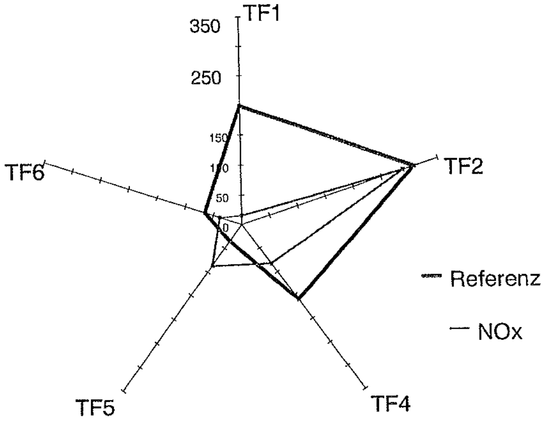

Abb. 14: Alarmzeitpunkt des Gassensors bezogen auf die jeweilige Referenz Klasse A

Näheres über die Auswertung von Multisensorsignalen mit Hilfe des optoelektronischen Gassensors wird an anderer Stelle dieser Tagung berichtet [1].

4. Zusammenfassung

Durch den Einsatz von Gassensoren und mit Hilfe von Signalverarbeitungsalgorithmen wird ein zeitlicher Detektionsgewinn bei gleichzeitig erhöhter Detektionssicherheit erzielt. Dies wird besonders bei Pyrolyse-, Schwel- und Glimmphasenbränden deutlich.

Der von Bosch erstmals vorgestellte Brandmelder Magic.Sens kombiniert die oben vorgestellte und zum Patent angemeldete Gasmeßtechnik mit den Standard-Detektionsverfahren Streulicht- und Temperaturmessung. Der neue Brandmelder bewertet die Signale des Streulichtsensors, des Temperatursensors und die Einzelsignale eines Dreifach-

Gassensor-Arrays mit Hilfe der Mustererkennung. Damit wird die Detektionszeit im Vergleich zu den heute am Markt angebotenen Brandmeldern auf bisher unerreichte Werte verringert. Magic.Sens arbeitet durch den höheren Informationsgehalt auch in Umgebungen zuverlässig, wo reine Rauchmelder nicht eingesetzt werden können.

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Ergebnisse eigener Untersuchungen zur Brandbekämpfung an Bord von Seeschiffen unter Einsatz der Gasanalyse der Raumluft und der Fuzzy-Technik

Abstract

The reliability in automatic firedetection in the field of maritime shipping is insufficient. The known systems supply many false alarms or no alarms. There were made scientific studies by using gas sensors in combination with a fuzzy-logic to increase the probability of response in a defined time. The results which were attained with this method are represented in this lecture.

Einleitung

Die Zuverlässigkeit der automatischen Branderkennungsanlagen hinsichtlich Ansprechwahrscheinlichkeit und Ansprechzeit entspricht im Einsatzgebiet Seeschiffahrt nicht den Erfordernissen. Mittels herkömmlicher Verfahren können Umwelteinflüsse oft nur ungenügend unterdrückt werden, wodurch es zu Nichterkennung von Gefahren kommt oder zu häufigen Falschalarmen. Die derzeit verwendeten Sensortechnologien in der Branderkennung sind aufgrund ihres Wirkungsprinzips oftmals nicht in der Lage, einen Brand rechtzeitig zu erkennen (fehlende Alarme beim Vorliegen eines Brandes). Eine hohe Falschalarmrate wiederum führt zwangsläufig dazu, daß die entsprechende Anlage ignoriert und im Extremfall sogar abgeschaltet wird.
Im Gegensatz zu den gebräuchlichen Brandmeldern liefert eine Raumluftanalyse bei Verwendung neuer Sensortechnologien komplexere Meßinformationen. Die Fuzzy-Logik bietet hier interessante Möglichkeiten, die Daten aus der Gasanalyse effizient zu interpretieren.

Voraussetzungen

Bei jedem Brandprozeß entstehen toxische Gase, die als eindeutige Indikatoren für ein Brand angesehen werden können. Ausgehend von dieser chemischen Reaktion werden bei der Gasanalyse die typischen Reaktionsprodukte erfaßt. Dabei handelt es sich um die echten Brandkenngrößen Kohlenmonoxid (CO), das bei unvollständiger Verbrennung auftritt, und Kohlendioxid (CO_2), das Produkt der vollständigen Verbrennung ist. Da die freie Verbrennung meist unvollständig abläuft, kann die CO-Konzentration in der Raumluft als primäre Brandkenngröße angesehen werden. Die CO_2-Konzentration wird als gleichwertige und ergänzende Größe gemessen. In Einzelfällen, wo diese zu erwarten sind, können Stickoxide als zusätzliches Bewertungskriterium herangezogen werden (z.B. bei Vorkommen ammoniakhaltiger Substanzen).

Auch bei der Raumluftanalyse existiert die Schwierigkeit, Signalverläufe von Brandkenngrößen und deren Kriterien mittels fester Schwellwerte bzw. fester Ja/Nein-Logik zu bewerten. Die gewonnenen Daten aus der Gasanalyse sollen mittels Fuzzy-Logik ausgewertet werden. Dadurch ergibt sich die Möglichkeit der Auswertung in einer unscharfen Bewertung des entsprechenden Signalverhaltens, um sich somit qualitatives Wissen von Experten für die Gefahrenbewertung nutzbar zu machen.

Für die Nutzung des in dieser Form abgespeicherten Expertenwissens für die Gefahrenbewertung wurden folgende Schritte notwendig:

- Fuzzifizierung der scharfen Meßwerte (Eingangsgrößen)
- Aufstellen der Regelbasis (Eingangsgrößenverarbeitung, Entscheidungsfindung)
- Defuzzifizierung der linguistischen Bearbeitungsergebnisse in scharfe Werte (Ausgangsgrößen).

Ziel der Entwicklung eines solchen Fuzzy-Systems ist, bei mindestens gleicher Detektionssicherheit gebräuchlicher Brandmeldetechnik, die Zustände Nichtbrand und Brand eindeutig voneinander zu unterscheiden, und somit eine wesentliche Reduzierung der Falschalarme zu ermöglichen.

Vorgehensweise

Im eigenen Brandlabor des Instituts wurden zunächst Messungen unter realen Bedingungen der Brandentdeckung, insbesondere unter Maschinenraumbedingungen, durchgeführt. Die Untersuchungen erfolgten unter definierten Voraussetzungen, die der Reproduzierbarkeit sowohl der Ausgangslagen als auch der Ergebnisse dienen.

Bei den Messungen wurden für die Raumluftanalyse moderne Gassensoren für die typischen Brandkenngrößen CO und CO_2 verwendet. Im Vergleich dazu wurde parallel mit herkömmlichen Brandmeldern (optische Rauchmelder, Ionisationsmelder) detektiert.

Die Daten der verschiedenen Brandversuche wurden mit der genannten Meßtechnik zunächst aufgezeichnet und gespeichert. Dann wurden die Meßdaten der realen Brandversuche für eine Computer-Simulation verwendet. Mit Hilfe der Computer-Simulation wurde der Fuzzy-Controller entwickelt, getestet und optimiert.

Ergebnisse

Im Verlaufe der Untersuchungen konnten die Vorteile der Raumluftanalyse gegenüber den üblichen Brandmeldern festgestellt werden. Es wird auch gezeigt, daß bei der Raumluftanalyse mindestens zwei Brandkenngrößen (CO, CO_2) detektiert und verarbeitet werden müssen, um eine sichere Detektion sowohl von Brand- als auch von Nichtbrandsituation zu gewährleisten. Kohlenmonoxid und Kohlendioxid entstehen bei jedem realen Brand in unterschiedlichen von der Brandart und vom Brandstoff abhängigen Konzentrationen. Jedes dieser Gase für sich allein stellt noch keinen eindeutigen Hinweis auf einen Brand dar. Die Ursachen hierfür liegen in der Querempfindlichkeit der verfügbaren Sensoren sowie in der Tatsache von natürlichen Konzentrationsschwankungen von Kohlendioxid. Treten Kohlenmonoxid und Kohlendioxid (oberhalb der natürlichen Konzentration) in Verbindung auf, ist dies ein eindeutiger Hinweis auf einen Brand.

Versuch	CO-Sensoren			Optische Rauchmelder			Ionisationsrauchmelder			Brand- & Gefahrenmelder		
	<3min	3..6min	>6min	<3 min	3..6min	>6min	<3min	3..6min	>6min	<3min	3..6min	>6min
Spiritus 1	-	-	-	-	-	-			IRM1 IRM2 IRM3	Fuzzy		
Spiritus 2	-	-	-	-	-	-			IRM1 IRM2 IRM3	Fuzzy		
Benzin 1	CO_1 CO_2			ORM1 ORM2					IRM1 IRM2 IRM3	Fuzzy		
Diesel, Motorbetrieb, Lüfter an (Maschinenraumbrand)	CO_1 CO_2			ORM1 ORM2					IRM1 IRM2 IRM3	Fuzzy		
n-Heptan	CO_1 CO_2			ORM1 ORM2					IRM1 IRM2 IRM3	Fuzzy		
Offenes Holzfeuer			CO_1 CO_2			ORM1 ORM2	IRM2	IRM1	IRM3			Fuzzy
Textilbrand		CO_1 CO_2				ORM1 -	IRM1 IRM2	IRM3		Fuzzy		

Tabelle 1: Ansprechverhalten der verwendeten Brandmelder im Vergleich zum Fuzzy-Melder unter realitätsnahen Brandbedingungen

Die Übertragung der Brandgase vom Brand zum Sensor ist stark abhängig von der Brandart, der Brandfläche und demzufolge der Thermik, dem Brandstoff, den Lüftungsverhältnissen sowie der Anordnung der Sensorik. Bei Maschinenbetrieb ist aufgrund der turbulenten Strömungsverhältnisse sowie auftretenden Dämpfen und Gasen mit erschwerten Bedingungen für die Brandentdeckung zu rechnen.

Bei den durchgeführten Versuchen und Simulationen wurde in allen Fällen durch den Brand- und Gefahrenmelder auf Fuzzy-Basis die entstehende Gefahr sicher detektiert. In der Simulation wurde die grundsätzliche Eignung der verwendeten Fuzzy-Automaten für die Brandentdeckung hinreichend belegt.

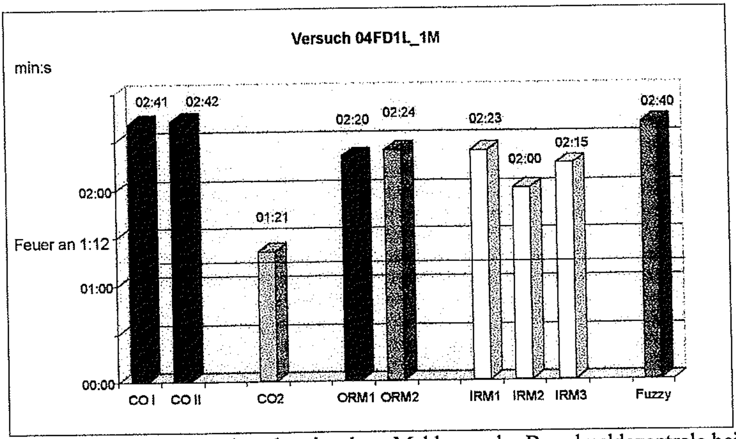

Abb. 1: Zeitliches Ansprechen der einzelnen Melder an der Brandmeldezentrale bei einem Maschinenraumbrand

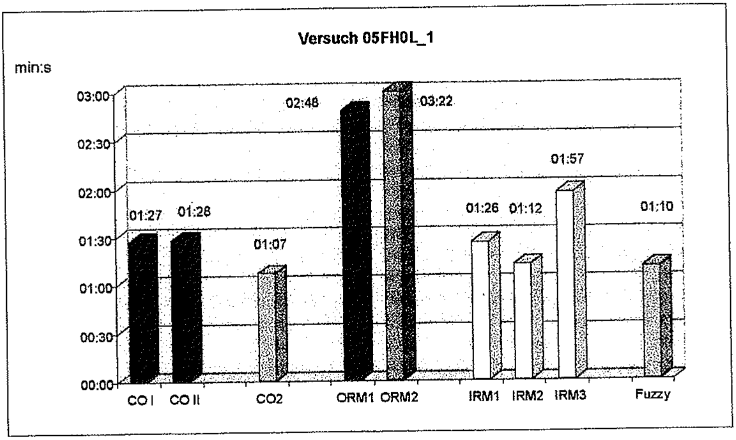

Abb. 2: Zeitliches Ansprechen der einzelnen Melder an der Brandmeldezentrale bei einem n-Heptan-Feuer

Auf der Basis der Untersuchungsergebnisse können konkrete Aussagen zum Ansprechverhalten des Brand- und Gefahrenmelders mit Fuzzy-Technologie im Vergleich zu herkömmlicher Brandmeldetechnik getroffen werden. Es konnte gezeigt werden, daß das neue Meldersystem in jeder Lage/ jedem Brandfall den herkömmlichen Systemen überlegen war und die Gefahren stets eindeutig detektierte. Sowohl die Branderkennung wurde stark verbessert, als auch die Erkennung von Nichtbrandsituationen in Grenzfällen (z.B. bei Zigarettenrauch).

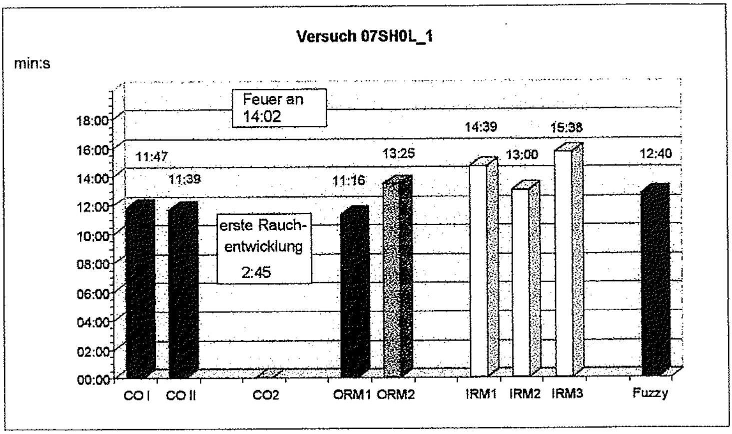

Abb. 3: Zeitliches Ansprechen der einzelnen Melder an der Brandmeldezentrale bei einem Schwelbrand in Anlehnung an EN54/9

Aufgrund der in den durchgeführten Versuchen und im Verlauf der Entwicklung des Brand- und Gefahrenmelders gewonnenen Erkenntnisse lassen sich folgende Ergebnisse der Arbeit formulieren:

1. Die Raumluftanalyse ist ein zur Brandfrühentdeckung grundsätzlich geeignetes Verfahren:

   Es ist hinreichend bekannt, daß bei offenen Bränden immer toxische Gase in unterschiedlichen Konzentrationen entstehen. Bestandteile des Brandgasgemisches sind bei offenen Bränden immer Kohlenmonoxid und Kohlendioxid. Dies führt zu der Feststellung, daß diese Gase als Zielgase in der Raumluftanalyse zur Branddetektion verwendet werden können.

2. Die Benutzung scharfer Schwellwerte zur Signalauswertung kann zu Falschalarmen auch bei Verwendung von Gassensoren führen:
   Insbesondere branduntypische kurzzeitige Signalanstiege können zur Überschreitung der eingestellten Schwellwerte und somit zu Falschalarmen führen. Diese Signalanstiege können durch elektromagnetische Einflüsse oder brandähnliche Situationen hervorgerufen werden. Die Schwellwertauswertung ist nicht in der Lage, diese Störungen zu eliminieren. Dies wurde in den durchgeführten Versuchen belegt.

1. Die Signalbewertung mit Fuzzy-Logik stellt eine geeignete Alternative zur Schwellwertauswertung dar:
   Durch die Verwendung von Fuzzy-Algorithmen bei der Signalauswertung können Störeinflüsse sicher erkannt und dementsprechend unterdrückt werden. Die Überlagerung der Ereignismengen Brand und Nichtbrand kann schon allein durch die Fuzzy-Bewertung nur eines Sensorsignals verringert werden.
2. Die Kombination von Raumluftanalyse und Fuzzy-Signalbewertung ermöglicht eine neue Qualitätsstufe in der Brandentdeckung:
   In diesem Verfahren können die positiven Effekte der Verwendung eindeutiger gasförmiger Brandkenngrößen mit denen der Signalbewertung und Unterdrückung von Störeinflüssen verbunden werden. Die Nachteile der Verwendung von Gassensoren mit scharfen Schwellwerten treten hier nicht auf. Dies führt zu einer wesentlichen Erhöhung der Detektionsqualität, da die Verwendung eindeutiger Brandkenngrößen und eine nachfolgende Sensorsignalbewertung mittels Fuzzy-Logik das Auftreten von Falschalarmen verhindern kann.
3. Die Unterdrückung von Falschalarmen aufgrund von Querempfindlichkeiten kann nur durch die Betrachtung einer zweiten Brandkenngröße erfolgen:
   Aufgrund der durchgeführten Untersuchungen läßt sich feststellen, daß die Freisetzung von Stoffen, auf die ein Sensor querempfindlich ist, oftmals einen brandähnlichen Signalanstieg zur Folge hat. Ein daraus resultierender Falschalarm kann nur durch die Verwendung eines zweiten Sensorsignals unterdrückt werden. Dieser zweite Sensor muß ein anderes Zielgas (Brandkenngröße) detektieren und möglichst ein anderes Wirkungsprinzip besitzen, damit gleichartig gelagerte Querempfindlichkeiten vermieden werden. Die Bewertung von mehreren

Sensorsignalen mittels Fuzzy-Logik ermöglicht die Einordnung von vorliegenden Situationen in bestimmte Situationsklassen. Die Ereignismengen Brand und Nichtbrand können somit sicher klassifiziert werden. Dies hat eine fast vollständige Entflechtung dieser Mengen zur Folge.

4. Die Verknüpfung mehrerer Sensorsignale mit Fuzzy-Logik hat nicht zwangsläufig eine Verlängerung der Detektionszeit zur Folge:
   Die Verwendung von boolscher Logik bei der Verknüpfung von Sensorsignalen oder Brandmeldern hat eine teils erhebliche Verlängerung der Detektionszeit zur Folge. Die vorliegenden Simulationsergebnisse belegen, daß bei Verwendung von Fuzzy-Algorithmen zur Verknüpfung mehrerer Signale die Detektionszeit verringert werden kann gegenüber der Detektionszeit eines Kohlenmonoxidsensors mit Schwellwertauswertung.
5. Aufgrund der heutzutage noch teils höheren Kosten für Gassensoren und vorhandener Reglementierungen für die Installation von Brandmeldesystemen besteht insbesondere in der Schiffahrt die Möglichkeit, Redundanzen innerhalb der Brandmeldesysteme zugunsten eines Brand- und Gefahrenmelders abzubauen. Die Installierung eines solchen Melders müßte derart erfolgen, daß die Überwachung definierter Raumvolumina gegeben ist (z.B. Abluftsystem). Auf diese Weise könnte ein bestehendes Brandmeldesystem bei annähernd gleichen Kosten in seiner Zuverlässigkeit wesentlich verbessert werden.
6. Das Fuzzy-System läßt sich in weiteren Versuchsreihen weiter trainieren. Dies gilt insbesondere im Hinblick auf die Querempfindlichkeit bestimmter Gassensoren, wegen der mitunter auch die Einbeziehung weiterer Brandkenngrößen/Fuzzy-Automaten in das System nötig sind. Bei gegebenen Meßwerten beschränkt sich die Optimierung des Fuzzy-Systems im wesentlichen auf den Programmieraufwand des Fuzzy-Controllers (z.B. Berücksichtigung von neuem Expertenwissen bei der Entscheidungsfindung).

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IR Beam Gas Detection System

Abstract

A gas detection system consisting of IR beam gas detectors and a control panel is presented.

The detector consists of an IR beam remitter and a receiver. It detects the absorption, which is mainly caused by the cloud of hydrocarbon gas, of an IR beam transmitted between the two parts of the detector. The panel receives data from detectors, processes data and gives alarms in certain levels according to the special algorithm.

The system can be commonly used for the protection of large areas where the greatest risk is from the leak of hydrocarbon gases, such as oil depots, oil pump rooms, oil terminals, refineries, gas stations, related factories and so on.

1 Introduction

The leak of combustible gases often causes explosion and fire when the cloud of the leaking gas reaches a certain concentration and meets a flame. In order to avoid this kind of incidents from taking place, it is very important to detect the leak of gases and give out early warning.

Point gas detectors can be used for gas detection, but they have some disadvantages such as poisoning from reactive gas and overwhelmed by gas cloud of high concentrations. Therefore, IR Beam Gas Detection System has been developed to provide more reliable detection.

2. Working principle of the detection system

A gas detection system consists of IR beam gas detectors and a control panel. The detector works on the basis that one kind of the hydrocarbon gases absorbs the infrared radiation of a certain wavelength and consists of an IR beam remitter and a receiver. The IR beam from the remitter transmits through a detection zone and then reaches the receiver. When there is a cloud of hydrocarbon gas in the path, the infrared beam is absorbed by the cloud of hydrocarbon gas. The system finally gives out warning signals according to the intensity reduction of the beam.

To reduce and avoid interference from dust, rain and etc., two channels of different wavelengths are used. One is for detecting, the other is for reference. The detecting of leak gases is based on the comparison between beam intensities of two channels at the receiver. In quiescent state, beam intensities of two channels balance. When there is a gas cloud in the beam path, the intensity of beam at the detecting wavelength is absorbed and the ratio of beam intensities of two channels is changed. The intensity reduction of the beam has direct proportion to Low Explosive Limit (LEL) of gas cloud and the length (meters) of the beam that a gas cloud occupied.

According to Bill, when beams of wavelength λ_1 and λ_2 transmit in air, their intensities shall be following respectively:

$$I_{\lambda 1} = I_{0\lambda 1} \exp\{-\int_0^L [\alpha(\lambda_1, x) + \beta(\lambda_1, x)]dx - \int_{L1}^{L2} [\alpha'(\lambda_1, x) + \beta'(\lambda_1, x)]dx\} \text{..........}(1)$$

$$I_{\lambda 2} = I_{0\lambda 2} \exp\{-\int_0^L [\alpha(\lambda_2, x) + \beta(\lambda_2, x)]dx - \int_{L1}^{L2} \beta'(\lambda_2, x)]dx\} \text{..........................}(2)$$

Where $I_{\lambda 01}$ and $I_{\lambda 02}$ are original beam intensities of wavelength λ_1 and λ_2, $I_{\lambda 1}$ and $I_{\lambda 2}$ are beam intensities of wavelength λ_1 and λ_2 at receivers, L is the length of the beam (m), L_2 - L_1 is the length of the beam that a gas cloud occupied, α , β are the absorptance and scattered coefficient of the air, α' and β' are the absorptance and scattered coefficient of the gas.

Because λ_1 and λ_2 are chosen to be near in design, it can be considered that

$$\alpha(\lambda_1, x) = \alpha(\lambda_2, x)$$

$$\beta(\lambda_1, x) = \beta(\lambda_2, x)$$

$$\beta'(\lambda_1, x) = \beta'(\lambda_2, x)$$

Divide equation (1) by (2) and get logarithm, then

$$\int_{L1}^{L2} \alpha'(\lambda_1, x)dx = \ln\frac{I_{0\lambda1}}{I_{0\lambda2}} - \ln\frac{I_{\lambda1}}{I_{\lambda2}} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

It is confirmed that by experiences that $\alpha'(\lambda_1, x)$ is related to the intensity of gas, therefore

$$\alpha'(\lambda_1, x) = k(\lambda_1)p(x)$$

where $k(\lambda_1)$ is absorptance of gas per gram molecule and $p(x)$ is the intensity of gas at x point.

Provided the intensity of gas cloud is average in the beam path, equation (3) can be written as

$$\int_{L1}^{L2} \alpha'(\lambda_1, x) = \alpha'(\lambda_1)(L_2 - L_1) = k(\lambda_{11})P(L_2 - L_1) = \ln\frac{I_{0\lambda_1}}{I_{0\lambda_2}} - \ln\frac{I_{\lambda_1}}{I_{\lambda_2}}$$

The gas intensity p(x) between L_2 and L_1 can be written as (4).

$$P(L_2 - L_1) = \frac{1}{K(\lambda_1)}[\ln\frac{I_{0\lambda_1}}{I_{0\lambda_2}} - \ln\frac{I_{\lambda_1}}{I_{\lambda_2}}] \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

It can be got from equation (4) that

a. when there is no gas in the beam path,

$$\frac{I_{0\lambda_1}}{I_{0\lambda_2}} = \frac{I_{\lambda}}{I_{\lambda_2}}$$

p(x) = 0;

b. when there is a gas cloud in the beam path, the absorption of $I_{\lambda 1}$ is related to p(x).

Because length L_2 - L_1 is difficult to decide in practice, the intensity of gas cloud in length L_2 - L_1 is changed to the average intensity (p') of gas cloud in length L.

$$P' = \frac{p(L_2 - L_1)}{L} = \frac{1}{K(\lambda_1)L}[\ln\frac{I_{0\lambda 1}}{I_{0\lambda 2}} - \ln\frac{I_{\lambda 1}}{I_{\lambda 2}}] \qquad (5)$$

P'(L) is set as the measuring value.

Provided T is the mole percentage of gas in whole mixed volume, then

$$T = \frac{P'V}{M} \qquad (6)$$

Where V is mole volume of mixed gas under one atmosphere. M is mole mass of gas.

Divide two sides of equation (6) by LEL and put equation (5) into (6), then

$$\frac{T}{LEL} = \frac{V}{M \bullet LEL \bullet K(\lambda_1) \bullet L}[\ln\frac{I_{0\lambda 1}}{I_{0\lambda 2}} - \ln\frac{I_{\lambda 1}}{I_{\lambda 2}}]$$

$$\frac{T}{LEL} \bullet LEL \bullet L = \frac{V}{M \bullet K(\lambda_1)}[\ln\frac{I_{0\lambda 1}}{I_{0\lambda 2}} - \ln\frac{I_{\lambda 1}}{I_{\lambda 2}}] \qquad (7)$$

Because T/LEL is the percentage of LEL, that is xx %, when L = 1 m, equation (7) changes to

$$xx\%LELm = \frac{V}{M \bullet K(\lambda_1)}[\ln \frac{I_{0\lambda1}}{I_{0\lambda2}} - \ln \frac{I_{\lambda1}}{I_{\lambda2}}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Here LELm is set as the measuring dimension.

3. Method of calibrating threshold value

Threshold values of IR beam detectors can be got according to following method. The complete set of the calibrating device is showed in figure 1. The length of the can for mixing gas and air is 1000mm, r is 120 mm, two sides of the can are sealed with glasses that is 3 — 5 mm thick and with more than 90% transmissivity to λ_1 and λ_2.

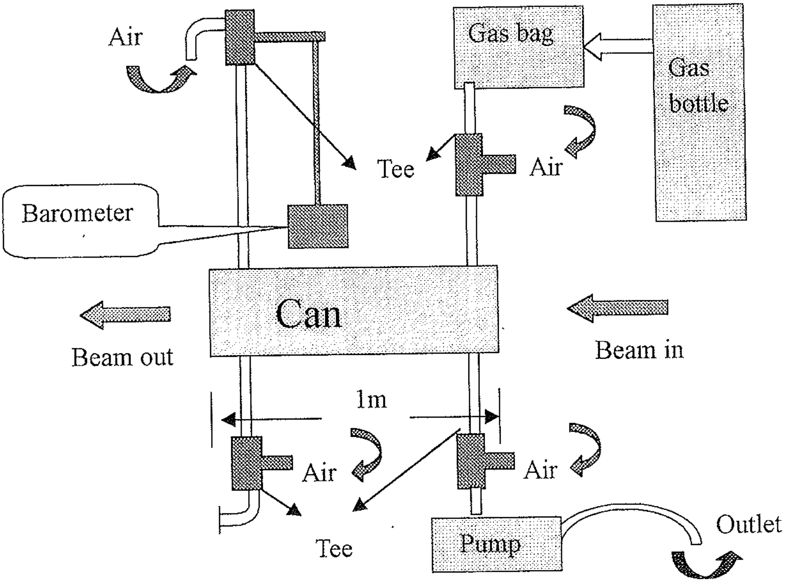

Figure 1 calibrating device

The calibrating device is put in front of the receiver of the detector so as to make the beam from the remitter go through the can and reach the receiver. The distance between the remitter and the receiver is 20 or 30m. In order to get balanced signals in two channels the receiver is adjusted.

The desired intensity (volume percentage) of gas is made according to equation (9).

$$\left(\frac{\Delta P}{P}\right)_{V.T} = \left(\frac{\Delta V}{V}\right)_{P.T} \qquad \text{......................................(9)}$$

That means that if a standard gas with purity A is used to make the mixed gas with intensity of x LEL, $\triangle$V air shall be replaced by same volume standard gas in same pressure. That is

$$\frac{xLEL}{A} V = \Delta V \qquad\qquad \frac{xLEL}{A} = \left(\frac{\Delta V}{V}\right)_{P.T}$$

By equation (9), the above equation can be written as

$$\frac{xLEL}{A} = \left(\frac{\Delta P}{P}\right)_{V.T}$$

then

$$(\Delta p)_{V.T} = \frac{xLEL}{A} P \qquad \text{.............................(10)}$$

To consider the length m occupied by the mixed gas, pressure difference $\triangle p$ is calculated according to equation (11).

$$(\Delta P)_{V.T} = \frac{xLEL}{Am} P \qquad (11)$$

When the procedure of mixing gas is carried out, some air shall be first drawn out from the can to make the pressure difference to $\triangle p$, then put standard gas into the can to make the pressure return to P. If a detector is adjusted to give alarm under this condition, then its alarm threshold value is set as x LELm.

4. Concluding Remark

IR beam gas detection systems have advantages compared with systems of point gas detectors. The detector is capable of detecting gas cloud over a distance of up to 100 meters. The performance of the detector is not affected by poisoning from reactive gases and will not be overwhelmed by gas cloud of high concentration. The detecting effect of the system is not reduced by dust, smoke and rain because of the use of two channels and the special compensation algorithm.

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Versuche zur Eignung von Gassensoren für die Brandmeldetechnik

Abstract

In the fire room of VdS Schadenverhütung the suitability of gas sensors for fire detection was assessed on the basis of selected test fires. Due to high cross sensivities of gas sensors to other substances than fire gases investigations designed to establish the influence of sources of false alarms were conducted as well. This way information on frequently occurring sources of false alarm could be gained. Further information on the capability of fire detection and the reliability against false alarm of gas sensor based detectors could be derived.

Kurzfassung

Im Brandraum von VdS Schadenverhütung wurden Gassensoren mit Testfeuern stichprobenartig auf ihre Eignung für die Branderkennung untersucht. Wegen der hohen Querempfindlichkeiten von Gassensoren gegen andere Stoffe als Brandgase wurden auch Versuche zum Einfluß von Täuschungsgrößen durchgeführt; auf diese Weise konnten bereits einige Erkenntnisse über häufig vorkommende Störquellen gewonnen werden. Weitere Erkenntnisse über Detektionsfähigkeiten und Sicherheit gegenüber Täuschungsalarmen von Brandgasmeldern lassen sich ableiten.

1 Einleitung

Für Standardanwendungen in der automatischen Brandmeldetechnik haben sich in den vergangenen vier Jahrzehnten vor allem Rauchmelder nach dem Ionisationskammer- und dem Streulichtprinzip durchgesetzt. Daneben werden in geringerem Umfang auch Rauchmelder nach dem Durchlichtprinzip, Flammenmelder und Wärmemelder verwendet. Es gibt jedoch Bedingungen, bei denen herkömmliche Detektoren versagen, z.B. bei der Erkennung von Schwelbränden in Bereichen mit hohem Staubanfall; hier können Gassensoren eine Alternative darstellen.

Im wesentlichen wegen der starken Querempfindlichkeiten, der unzureichenden Langzeitstabilität und des großen Strombedarfs bei hohen Preisen hatten Brandgasmelder lange Zeit keine Chance, sich gegen konventionelle Detektoren zu behaupten. Inzwischen wurden Gassensoren weiterentwickelt, und Brandgasmelder haben sich beispielsweise für die

Überwachung von Bekohlungsanlagen in Braunkohlenkraftwerken durchaus bewährt [1]. Vielversprechende Untersuchungen für den Einsatz in anderen Anwendungsbereichen sind im Gange.

Vom Fachgebiet Brand- und Explosionsschutz der Bergischen Universität Wuppertal wurden mit Unterstützung von VdS Schadenverhütung mehr als 100 stichprobenartige Versuche mit elektrochemischen Sensoren und Halbleitersensoren durchgeführt, um spezifische Hinweise auf Einsatzgebiete und Einsatzgrenzen von Brandgasmeldern zu erhalten. Zur Referenzanalyse wurden verschiedene Gasmeßgeräte und Rauchdichtemeßgeräte eingesetzt. Untersucht wurde die Erkennung der genormten Testfeuer nach EN 54, der Testbrände für auf Rauch ansprechende Auslösemechanismen nach IfBt-Mitteilung 2/1978 sowie weiterer ausgewählter Testbrände.

2 Untersuchte Gassensoren

Die folgenden, auf Halbleitertechnik beruhenden Gassensoren wurden stichprobenartig daraufhin untersucht, ob und inwieweit sie sich zur Erkennung von Bränden eignen und wie empfindlich sie auf Täuschungsgrößen reagieren. Die Signale der Einzelsensoren wurden unabhängig von den Brandmeldern, in denen sie eingesetzt werden, ausgewertet.

- GSME S-3
  Die Gassensormeldeeinheit S-3 basiert auf der gemeinsamen Entwicklung durch die Universität Gießen und RWE Energie AG. Der Melder mit integrierter Logik besitzt drei unterschiedlich selektive Halbleitersensorelemente (s. Tab. 1) und wurde für die Detektion von Braunkohlenstaub-Schwelbränden optimiert [2]. Er hat einen Meßzyklus von 30 Sekunden und kann mit 230 V oder 24 V bei 15 VA betrieben werden.
- Phthalocyanin-Sensor („PC-Sensor“)
  Der PC-Sensor (s. Tab. 2) verfügt über eine organische Halbleiterschicht aus Kupfer-Phthalocyanin. Er wurde im Rahmen der Untersuchungen mit einem Meßzyklus von 30 Sekunden betrieben und durch einen Sintermetall-Filter geschützt.
- Elektrochemische Zelle zur Messung von CO
  Die elektrochemische Zelle diente als Referenzmeßgerät für die Messung von CO (s. Tab. 2). Die Sensorsignale werden auch hinsichtlich der Eignung elektrochemischer Zellen für den Einsatz in der Brandmeldetechnik bewertet.

Bezeichnung	Meßprinzip	Zielgas	Meßbereich	Querempfindlichkeiten
UST 1000	Halbleitertechnik	CO	0-50 ppm	H_2: 30 %; CH_4: 5 %; EtOH: 50 %
UST 6000	Halbleitertechnik	H_2	0-20 ppm	CO: 0,5 %; CH_4: 1 %; EtOH: 5 %
UST 7000[1]	Halbleitertechnik	-	kann nicht angegeben werden[2]	im wesentlichen: Lösungsmittel: pos. Signal NO_X: neg. Signal

Tabelle 1: Sensoren der GSME S-3

Bezeichnung	Meßprinzip	Zielgas	Meßbereich	Querempfindlichkeiten
PC-Sensor (PC=Phthalocyanin)	Halbleitertechnik	-	kann nicht angegeben werden	im wesentlichen: NO_X: pos. Signal Amine: neg. Signal
Fa. Sieger/ Zellweger	Elektrochemische Zelle	CO	0-100 ppm	H_2: 30 %; EtOH: 50 %; C_2H_2: 200 %

Tabelle 2: Phthalocyanin-Sensor, elektrochemische Zelle

3 Brandversuchsraum

Für die Untersuchungen des Verhaltens von Gassensoren auf Brandkenngrößen und Täuschungsgrößen wurde der Brandversuchsraum von VdS Schadenverhütung in Köln genutzt. Es handelt sich dabei um einen nichtklimatisierten Raum mit einem Volumen von 240 m^3. Wie dies nach EN 54 für Rauchmelder vorgegeben ist, wurden auch die untersuchten Gasmeßgeräte in einem Abstand von 3 m um den in Raummitte befindlichen Brandherd direkt unterhalb der Decke positioniert.

Die Testbrände nach IfBt-Mitteilung 2/1978 (s. Abschnitt 5) wurden im gleichen Brandversuchsraum durchgeführt und die Raumluft über den angeschlossenen Lüftungskanal abgesaugt.

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[1]) Der Sensor wird im weiteren auch als Lösungsmittel/NO_X-Sensor bezeichnet.

[2]) Als Meßgröße dient die relative Leitwertänderung. Eine quantitative Angabe des Meßbereichs ist nicht möglich.

4 Meßtechnik

Folgende Meßgeräte standen für die durchgeführten Untersuchungen zur Verfügung:

Rauchdichtemeßgeräte

- Rauchdichtemeßgerät Typ RM 41.S, Fa. Sick (Meßgerät für Rauchdichte nach dem Extinktionsverfahren [3])
- MIC, Fa. Cerberus (Meßgerät für Rauchdichte nach dem Ionisationsstromprinzip [4])

Gasmeßgeräte

- IR-Sensor Opt Sens CO_2, Fa. EH Gastec
- Paramagnetische Sauerstoffwaage Servomex OA 580, Fa. Sybron Taylor

Sonstige Meßgeräte

- 2 Thermoelemente unter der Decke des Brandraumes zur Messung der Raumtemperatur
- 1 Thermoelement zur Messung der Heizplatten- oder Probentemperatur
- Waage zur Messung des Abbrandgewichts

5 Testfeuer

Um die Eignung der Gassensoren für die Erkennung von Brandkenngrößen zu untersuchen, wurden die Sensoren definierten Testfeuern in dem beschriebenen Brandraum ausgesetzt und die Ausgangssignale der Sensoren aufgezeichnet. Es wurden folgende Testfeuer durchgeführt:

- Testfeuer nach EN 54 Teil 9 (Stand 8/84)

  Teil 9 der EN 54 [5] beschreibt die Testfeuer des Erprobungstests, „denen Brandmelder unterworfen werden, um Bedingungen zu erfüllen, die in anderen Teilen der Norm festgelegt sind“. Der Erprobungstest soll Informationen über das unter echten Brandbedingungen zu erwartende Ansprechverhalten von Brandmeldern zu liefern.

  TF 1: „Offenes Zellulosefeuer“
  TF 2: „Pyrolyseschwelbrand“
  TF 3: „Glimm-Schwelbrand“
  TF 4: „Offener Kunststoffbrand“
  TF 5: „Flüssigkeitsbrand“ (n-Heptan)
  TF 6: „Flüssigkeitsbrand“ (Spiritus)

- Testfeuer nach IfBt-Mitteilung 2/1978

  Die IfBt-Mitteilung 2/1978 behandelt die „Beurteilung der Brauchbarkeit von Rauchauslöseeinrichtungen im Rahmen der Zuteilung von Prüfzeichen für Absperrvorrichtungen“ [6]. Abschnitt 4.5 der Mitteilung beschreibt den Erprobungstest für Rauchauslöseeinrichtungen. Die Testfeuer (in Anlehnung an EN 54 Teil 9) werden jeweils bei Strömungsgeschwindigkeiten von 1 m/s sowie 20 m/s durchgeführt.

Brand I „Schwelbrand“
Brand II „Kunststoffbrand“
Brand III „Flüssigkeitsbrand“ (Decahydronaphthalin)

- Nicht genormte Testfeuer
  - Braunkohlenstaub-Schwelbrand
  - Steinkohlenstaub-Schwelbrand
  - Selbstentzündung von Leinölfirnis
  - Kabelbrand
  - Verbrennung von Kunststoffagglomerat

6 Untersuchungen auf Täuschungseinflüsse

Es ist bekannt, daß Gassensoren in teilweise hohem Maße auf andere Stoffe als ihre Zielgase reagieren (Querempfindlichkeit). Die Höhe einer Querempfindlichkeit kann bis zu mehreren hundert Prozent betragen. Die folgenden Untersuchungen wurden durchgeführt, um den Einfluß einer Auswahl von Störquellen auf Gassensoren zu bestimmen und erste Erkenntnisse hinsichtlich notwendiger Einschränkungen der Anwendungsbereiche für Brandgasmelder in Abhängigkeit des verwendeten Sensorprinzips und Sensortyps zu gewinnen:

Täuschungsgrößen von Verbrennungsprozessen
- Pkw-Abgase
- Zigarettenrauch

Täuschungsgrößen aus Nicht-Brand-Situationen
- Lösungsmittel (Aceton, Nitro-Verdünnung, Lack auf Alkydharzbasis, Ethanol)
- Parfum

7 Untersuchung von Hintergrundkonzentrationen

Gassensoren werden nur dann erfolgreich in der Brandmeldetechnik eingesetzt werden können, wenn mit ihnen ausgestattete Melder ausreichend täuschungsalarmsicher funktionieren. Um diese Anforderung zu erfüllen, ist es notwendig, daß sich die Signale, die während Brandversuchen gewonnen werden, deutlich von den vorherrschenden Hintergrundkonzentrationen im Einsatzbereich abheben. Die Untersuchung solcher Hintergrundkonzentrationen ist für Brandgasmelder ungleich wichtiger als für konventionelle Brandmelder; im wesentlichen gibt es hierfür folgende Gründe:

- Die Verwendung bestimmter Stoffe könnte - im Hinblick auf potentielle Täuschungsgrößen - zwar durch Produkthinweise für den Einsatzbereich von Brandgasmeldern untersagt werden, für den Einzelfall wäre jedoch nicht auszuschließen, daß Stoffe, auf die Gassensoren mit hoher Querempfindlichkeit reagieren, verfahrenstechnisch bedingt freigesetzt werden.

- Die Lebensdauer von Halbleitersensoren und elektrochemischen Zellen kann durch Einwirkung von Sensorgiften oder durch extreme klimatische Beanspruchungen deutlich herabgesetzt werden.
- Anwendungsbereiche mit widrigen Umgebungsbedingungen, für deren Überwachung konventionelle Brandmelder nicht geeignet sind, stellen potentielle Betätigungsfelder für alternative Detektionsprinzipien dar. Die Eignung von Brandgasmeldern für den Einsatz in einem solchen Bereich muß erst nachgewiesen werden.

Es wurden zwei Vor-Ort-Untersuchungen durchgeführt, die Schlußfolgerungen auf die Eignung der Gassensorik zur Überwachung hinsichtlich der Branderkennung problematischer Anwendungsbereiche erlauben:

1) Ein Brand, der sich in einem Silo für Kunststoffagglomerat innerhalb eines Recycling-Unternehmens ereignete, veranlaßte den zuständigen Versicherer, Untersuchungen für eine wirksame Branderkennung zur Ansteuerung einer Löschanlage einzuleiten. Das zwischengelagerte Material hatte die gleiche Zusammensetzung wie der Brennstoff, der für den Brandversuch „Verbrennung von Kunststoffagglomerat“ verwendet wurde; es handelte sich um ein Gemisch von etwa 80 % Polyethylen und 20 % Polypropylen.
2) Im zweiten Fall sollte die Einsetzbarkeit von Gassensoren zur reingasseitigen Branderkennung in einer Schweißrauchfilteranlage untersucht werden. Zu diesem Zweck wurden Brandversuche an einer Versuchs-Anlage durchgeführt und die während des Brandversuchs erhaltenen Meßwerte mit der Aufzeichnung von Hintergrundkonzentrationen unter Betriebsbedingungen verglichen.

8 Bewertung der Ergebnisse

8.1 Testfeuer

8.1.1 Testfeuer nach EN 54

Die Auswertung der Testfeuer nach EN 54 (s. Bilder 1 bis 3) zeigt, daß Brandgasmelder mit den untersuchten Sensoren grundsätzlich in der Lage sind, alle diese Feuer zu erkennen. Die einzelnen Gassensoren sind jedoch unterschiedlich gut geeignet, die verschiedenen Testfeuer zu entdecken. Es läßt sich folgende Zuordnung treffen:

1) TF1: offenes Zellulosefeuer

Der offene Holzbrand TF 1 kann bis Brandende durch die eingesetzten CO- und CO_2-Sensoren, den PC-Sensor und die Gasmeßgeräte detektiert werden; die Signalerhöhung ist in allen drei Fällen deutlich (s. Bild 1).

2) TF 2 und TF 3: offenes Zellulosefeuer und Glimm-Schwelbrand

   Erwartungsgemäß eignen sich Brandgasmelder mit dem Zielgas Kohlenmonoxid besonders für die Erkennung von unvollständigen Verbrennungsvorgängen (s. Bild 2). Für eine frühe Detektion der Schwelbrände TF 2 und TF 3 können außerdem die Signale der untersuchten H_2-, Lösungsmittel/NO_X- und PC-Sensoren verwertet werden.

3) TF 4 bis TF 6: offener Kunststoffbrand und Flüssigkeitsbrände

   Zur Detektion der offenen Flammenbrände TF 4 bis TF 6, die praktisch keine Entstehungsphase besitzen, können vor allem die Konzentrationsänderungen von Sauerstoff und Kohlendioxid sowie das Signal des PC-Sensors genutzt werden (s. Bild 3).

Brandverläufe und Brennstoffe der Testfeuer 4 bis 6 sind für eine Bewertung von Brandgasmeldern nur bedingt geeignet; sie zeigen jedoch, daß Gassensoren, sofern sie Produkte einer unvollständigen Verbrennung detektieren, nicht in besonderer Weise zum Erkennen von reinen Flammenbränden geeignet sind. Halbleitersensoren mit negativer Querempfindlichkeit auf NO_X sind hier aufgrund der NO_X-Freisetzung bei offenen Flammenbränden besonders problematisch.

8.1.2 Testfeuer nach IfBt 2/1978

Auch bei der Branddetektion in Lüftungsleitungen nach IfBt 2/1978 erwiesen sich die Signale der eingesetzten CO- und H_2-Sensoren für die Schwelbranderkennung als geeignet; eine erhöhte CO_2-Konzentration war vor allem bei offenen Bränden zu verzeichnen.

8.1.3 Nicht genormte Testfeuer

Bei den nicht genormten Testfeuern handelt es sich um Schwelbrände und Brände mit ausgeprägter Schwelphase. Schwelvorgänge, die über die Erhitzung eines Stoffes allmählich initiiert werden sowie über glühende Partikel eingeleitete Glimmbrände, stellen typische Formen einer Brandeinleitung dar; die untersuchten Gassensoren eignen sich besonders für die Detektion der während solcher Frühstadien eines Brandes erzeugten Gase. Entsprechend können hier vor allem die Signale der CO-, H_2-, PC- und Lösungsmittel/NO_X-Sensoren als Brandkriterien verwertet werden.

Schwelbrände von Braun- und Steinkohlenstaub waren durch Gassensoren eindeutig zu detektieren, Rauch wurde hingegen nicht in nennenswertem Maße freigesetzt. Sowohl CO-, als auch H_2- und Lösungsmittel/NO_X-Sensoren lieferten signifikante Brandkriterien. Da Kohle stetig Kohlenmonoxid entwickelt, scheint ein Multigassensormelder gegenüber einem reinen CO-Melder hier im Vorteil zu sein.

Der größte Zeitvorteil für Brandgasmelder läßt sich bei der Detektion eines Selbsterhitzungsvorgangs erwarten: ein durch Selbstentzündung von Leinölfirnis entstandenes Feuer hätte durch einen Brandgasmelder mit geeignetem Auswertungsalgorithmus 45 bis 50 Minuten früher erkannt werden können, als dies mit konventioneller Brandmeldetechnik möglich gewesen wäre.

Das Verschmoren eines Stromkabels im VdS-Brandraum ließ sich mit Hilfe der eingesetzten Meßtechnik nur schlecht detektieren. Ergebnisse einer anderen Untersuchung weisen jedoch darauf hin, daß Brandgasmelder für den Einsatz in horizontal wie auch vertikal verlaufenden Kabelkanälen gut geeignet sind [7]. Kohlenwasserstoffe, Chlorwasserstoff wie auch Kohlenmonoxid stellen demnach mögliche Brandkenngrößen für die Überwachung von Kabelkanälen dar.

8.2 Täuschungsgrößen

Die Beaufschlagung von Gasmeßgeräten und -sensoren mit Täuschungsgrößen zeigt, daß sich vor allem Querempfindlichkeiten auf Lösungsmittel stark negativ auf die Täuschungsalarmsicherheit eines Brandgasmelders auswirken können. Relativ geringe Mengen von Ethanol, Parfum oder Aceton können ausreichend sein, einen Alarm auszulösen. Die Dämpfe von Nitro-Verdünnung hingegen bewirken bei den untersuchten Sensoren negative Signalwerte und scheinen somit - je nach Konzentration - die Detektionsfähigkeit eines Brandgasmelders temporär einschränken oder sogar aufheben zu können.

8.3 Hintergrundkonzentrationen

Querempfindlichkeiten spielen bei der Betrachtung von Hintergrundkonzentrationen eine wesentliche Rolle. Es muß davon ausgegangen werden, daß die ermittelten Hintergrundkonzentrationen großenteils nicht auf die Einwirkung eigentlicher „Zielgase“ zurückzuführen sind; in verschiedenen Anwendungsbereichen kann es jedoch auch zu einer verfahrenstechnisch bedingten Freisetzung typischer Brandgase kommen.

Generell stellen Lösungsmittel-Dämpfe, wie auch Abgase von Verbrennungsmotoren, wesentliche Täuschungsgrößen dar, die bei der Ermittlung von Hintergrundkonzentrationen zu berücksichtigen sind.

8.3.1 Silo für Kunststoffagglomerat

Der Vergleich der Aufzeichnungen von Hintergrundkonzentrationen im Silokopf mit den Ergebnissen entsprechender Brandversuche zeigt, daß sich in diesem Fall weder ein H_2- noch ein CO-Sensor für eine besonders frühe Branderkennung eignet. Durch das Auftreten unerwartet hoher H_2- und CO-Peaks wären entsprechend hohe Auslöseschwellen der Brandgasmelder notwendig, um Täuschungsalarme sicher ausschließen zu können.

8.3.2 Schweißrauchfilteranlage

Die Brandversuche an einer Schweißrauchfilteranlage lassen darauf schließen, daß i.a. Brandmelder mit den Brandkenngrößen Rauchdichte und Temperatur für Anwendungsbereiche mit hohen Strömungsgeschwindigkeiten besser geeignet sind als die untersuchten Gassensoren. Diese Schlußfolgerung wurde durch die Ergebnisse der Versuche zur Branddetektion in Lüftungsleitungen erhärtet.

Eine reingasseitige Brandfrüherkennung in Filteranlagen vor Durchbrennen des Filters ist dennoch nur mit Gassensorik möglich. Die Eignung von Brandgasmeldern ist für einen solchen Einsatz in hohem Maß von der Zusammensetzung des Filterstaubs abhängig.

8.4 Mehrkriterienauswertung

Durch die Verknüpfung der Brandkenngrößen Rauch und Temperatur mit einem gasförmigen Brandkriterium könnte ein hohes Maß an Sicherheit gegen Täuschungsalarme erreicht werden. Mit den Bildern 5 und 6 läßt sich anhand der Testfeuer nach EN 54 darstellen, wie eindeutig verschiedene Brände durch einfache Kombination mehrerer Brandkriterien erkannt werden können. Zur Veranschaulichung werden folgende Beispiele in Netzdiagrammen dargestellt (s. Bilder 5 und 6):

- Multigassensor (Zielgase: CO, CO_2 und H_2)
- Kombinations-Melder (Brandkenngrößen: Rauch, Temperatur und CO)

Die Auswertung der Testfeuer über Netzdiagramme zeigt, daß der für dieses Beispiel zusammengestellte Multigassensor Werte liefert, mit denen man im wesentlichen zwischen Schwelbränden (TF 2, TF 3) und offenen Flammenbränden (TF 1, TF 4, TF 5 , TF 6) unterscheiden kann. Schwelbrände sind hierbei durch starke CO- und H_2-Signalerhöhung, offene Flammenbrände durch starke Erhöhung des CO_2-Signals, bei leichter CO- und H_2-Signalerhöhung, gekennzeichnet. Die Diagramme des Kombinations-Melders charakterisieren die einzelnen Testfeuer in deutlich stärkerer Weise. Über geeignete Auswertungsalgorithmen könnte wahrscheinlich mit beiden Meldern eine hohe Täuschungsalarmsicherheit erzielt werden.

8.5 Sonstige Ergebnisse

Es zeigt sich, daß eine Vielzahl von Gasen und Gasgemischen als Brandkriterien genutzt werden kann, dabei aber Querempfindlichkeiten (z.B. auf Wasserstoff, Kohlenwasserstoffe, Lösungsmittel und Stickstoffoxide) sowie Empfindlichkeiten auf Temperatur und Luftfeuchte zu berücksichtigen sind. Sofern es sich bei solchen Einflüssen um mögliche Brandkenngrößen handelt, müssen diese nicht unbedingt kompensiert werden. Die sichere Branddetektion eines Brandgasmelders hängt nicht zwingend von der hohen Selektivität der verwendeten Gassensoren ab.

Betrachtet man die Querempfindlichkeiten der verwendeten Gassensoren auf Halbleiter- und elektrochemischer Basis, so muß man zu dem Schluß kommen, daß eine Unterscheidung zwischen Zielgas und Querempfindlichkeit zum Teil willkürlich vorgenommen wird. Es stellt sich beispielsweise die Frage, ob eine elektrochemische CO-Zelle mit 200 % Querempfindlichkeit auf C_2H_2 nicht als C_2H_2-Zelle angesehen werden müßte, die eine Querempfindlichkeit von 50 % auf CO besitzt.

9 Eignung der Testfeuer nach EN 54 für die Erprobung von Brandgasmeldern

Betreiber von Brandmeldeanlagen haben oft geringes Interesse an einer besonders frühen Branderkennung. In ihrem Interesse liegt es vor allem, mit geringstem finanziellen und organisatorischen Aufwand den von Behörden und Versicherern gestellten Anforderungen an den Brandschutz bei optimaler Falschalarmsicherheit formell nachzukommen.

Eine besonders frühe Branderkennung ist offensichtlich auch nicht das Ziel der EN 54, da die Mehrzahl der darin beschriebenen Testfeuer den Anschein erwecken, Detektionszeiten spielten für die meisten Brände eine zu vernachlässigende Rolle. Zwischen dem Ansprechen je eines Rauchmelders der Klassen A und C liegen bei diesen Testfeuern im Durchschnitt nur etwa zwei Minuten, obwohl sich die Ansprechempfindlichkeiten der Melder und die damit zusammenhängende Sicherheit gegen Täuschungsalarm wesentlich unterscheiden. Man muß berücksichtigen, daß es sich bei diesen Feuern nicht um die Nachstellung repräsentativer Brandszenarien handelt, sondern daß diese den Zweck haben, hinsichtlich Rauchzusammensetzung sowie Rauch- und Wärmemengen verschiedene Brandverläufe zu erzeugen. Da Brände normalerweise mehr oder weniger ausgedehnte Brandentstehungsphasen aufweisen, ist ein zu erwartender Zeitvorteil von deutlich mehr als den oben erwähnten 2 Minuten durch eine frühe Brandmeldung zu erwarten. Man kann davon ausgehen, daß ein Ausschöpfen solcher Zeitvorteile entstandene Brandschäden oftmals gemindert hätte.

Brandgasmelder besitzen ihren besonderen Vorteil bei der Detektion von Schwelbränden und scheinen somit besonders geeignet, ein Feuer schon während der frühen Brandentstehungsphase zu detektieren. Die nach EN 54 beschriebenen Testfeuer 1,4,5 und 6 stellen offene Flammenbrände ohne bzw. mit zu vernachlässigend kurzer Brandentstehungsphase dar. Schwel- und Glimmbrände, wie sie in der Praxis häufig zu erwarten sind, werden auch durch die Testfeuer TF 2 und TF 3 nicht repräsentiert, da es sich bei diesen um künstlich beschleunigte Brände handelt. Folglich läßt keines dieser Testfeuer eine Aussage darüber zu, wie gut sich ein Brandmelder für die Brandfrüherkennung eignet.

Testfeuer für die Erprobung von Brandgasmeldern sollten entweder in Analogie zur EN 54 hinsichtlich der zu produzierenden Brandgasgemische entwickelt werden, oder sie sollten repräsentative Mischbrände darstellen, mit deren Auftreten in der Praxis, auch hinsichtlich des Brandverlaufs, überwiegend zu rechnen ist. Die Forderung nach der Entwicklung neuer Testverfahren, in denen verschiedene Brandphasen kombiniert sein sollten, wurde schon von Schierau [8] im Hinblick auf die Prüfung konventioneller Brandmeldetechnik erhoben. Eine besondere Eignung von Brandgasmeldern für spezielle Anwendungsbereiche könnte jeweils mit entsprechenden Testfeuern überprüft werden (z.B.: Braunkohlenstaub-Schwelbrand, Kabelbrand).

Die Aussagekraft der Detektion eines Testfeuers ist jedoch beschränkt. Vor allem Multisensormelder, die über geeignete Auswertungsalgorithmen verfügen, können leicht darauf getrimmt werden, nahezu jedes Testfeuer innerhalb kurzer Zeit zu identifizieren. So lassen sich unter Brandraumbedingungen für alle Brände typische Muster freigesetzter Gasgemische erkennen. Mit der Betrachtung jedes weiteren Brandkriteriums wird der Wiedererkennungswert eines bekannten Brandes noch gesteigert (s. Bilder 4 bis 6).

10 Ausblick

Wenn sich auch konventionelle Rauch- und Wärmemelder nicht zuletzt wegen ihrer vergleichsweise niedrigen Preise weiterhin in ihren meisten Anwendungsbereichen behaupten dürften, so scheinen Brandgasmelder doch für den Einsatz in einigen Bereichen prädestiniert zu sein. Bereiche mit hohem Staubaufkommen, mit Neigung zur Kondensation, mit der Gefahr der Selbstentzündung oder der Notwendigkeit einer frühestmöglichen Branderkennung kommen hier vor allem in Betracht.

Dabei kann mit Multisensormeldern ein Maximum an Sicherheit gegen Täuschungsalarme erreicht werden. Die Verbindung der Brandkenngrößen Gas, Temperaur und Rauch in einem „Kombinations-Melder" scheint in dieser Hinsicht besonders vorteilhaft zu sein. Die Verwendung solcher Melder wäre zum Beispiel zur Ansteuerung automatischer Feuerlöschanlagen von Interesse.

Wegen der für Gassensoren relevanten Problematik der Querempfindlichkeiten ist es erforderlich, vorherrschende Hintergrundkonzentrationen zu berücksichtigen sowie das Auftreten bestimmter Gase und Dämpfe für den Nichtbrandfall auszuschließen. Des weiteren können klimatische Extrema für den Einsatz von Gassensorsystemen ebensolche Ausschlußkriterien darstellen, wie das Auftreten von Sensorgiften. Ohne diese Parameter in repräsentativen Vor-Ort-Untersuchungen für einzelne Anwendungsbereiche zu bestimmen, kann keine zuverlässige Aussage über Detektionsfähigkeit, Täuschungsalarmsicherheit oder zu erwartende Lebensdauer eines Brandgasmelders getroffen werden.

Die Ergebnisse des Projektes zeigen, daß weiterführende Untersuchungen notwendig sind, um die Eignung von Brandgasmeldern für ausgewählte Anwendungsbereiche beurteilen zu können. Im Anschluß an das Projekt hat VdS Schadenverhütung daher im Juli 1998 den Auftrag an das Fachgebiet Brand- und Explosionsschutz der BUGHW erteilt, Grundlagen für das Aufstellen von Anforderungen und Prüfmethoden für Brandgasmelder zu erarbeiten, gemeinsam mit den VdS-Laboratorien die erforderlichen Prüfeinrichtungen zu realisieren und für den praktischen Einsatz von Brandgasmeldern relevante Umgebungseinflüsse zu untersuchen.

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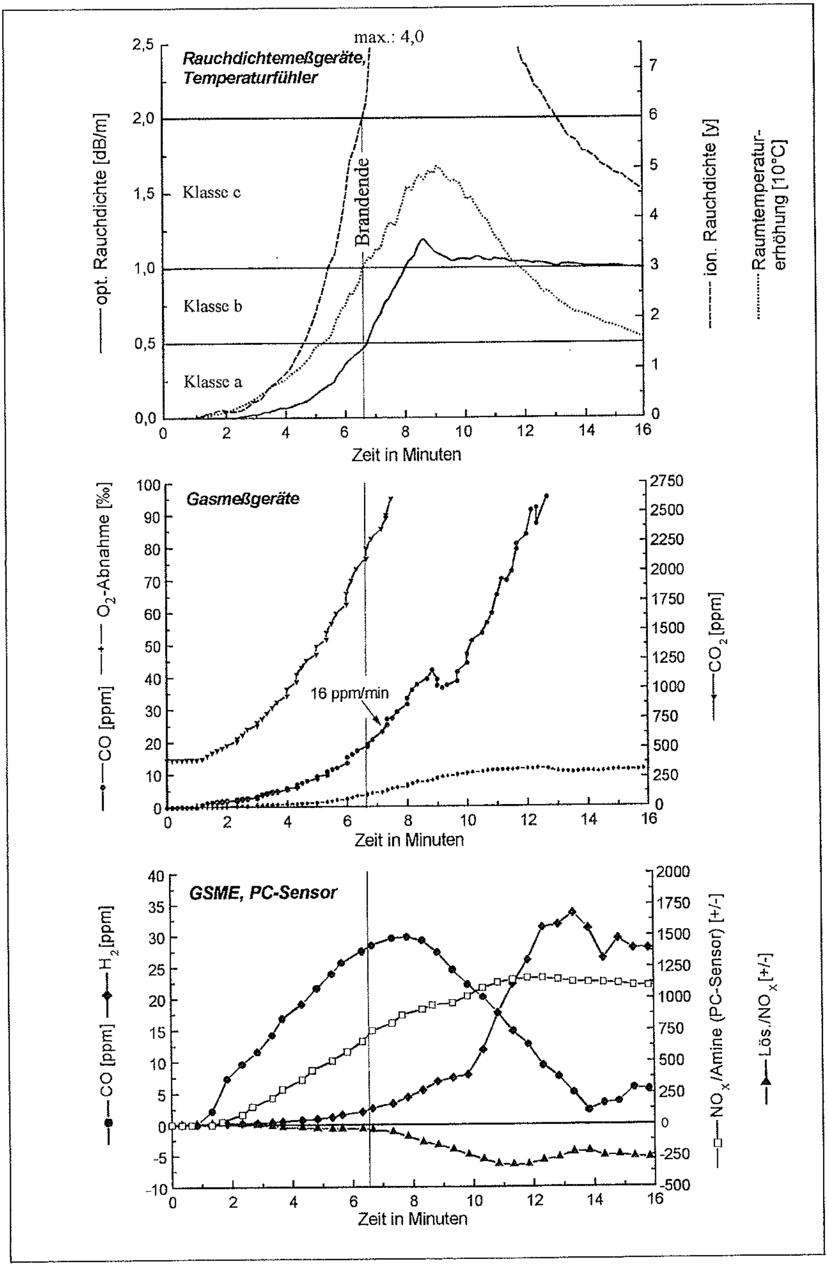

Bild 1: Meßergebnisse TF 1 nach EN 54

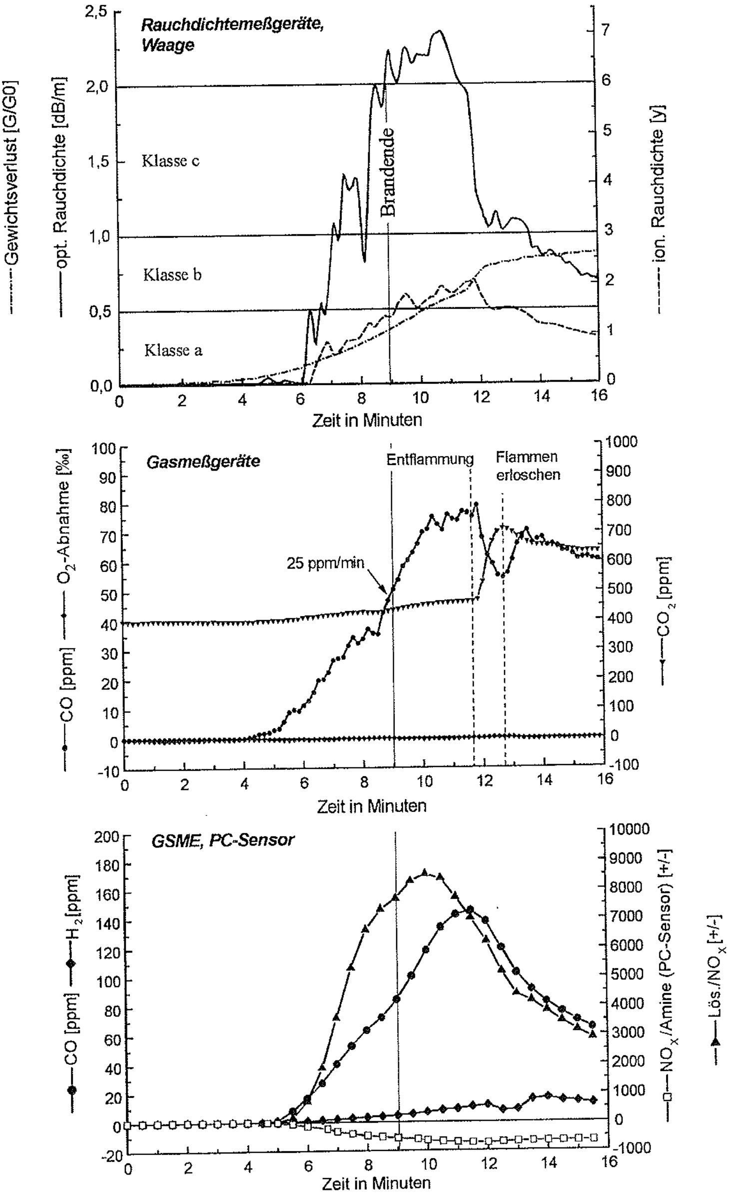

Bild 2: Meßergebnisse TF 2 nach EN 54

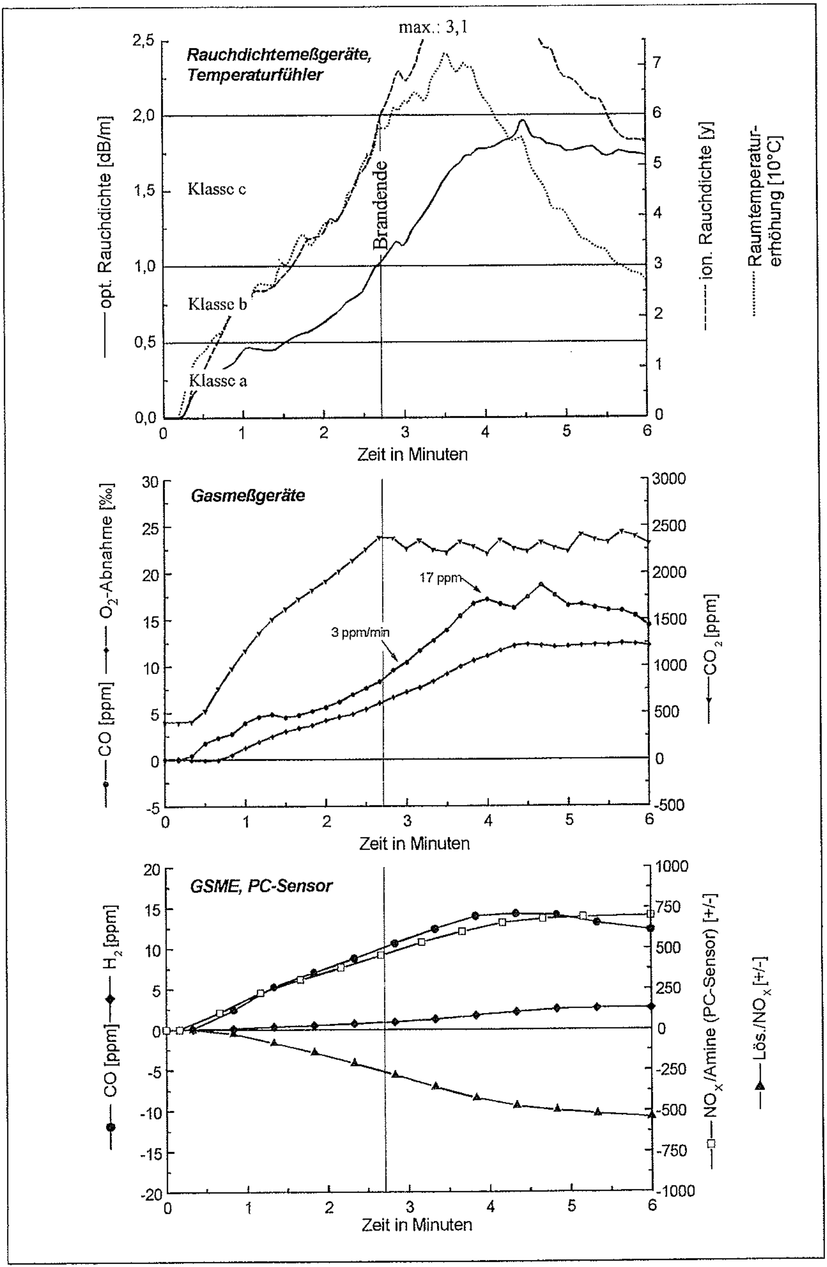

Bild 3: Meßergebnisse TF 5 nach EN 54

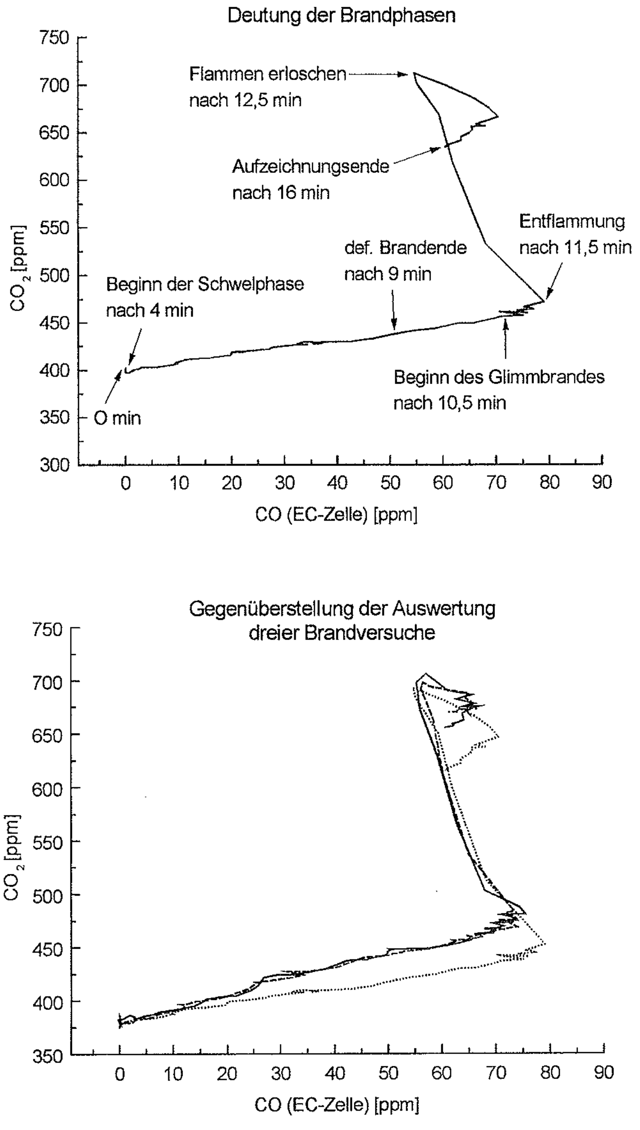

Bild 4: Auftragung der CO_2-Konzentration über der CO-Konzentration am Beispiel des TF 2

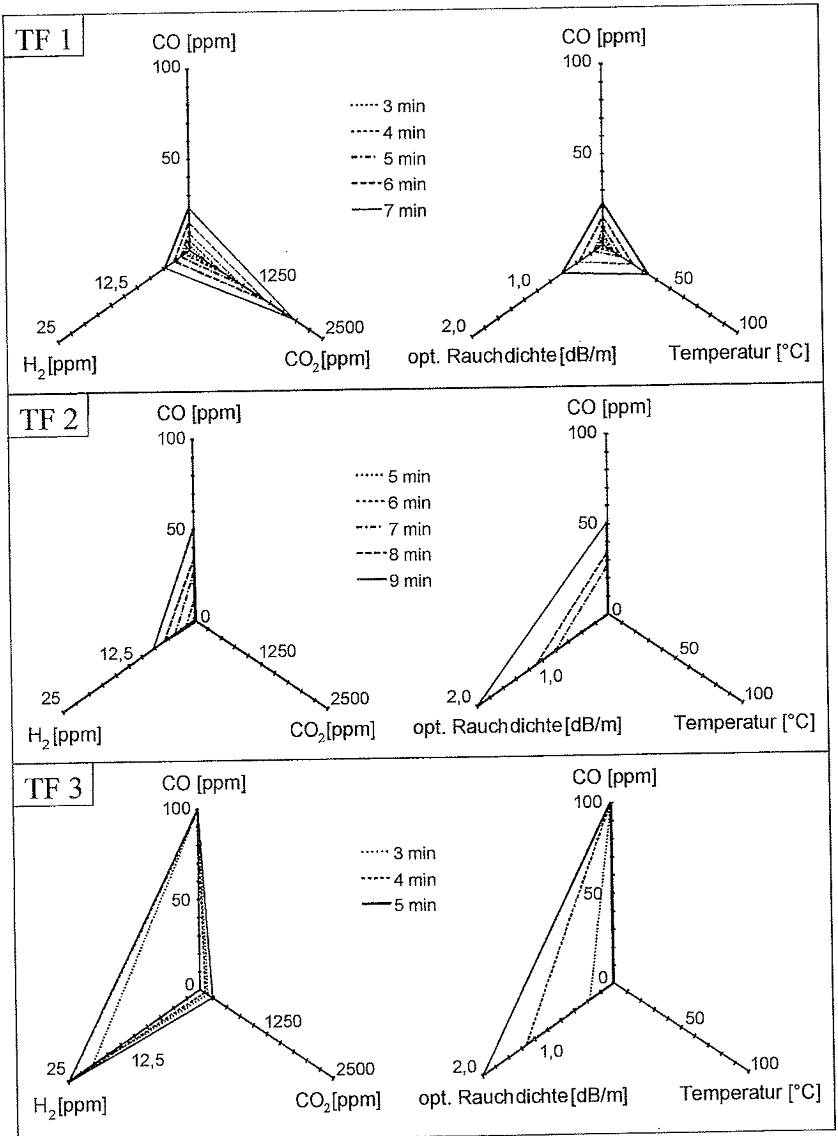

Bild 5: Entwicklung von Brandkenngrößen für die Testfeuer 1 bis 3 (bis zum Brandende)

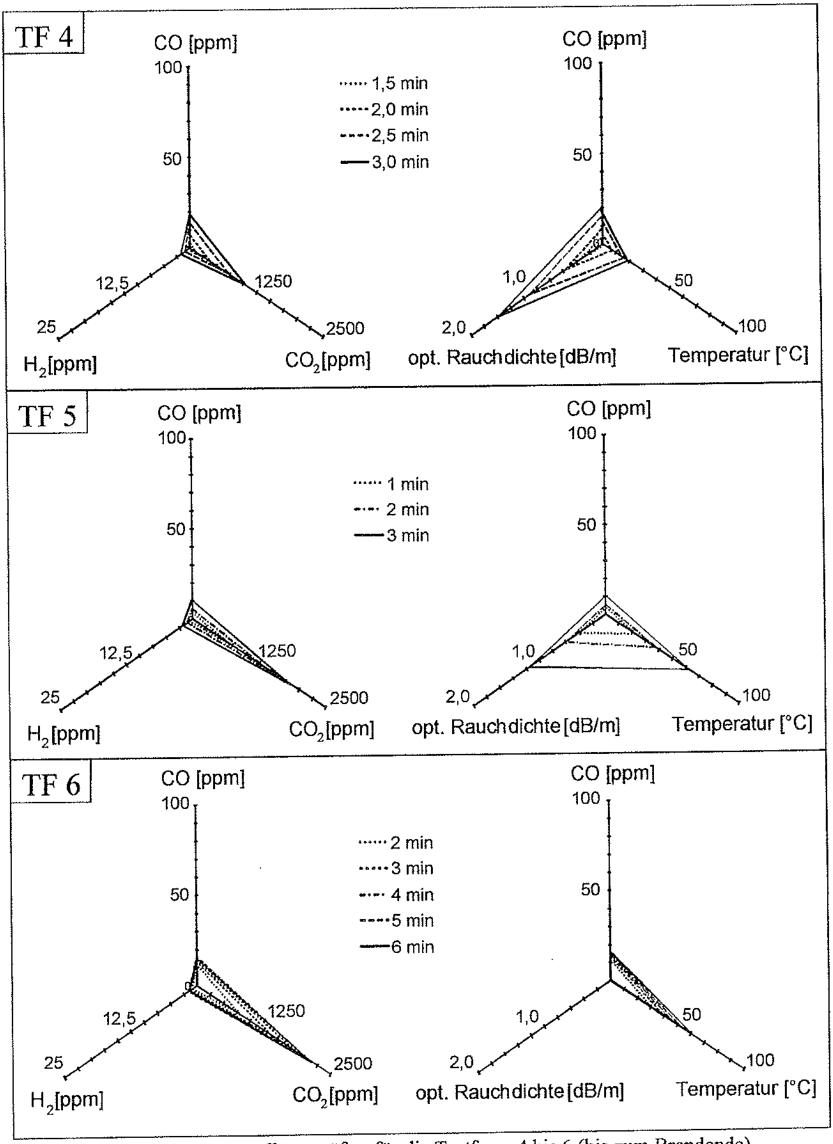

Bild 6: Entwicklung von Brandkenngrößen für die Testfeuer 4 bis 6 (bis zum Brandende)

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A CASCADE IMPACTOR WITH ELECTRICAL DETECTION OPTIMIZED FOR FIELD USE

ABSTRACT

We describe a cascade impactor with electrical detection which is optimized with respect to power consumption and give example results.

INTRODUCTION

Historically, measuring philosophy has changed from total dust to PM10 (particulate matter < 10µm) and recently the USEPA has added an additional PM2.5 standard /1/. In addition, based on a first publication by Oberdörster et al. /2/, it is claimed that ultrafine particles act by virtue of their number concentration.

For all these different approaches, suitable reference samplers must become available. The first instrument capable of characterizing the whole particle size range equipped with a sophisticated flow control was the Wide Range Aerosol Classifier (WRAC /3/). It is installed in a trailer and needs a power of 7.5 kW, clearly too much to be practical.

We therefore decided to develop a smaller version of a reference sampler with variable characteristics and equipped with a state-of-the-art flow control system, featuring cutpoints close to the popular PM10 and PM2.5 as well as a real-time electrical detection.

Contrary to gravimetry, optical and electrical detection techniques both provide quick response times but their signal is not mass-proportional as is required by many applications. If the temporal integral of the real-time signal can be correlated with the gravimetric result of the sampling, a calibration factor can be determined after the measurement, and the gravimetric concentration can be reconstructed later. Electrical measurements in cascade impactors are not new and a commercial instrument is available /4/ but has been limited to rather high concentrations due to small sampling flow rates and insufficient electrical detection limits.

Also, considerable flow rates are required for collecting sufficient dust for gravimetric analysis at low ambient concentrations. At the same time, a trade-off may be required between size resolution and mass collected. Commercial impactors are not optimized normally for the individual flow rate - pressure drop characteristics of the pump. Sometimes, energy is even wasted by critical orifices for flow regulation.

It was the objective of the present design to optimize an electrical impactor with respect to flow rate for a given pump / generator combination while allowing two different modes of operation, a „hi-resolution“ and a „hi-flow“ by simply taking out the last impaction stage.

The following paper describes design and performance of a prototype instrument originally designed for wind erosion studies where emphasis is on large particles /5/. Therefore, the device is presently not yet optimized for small particle detection as it would have to be for e.g. fire detection and atmospheric aerosol monitoring but its main features will remain unchanged.

DESIGN CONSIDERATIONS

At the inlet, particles are electrically charged by a corona charger. After entering the impactor, they deposit on the different stages according to their size. The charge delivered by the particles to the insulated impaction stages is detected by sensitive electrometers and can be recorded in real-time. After the sampling period, gravimetric analysis of the stage deposits can also be performed, if necessary.

There are essentially three intertwined design aspects for overall flow control, for the impactor stages and for particle charging/detection. Flow rate and size resolution must fit together in order to obtain a sensitivity high enough for real-time particle detection at ambient aerosol concentrations. At the same time, the whole device should be optimized with respect to power efficiency. So, a portable generator should be able to provide the power necessary for field operation.

Flow control and impaction stages

Good power efficiency can be obtained, if the pressure drop inside the impactor is used for measuring and controlling the flow rate. This approach makes any additional flow meters, critical orifices etc obsolete yet at the same time allows flexible change of operating parameters. There are venting holes in-the insulating teflon rings which separate the different stages; through them, the corresponding stage pressure is communicated to the outside sensor for flow control.

The particles are collected on stainless steel rings which can be evaluated gravimetrically. A corona charging section is integrated into the inlet, and the impaction stages are mounted in Teflon rings so that the current delivered by the charged particles in the various size fractions can be measured.

Calculations

The following hydrodynamic relations were used:

The critical flow density j_* (in kg/(m^{2}s)) for a certain pressure p is given by $j_*(p,T)=c_0(T)\cdot\sqrt{\frac{2}{\kappa+1}}\cdot\frac{p\cdot M}{RT}\cdot\left(\frac{2}{\kappa+1}\right)^{\frac{1}{\kappa-1}}$ where $c_0(T)=\sqrt{\frac{\kappa RT}{M}}$ is the sonic velocity. M,R,κ are the molecular weight, the gas constant and the adiabatic coefficient, respectively. The flow will be critical for pressure ratios $\frac{p_{out}}{p_{in}}>pvc=\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa}{\kappa-1}}$. Undercritical flow density (which applies here for all stages) is given by $j(p_{in},p_{out},T)=\left(\frac{p_{out}}{p_{in}}\right)^{1/\kappa}\cdot\sqrt{\frac{2\cdot\kappa\cdot M\cdot p_{in}^2}{RT\cdot(\kappa-1)}\cdot\left(1-\left(\frac{p_{out}}{p_{in}}\right)^{1-1/\kappa}\right)}$. In order to obtain the mass flow rate $\dot{m}$, the flow density has to be multiplied by the physical area F and the flow contraction number

$fc(p_{in}, p_{out}) = \sqrt{1 + 2 \cdot kont(p_{in}, p_{out}) \cdot (kont(p_{in}, p_{out}) - 1)}$ where $kont(p_{in}, p_{out}) = 0.61 + 0.28 \cdot (1 - p_{out} / p_{in})$ if p_{out} / p_{in} is greater than the critical pressure ratio pvc and $kont(p_{in}, p_{out}) = 0.61 + 0.28 \cdot (1 - pvc)$ otherwise.

The temperatures after stage i are $T_i = T_0 \cdot \left(\frac{p_{out,i}}{p_{in,i}} \right)^{1-1/\kappa}$. The gas viscosity is $\mu(T) = \mu_0 \cdot \sqrt{\frac{T \cdot (1 + S / 293)}{293 \cdot (1 + S / T)}}$ where $\mu_0 = 1.83 \cdot 10^{-5}$ kg/(ms) is the viscosity at 293K and $S = 123.6K$ is Sutherland's constant. The Knudsen number is $Kn(T, p) = 2\lambda(T, p) / d_p$ and $\lambda(T, p) = 2.004 \cdot \frac{\mu(T)}{p} \cdot \sqrt{\frac{\pi RT}{8M}}$ is the gas mean free path . The critical particle relaxation time is given by $\tau_{crit,i} = \frac{Stk_{circ} \cdot d_{n,i}}{2v_i}$ where $v_i = \frac{\dot{m} \cdot R \cdot T_i}{M \cdot p_i \cdot F_i}$ is the nozzle velocity in stage i . The actual cut-off diameter is then given by solving $\tau_p(d_{p,i}) = \tau_{crit,i}$ for d_p.

The particle relaxation time is given by $\tau_p(d_p) = B(d_p, p) \cdot d_p^3 \cdot \rho_p * \frac{\pi}{6}$ (ρ_p is the particle density) with the mobility

$$B(d_p, p, T) = \frac{(1 + Kn(T, p) \cdot (1.142 + 0.558 \cdot Exp(-0.999 / Kn(T, p))))}{3 \cdot \pi \cdot \mu(T) \cdot d_p}$$

The mass flow rate $\dot{\nu}$ in moles/s is related to the volumetric flow rate $\dot{V}$ in m^3/s at ambient conditions by $\dot{\nu} = \frac{p_0 \dot{V}}{RT_0}$.

Optimization procedure

The design procedure started with the choice of a turbine: channel-wheel turbines are not very noisy yet deliver high flow rates at acceptable pressure drops. The impaction stages were implemented as follows: the pressure drop was calculated via compressible flow with „vena contracta“. Keeping the mass flow rate constant over the whole device, the nozzle velocities and accordingly the cut-off diameters were determined. The optimization was performed by (heuristically) varying the nozzle diameters and numbers so that the Reynolds numbers of the different stages were nearly equal. At the same time the flow was to be maximized keeping cutpoints close to the desired sizes at logarithmically nearly equal distances. Since the cut-off curve slope depends mainly on the Reynolds number, changing the flow rate affects the cut-off characteristics for all stages in the same way making size determination easy for varying flow rate.

The two design modes „hi-res“ and „hi-flo“ with their characteristics are listed in Tab. 1. It can be seen that choice of cut-offs for both operation modes facilitates PM2.5 and PM10 interpolation without great error.

				hi-res		hi-flo	
stage #	nozzle number	nozzle diam. d_n (mm)	nozzle length (mm)	Re	calc. cutoff diam. d_p (µm)	Re	calc. cutoff diam. (µm)
0	-	-	-	-	80	-	68
1^a	15	23	50	1120	33	1600	28
2	18	10.4	30	2070	11	2950	9.2
3	83	2.5	8	1860	2.7	2700	2.2
4	165	1.1	5	2130	1.15	3055	0.8
5	250	0.7	2.1	2200	0.44		
filter	-	-	-	-	0	-	0

Tab. 1: *Design characteristics of the complete impactor with 5 stages set at a mass flow rate of 0.19 Moles/s (16.8* m^3/h *STP, "hi-res"). Ambient conditions* $p_0 = 10^5\,Pa$ *and* $T_0 = 293K$. *Hi-flo area: last stage replaced by a dummy; set at a mass flow rate of 0.27 Moles/s (24* m^3/h *STP, "hi-flo").* [a]*Slit nozzle equivalent circular nozzle array.*

Corona charger

Normally, aerosol particles carry a charge which depends on the material, the generation process and the aerosol age. Particles freshly generated from powder or liquid dispersion usually tend to have asymmetric charge distributions with charges much higher than calculated for „Boltzmann equilibrium". The quotation marks are used because there is no such thing as „Boltzmann equilibrium" (see /6/) but historically, this term was often used. Aged charge distributions nevertheless are usually close to „Boltzmann equilibrium".

There are two fundamental charging regimes: diffusion charging and field charging. Diffusion charging is roughly proportional to the particle diameter (with a small additional logarithmic term) while field charging at high field strengths is proportional to the diameter squared. In both cases, small particles carry a higher specific charge in As/g.

The charger must be designed in a way as not to produce significant losses of charged particles while ions on the other side must not be carried out of the charger since they would produce erroneous readings.

Theory and practice of corona diffusion charging at low flow rates is well developed and widely used in particle mobility analysis. (see e.g. /7/)

PERFORMANCE

Flow control

The mass flow rate can be calculated from first principles as described above and agrees very well with the experiments as shown in Fig. 1.

The mass flow rate $\dot{m}$ is uniquely determined by the ambient conditions p_0, T_0 and the pressure drop Δp_i inside the impactor up to stage i via a „set value" defined as $SV_i = \frac{p_0 \cdot \Delta p_i}{T_0 \cdot 10^4}$ (with pressures in Pascal and temperature in Kelvin); measuring and maintaining it at a preset value provides an economic way of *ab initio flow control* rendering further flow calibration unnecessary. Also, this method does not depend on the amount already collected in contrast to the

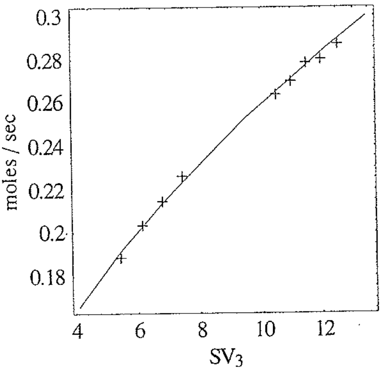

Fig. 1: *Mass flow rate as a function of set value SV_3.(see text) +: experimental values as determined by bellow gas meter under different temperature and pressure conditions. Right data cluster: „hi-flo" mode without last impaction stage; Left data cluster: „hi-res" mode with last impaction stage. Solid curve: ab initio compressible gas dynamics calculations.*

pressure drop of a filter which depends on the loading. Depending on the sign and magnitude of the difference, the turbine is powered with a higher or lower frequency of the 3 phases produced in the frequency transformer of the electronics box. The control algorithm is of PID type and assures perfect total sampling volume even after long time intervals.

Impaction stage calibration

The impactor stage calibration was performed by comparing downstream and upstream concentration using a TSI APS3320. The results for stage 5 are shown in Fig. 2. The critical Stokes number is smaller than reported in the literature for circular hole and is right in between slit nozzles and circular nozzles, probably due to the close circular nozzle arrangement.

Corona charger

The corona charger uses a 100 µm tungsten wire of 10 cm length in a 3.5 cm radius primary discharge unit consisting of perforated sheet metal (inner charging electrode) through which ions are diffusing to the outer charging electrode of 5 cm radius. The charging electrodes are connected by a 10 $G\Omega$ resistor which provides defined discharge conditions together with the

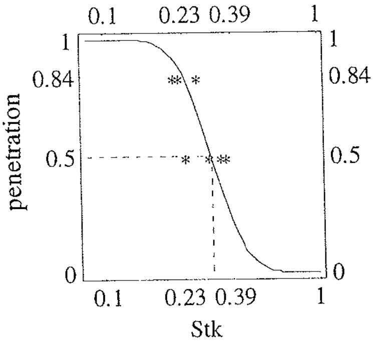

Fig. 2: *Stokes number vs. penetration of stage 5 as experimentally determined. The experimentally determined critical Stokes number is 0.31 and designated by the dashed lines.*

corona voltage drop. Ions are deposited a short distance downstream while charged particles are carried without significant losses into the impactor following the charging section.

The experimentally determined wire current as a function of applied (positive) voltage is shown in Fig. 5 (last page). Corona onset voltage depends on pressure and humidity and ranges around 6160 V. Typical calculated Nt-products for particle charging range around $3 \cdot 10^{13}$ $ions \cdot s / m^3$. The impaction stages together with the electrometer box are shown in Fig. 3.

EXAMPLE RESULTS

An example for the temporal response to MIRA G3 dust is shown in Fig. 4. It clearly demonstrates the quick response and the size-resolution capability.

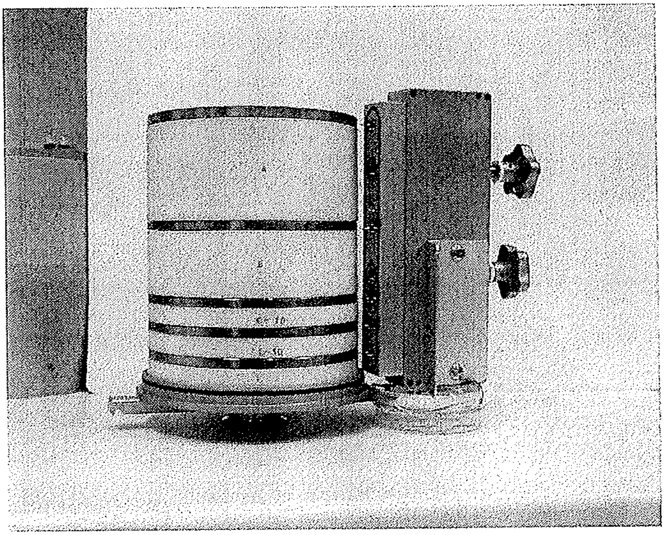

Fig. 3: *View of the impactor (without housing) and the electrometer box.*

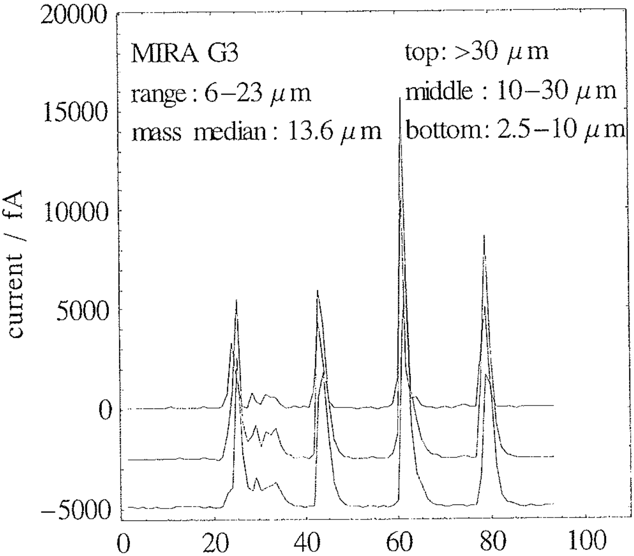

Fig. 4: *Time response to short concentration spikes of MIRA G3 dust. Curves are vertically shifted in order to improve visibility.*

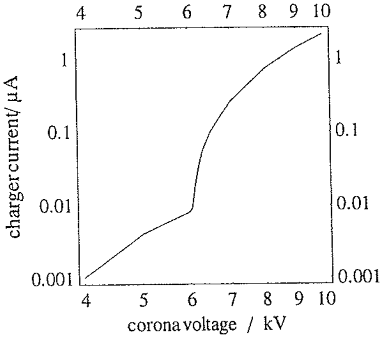

Fig. 5: *Corona wire current as a function of applied voltage. The corona onset is clearly visible at 6160V.*

CONCLUSIONS

It has been demonstrated that

- mass flow control based on ab initio calculations works well
- operation at different measuring regimes was implemented in a user-friendly way
- electrical detection works with high time resolution.

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Aerosol particle concentration and size distribution measurements of test-fires as a background for fire detector modelling

Abstract

For modelling of fire detectors the precise knowledge of those smoke characteristics affecting the detector is necessary. The particle concentration and size distribution, the temperature and the flow pattern of gases belong to these characteristics. While the computerized fluid dynamic (CFD) method simulates the gas flow and the propagation of the temperature in the volume, appropriate models for the particle behavior are missing. The processes taking place during smoke particle transport like coagulation, condensation, and evaporation, are not described by the CFD models so far. So it makes sence for improving the models to run measurement programs to collect appropriate data about the missing parameters with suitable time resolution. The paper describes such measurements in the particle diameter range of 3 nm to 10 µm and with a time resolution down to 4 seconds with the analyses of the results. A brief description of measuring instruments is also provided.

Introduction

Most of commonly used fire detectors react on some physical properties of aerosol generated by fires (light scattering, absorbing of air ions, etc.). These properties depend on the total concentration of particles in the aerosol as well as on their size distribution. Hereby, knowledge about the fire aerosol size distribution (size spectrum) and its numerical parameters is essential for the correct modelling of fire detectors. Conventional CFD models give information about the temperature and the smoke density only. Therefore a systematic investigation of the size distribution of aerosols generated by fires is necessary. As a source for such aerosols different test-fires can be used, which are defined as an European Standard (EN54/9, Klose et al., 1991; Fischer et al., 1993). Helsper et al. (1980) investigated the particle size distribution of European test-fires. That study was made with insufficient time resolution and particle size range (the lower limit of the particle diameter was 10 nm). The new technical possibilities allow to perform this study on a higher level of particle size range and time resolution.

Measurement set-up

The experiments were carried out in the fire detection laboratory of the Department of Communication Engineering at the Gerhard-Mercator-University in Duisburg. The laboratory has an area of approximately 100 m^2 according to the European Standard EN 54 part 9. The height of the ceiling is adjustable and most test-fires are made with the standard ceiling height of 4 m. The measurement set-ups are installed on the ceiling on the 3 meter radius around the vertical line going through the fire place on the floor, and they suck the smoke aerosol via short pipes from the laboratory (see EN54/9). Several typical devices like MIREX (smoke density measurement device based on the light extinction principle), MIC (Measurement Ionisation Chamber) and temperature sensors are used in parallel. Gas components (CO, CO_2) also have been monitored. With these systems a comprehensive control of the fire experiments becomes possible.

Instrumentation

Two aerosol spectrometers were used in this study in parallel: an Parametric Charging Particle Analyzer (PCPA) developed at the Department of Communication Engineering of Duisburg University, and an Electrical Aerosol Spectrometer (EAS) developed at the Institute of Environmental Physics of the University of Tartu (Estonia). Besides, a condensation particle counter (CPC, TSI model 3020) was used for determination of the total number concentration of particles with diameterd_p>10 nm.

a) PCPA

The Parametric Charging Particle Analyzer is a sequentially working device using the well known correlation between particle size and number of charges on the particle surface after a charging process in a definit environment. The measurement principle is an integral one, i.e. it uses the whole aerosol for creating the measurement values. It is different from the fractionating ones, which separate the particles in distinguishable classes (size, mobility etc.). Thus after an implemented unipolar charging procedure (Sievert, Luck, 1993; Sievert, 1998) the PCPA determines the total number of charges on the polydisperse aerosol per volume. For the back calculation of the particle size distribution a series of several charge measurements (one after another) with different charging conditions is performed. The good sensitivity of the device, which is due to the incorporation of all particles for each measurement, is coupled with some dynamic error if the size distribution changes during one measurement-series. The current software uses a set of 10 measurement results with different charging conditions, in which each measurement takes 2 seconds including offset correction. The reconstruction of the associated particle size distribution bases on the inversion of a Fredholm integral equation (Beckord et al., 1993; Beckord, 1995; Franken, 1997). The result is presented using predetermined values of the particle diameter in the range from 1 nm to 1500nm in 1500 points. The determination of the particle size distribution is stable and reliable and takes appox. 10 min. Faster procedures are in preparation.

b) EAS

An Electrical Aerosol Spectrometer (EAS) with a wide measurement range (particle diameter d_p= 10 nm - 10 μm) has been developed at the Department of Environmental Physics of the University of Tartu in the 1970s and 1980s (Mirme et al., 1981; Mirme et al., 1984; Kikas et al., 1996). It is a multi-channel instrument using parallel measurement principle. All the channel signals are collected in parallel and the signal means over collection time are measured. So the dynamic measurement errors are minimized (Mirme, Tamm, 1991), and the measured distribution (spectrum) is the estimated mean over signal collection time. Parallel measurement principle enables to achieve a high time resolution. If particle concentration is high enough (the case which appears always by fire aerosols) the lower limit for the spectrum measurement time is the travelling period of the aerosol through the spectrometer of about one second. The wide particle size range is achieved by using two mobility analysers with two different unipolar chargers: diffusion and field charging ones. Cylindrical collecting electrodes of the mobility analysers are divided into ring-shaped isolated sections, each of them is provided with its own electrometer for measurement of the electric current carried by the particles precipitating to this section.

An essential advantage of EAS is the covering of the wide measurement range by one measurement principle, therefore for all particles the same equivalent diameter (close to Stokes' diameter) is measured. Experimental calibration procedure with standard aerosols (Mirme, Tamm, 1993) enables to convert channel signals to particle size spectrum by a simple, mathematically strict, linear inversion procedure. Particle size spectrum can be presented in the form of distribution density function or as a set of fraction concentrations, in both cases of number, surface or volume (as a standard, 12 fractions, the limits of which are distributed uniformly on a logarithmic scale of particle diameters: 4 fractions per decade, see Fig. 4). Random measurement errors of output data are calculated and recorded.

For this study, EAS was rebuilt. By adding of new sections to the mobility analyser with diffusion charger, the lower limit of the measurement range of the particle diameter was shifted down to 3.2 nm. Now standard record of the spectrum contains 14 fractions.

Short measurement time was not required for aerosol measurements so far. In the context of this study it becomes favourable to improve the time resolution. Therefore a new software has been developed for measurement process control, which enables to realize a time resolution of 4 sec for one spectrum recording. It enables to follow the very quick particle spectrum development.

EAS was operated during the experiments in a way that an instrument regime parameters test as well as an electrometers offset level test was made just before the ignition of the fire. Next approximately 200 spectra records were collected in the memory of the computer and then stored to disk after the next instrument test. In case of need the monitoring of spectrum could be continued. The aerosol was diluted with an injection type diluter driven by compressed clean air. The dilution factor ranged from 1.4 to 150, depending on the fire type.

Data acquisition

At least three experiments were made for each test-fire (Table 1) in standard conditions (4 m ceiling height, inlet 5 m from the fire place (see paragraph Measurement set-up)). The aerosol spectrum was recorded by the PCPA and the EAS, and the total number

Test-fire	*Firetype*	*Material*
TF1	*open cellulose fire (wood)*	*27 beechwood sticks, 1*2*25 cm^3*
TF2	*smoldering pyrolysis (cellulosic)*	*24 beechwood sticks, 1*2*3.5 cm^3*
TF3	*smoldering fire (cotton)*	*90 cotton fuses, 3g, 80 cm*
TF4	*open plastic fire (polyurethan)*	*3 mats of polyurethan, 50*50*2 cm^3*
TF5	*liquid fire (n-heptan)*	*650 g n-heptan, 3 Vol.% toluen*
TF6	*liquid fire (ethanol)*	*2000 g methylated spirits*
	liquid fire (decalin)	*170 g decalin, 5 g methylated spirits*

Table 1: Test fires according to EN 54, part 9.

concentration by the CPC, from the moment of the ignition of the fire at least up to cease of the fire, usually a little longer. The cotton smoldering fire (TF3) continues very long time, and the aerosol spectrum do not change significally after some initial period, therefore the recording of the data usually was finished before the end of the fire in this particular case. For investigation of the possible changes in the particle size distribution according to the volume of the fire laboratory and according to the distance between the fire place (aerosol source location) and the instruments inlet, one experiment for each test-fire was made under extreme conditions (6 m ceiling height, inlet distance 8.1 m from the fire place).

The EAS recorded a spectrum every 4 seconds. The PCPA performed a measurement every 20 sec and the number concentration was monitored by the CPC every 2 sec.

Results

For the investigation of the reproducibility of the test-fires, in Fig.1 the time variation of the total number concentration obtained as the sum of fraction concentrations measured by the EAS, for three experiments using open wood fire (TF1) is depicted. Experiments TF1-490 and TF1-491 were made in standard conditions, experiment TF1-506 correspond to extreme conditions. Open wood fire, as all the flaming fires, is comparably well reproducible. In standard conditions, the difference between the values of total number concentration at the same time instant measured from the ignition moment do not exceed 15% in different experiments in the vicinity of the maximum concentration. For other flaming test fires, the difference can reach 30% (TF4-polyurethan fire).

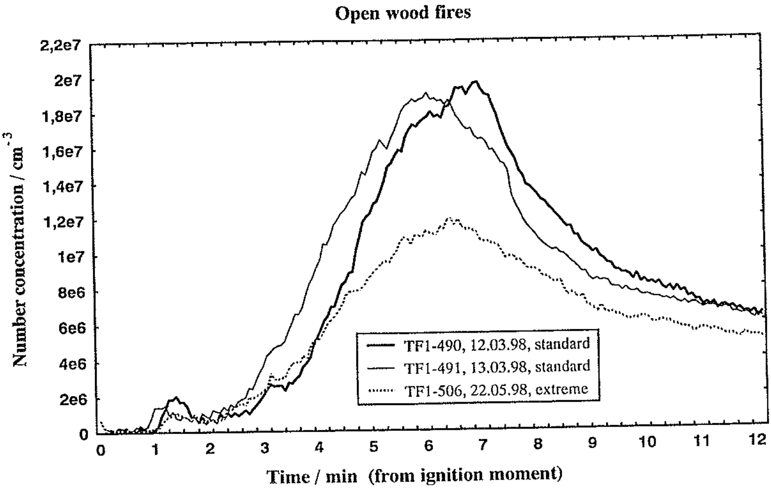

Fig. 1: Total number concentration of particles measured by EAS for three TF1 experiments: No.TF1- 490 and TF1-491 were made at ceiling height of 4m, No. TF1-506 at 6 meter.

Reproducibility of smoldering fires is worse. For cotton fires (TF3, see Fig. 3), the difference can reach 40%. Smoldering wood fire (TF2) is characterized by appearing a small flame just before the end of the burning process (Fig.2). The time interval between the start of heating and the flame appearance varies from 11,5 min to 15 min.

Under the extreme condition the maximum of the total particle number concentration is approximately 40% lower for all fires.

Time variation curves of the total number concentration for quickly developing flaming fires are comparably smooth (see the example in Fig.1). The same curves for smoldering fires are characterized by large fluctuations (Fig. 3). Smoldering fire with low temperature causes no essential convection to mix the air well enough. For this reason moving air parcels with different particle concentrations exist and cause recognizable fluctuations at the particle concentration measurement. The fluctations in the geometric mean radius (Fig. 2) indicate that the particle size distribution is different within different air parcels.

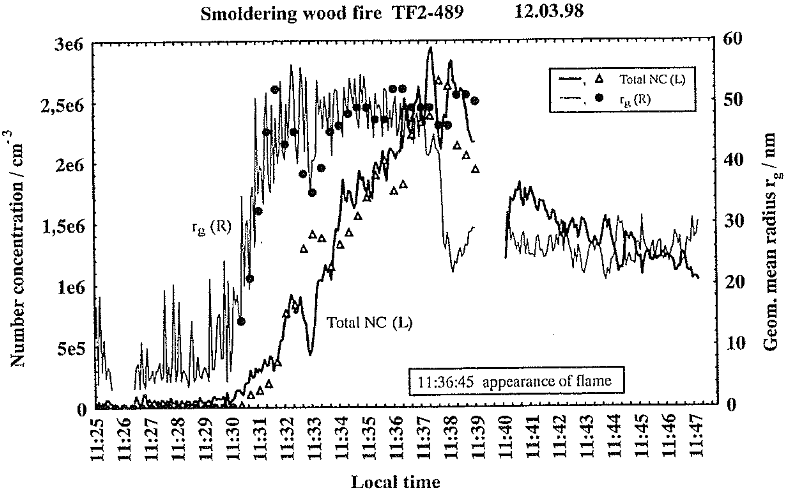

Fig. 2: Total number concentration and geometric mean radius of particles measured by EAS (solid lines) and PCPA (dots) for smoldering wood (TF2), ceiling height = 4 m.

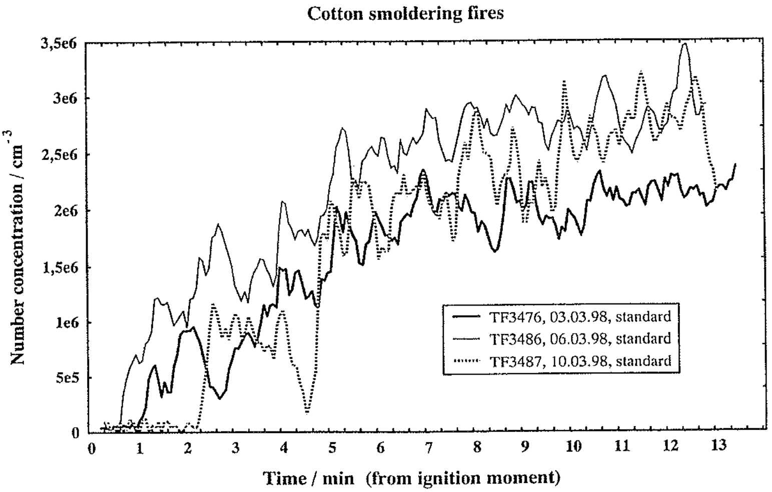

Fig. 3: Typical total number concentration for smoldering cotton TF3.

Considering the dynamics of particle size spectrum all the fires, except the alcohol fire (TF6), can be characterized by the existance of a stable, nearly log-normal shaped component in the number spectrum with the modal point at 75 nm. This „self-preserving„ central component (CC) of the spectrum develops during the first 1-4 min after ignition. Besides CC there seems to be an ultrafine (d_p<30nm) and a coarse (d_p>300nm) component which behave independently from the CC to some extent. As a general result it can be stated that spectra of test-fires differ from each other mainly due to the behaviour of these two components.

Open wood flaming fire. The ultrafine component is prevailing in number spectrum during the first two minutes. Then quite quickly the CC developes and from approximately the 8th minute coarse mode at 1300 nm begins to rise.

Smoldering wood fire. The CC develops during 3-4 first minutes after switching on the heating. At about the 8th minute the flame appears, and after that the ultrafine component begins to develop very quickly, so that the geometric mean diameter of the spectrum curve shifts from 100 nm to 50 nm (Fig.2). During all the time an additional mode at d_p=420 nm exists.

Cotton smoldering fire. The CC develops very quickly: during 1-2 min, but stabilises finally during 6-7 min. Approximately at the 10th min the dramatic rise of smallest particles (d_p=4.2 nm) begins accompanied by a dramatic concentration decrease of particles in the range of d_p=13 nm and also of particles with d_p>3000 nm.

Polyurethan flaming fire. CC developes during 1-2 min, accompanied by an estimated weak modes in the diameter range of 420 nm to 1300 nm. Comparably high concentration of ultrafine particles during the first 4 min drops from the 5th min.

n-heptane flaming fire. CC is high from very beginning and develops comparatively few. Weak mode at d_p=1300 nm is noticeable. The quick concentration decrease in the diameter range of 10 nm and larger than 3000 nm begins after the 3rd min.

Decaline flaming fire. CC rises quickly during the first 3 min and continues to grow slowly. Concentration of the ultrafine component remains all the time practically constant on quite high level, weak modes in the diameter range of 420 nm to 1300 nm can be estimated.

All the characteristic features in the development of test-fires particle size spectra described above can be explained by the processes of nucleation, condensational growth and coagulation of particles. The time scale of the processes evidently reflects the turbulent air movement pattern in laboratory.

Aerosol size spectrum of the alcohol fire (TF6) behaves quite differently from all other test-fires. During the first 6 min a component similar to CC, but with the mode at a diameter of 42 nm slowly rises. In parallel to that the concentration of particles with d_p>240 nm is also increasing. Approximately from the beginning of the 7th min very intensive generation of particles begins, and the concentration of the ultrafine component raises dramatically (Fig. 4). This event is correlated with the air temperature above the flame: the nucleation of particles increases dramatically, when the temperature drops.

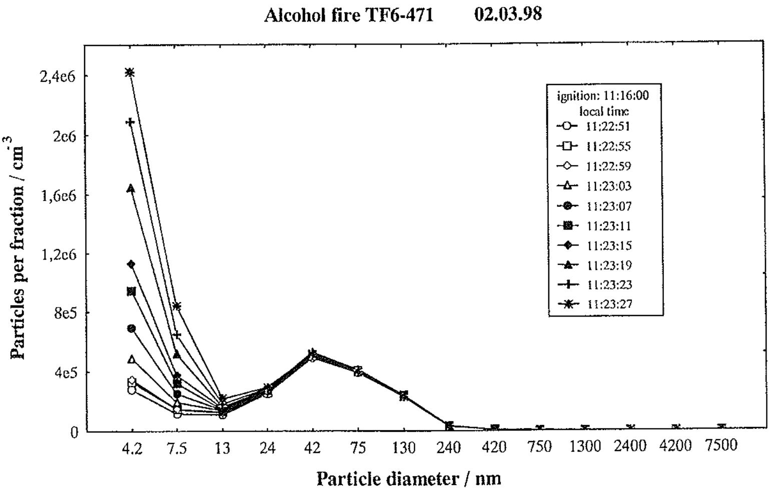

Fig. 4: Particle number spectra of alcohol fire (TF6), measured every 4 sec after beginning of the intensive nucleation.

Acknowledgement

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Messung der elektrischen Ladung bei Testbränden

Abstract

A fire burning with visible flames produces electrically charged particles. A measuring instrument was built for that purpose. This instrument is introduced and theoretically described; the measurement results are discussed. Futhermore, a low current from the fire place to earth is supposed and verified in experiment.

Das Prinzip

Bei einem Feuer entstehen Partikel in einem weit verteilten Größenbereich in hohen Konzentrationen. Aufgrund des Prozesses der Flammenionisation sind die Partikel elektrisch geladen. In der Literatur (z.B. [1, 2, 3]) wird angegeben, daß für den Mittelwert des Quadrats der Ladung q auf den Partikeln gilt:

$$\overline{q^2} \sim rT \tag{1}$$

Hierin ist r der Radius eines als kugelförmig angenommenen Partikels und T die absolute Temperatur. Diese Beziehung gilt für sehr kleine Partikel nicht mehr (siehe [1, 2]), doch im Prinzip läßt sich sagen, selbst dann, wenn die Partikel nicht mehr als kugelförmig angenommen werden können, daß

1. größere Partikel im Mittel mehr Ladungen tragen als kleinere, und
2. mehr Ladungen auf den Partikeln vorzufinden sind bzw. mehr Partikel überhaupt geladen sind, je heißer das Feuer brennt.

Über das Vorzeichen der Ladungen kann an dieser Stelle nichts ausgesagt werden; lediglich die Summe aller Ladungen muß aufgrund des Ladungsgleichgewichts Null ergeben. Es ist weiterhin denkbar, daß eine Unsymmetrie im Aufladevorgang unterschiedlich viele positive als negative Ladungen auf die Partikel aufbringt, so daß die Differenz zu einem Ausgleichsstrom zwischen Brandmaterial und Erde führt.

Geladene Teilchen auf dem Weg zum Meßgerät

Ein direkter Zusammenhang zwischen der Ladung auf Partikeln und der Temperatur der Flamme gilt streng genommen nur in unmittelbarer Nähe der Flamme. Die in einiger Entfernung von der Flamme vorhandene Ladung ist prinzipiell geringer.

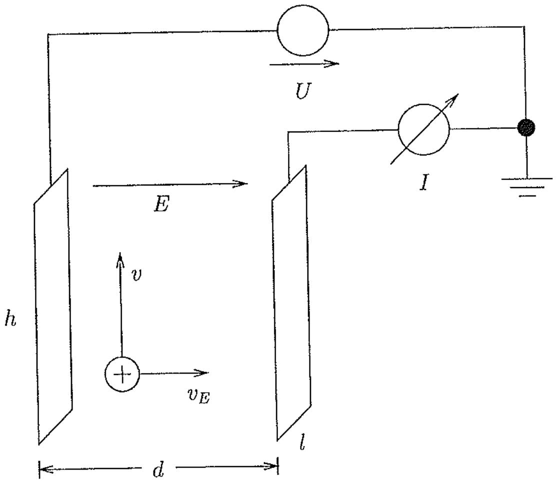

Abbildung 1: Meßgerät zur Ladungsmessung

Die Ursachen hierfür sind in Wechselwirkungen der Partikel untereinander und der Partikel mit der Umgebung zu suchen (z.B. Koagulation, Sedimentation). Diese Einflüsse sollen hier aber nicht diskutiert werden.

Auch hier ist es denkbar, daß eine Unsymmetrie im Transportvorgang dazu führt, daß nicht gleich viele negative wie positive Ladungen von der Flamme in den Raum transportiert werden. Daraus muß wiederum ein Ausgleichsstrom zwischen der Feuerstelle und Erde resultieren.

Das Meßgerät

Das verwendete Meßgerät (Abb. 1) zur Messung der Ladungen besteht im Prinzip aus zwei gegenüberliegenden, elektrisch leitenden Platten. Eine der beiden Platten wird als Ablenkelektrode, die andere als Meßelektrode bezeichnet. Zwischen den Platten wird durch eine Konstantspannungsquelle ein elektrisches Feld E mit

$$E = \frac{U}{d} \qquad (2)$$

aufgebaut. Der Teil des zur Aufrechterhaltung des elektrischen Felds nötigen Ausgleichstroms, der zwischen Erde und der sogenannten Meßelektrode fließt, wird gemessen. Er stellt ein Maß für die an der Meßelektrode abgeschiedenen Ladungen *einer Polarität* dar.

Das Meßprinzip selbst beruht darauf, daß ein geladenes Teilchen geeigneter Polarität, das aufgrund der strömenden Luft mit der Geschwindigkeit v zwischen die Platten gerät, durch das elektrische Feld E in Richtung der Meßelektrode mit der Geschwindigkeit v_E mit

$$v_E = bE \tag{3}$$

bewegt wird. Die Größe b stellt die elektrische Beweglichkeit des Teilchens dar. Sobald das Teilchen die Meßelektrode berührt, gibt es dort seine Ladung ab und verursacht einen Stromfluß.

Diese Überlegung gilt im Prinzip für beide Elektroden; aufgrund der Art der Erdung der Meßapparatur wird aber nur derjenige Strom gemessen, der von Teilchen verursacht wird, die ihre Ladung an die Meßelektrode abgeben. Diese sind nur Teilchen *einer Polarität*, in Abhängigkeit von der Polarität der Spannung U.

Für die weiteren Rechnungen sei $U > 0$ vorausgesetzt, so daß positive Ladungen gemessen werden. Die Rechnungen gelten im Prinzip genauso für negative Ladungen, wenn man die Spannungsquelle umpolt.

Das Gerät selbst mißt eine Größe, die sich zusammensetzt aus der Ladung eines Teilchens q_T, die bei vereinfachender Annahme von kugelförmigen Teilchen vom Radius r abhängt, der Anzahl der Partikel N im Meßvolumen, die ebenfalls je nach Partikelgröße variieren kann, sowie der Wahrscheinlichkeit P_D, daß ein Partikel dieser Art tatsächlich detektiert wird, und einer Konstanten K:

$$i = K \int_{r=0}^{\infty} P_D(r) q_T(r) \mathrm{d}N(r) \tag{4}$$

Im allgemeinen, d.h. wenn man keine kugelförmige Gestalt der Partikel voraussetzt, kann r als ein verallgemeinertes Größenmaß betrachtet werden, so daß der Zusammenhang im Prinzip nach wie vor gilt.

In $N(r)$ findet sich der Einfluß der Partikelgrößenverteilung.

Die Konstante K kann angegeben werden als Integral über die Eintrittsgeschwindigkeit v der Partikel bzw. der Strömung auf der Fläche der Eintrittsöffnung A:

$$K = \int_A v \mathrm{d}A \tag{5}$$

Wenn man vereinfachend annimmt, daß die Strömungsgeschwindigkeit unabhängig vom Ort ist, ergibt sich

$$K = Av = ldv \tag{6}$$

Die Wahrscheinlichkeit, daß ein Teilchen detektiert, d.h. an der Meßelektrode abgeschieden wird, $P_D(r)$, kann, ebenfalls vereinfacht, als

$$P_D(r) = \min\left\{\frac{b(r)Uh}{vd^2}; 1\right\} \tag{7}$$

angegeben werden. Diese setzt sich zusammen aus der elektrischen Beweglichkeit b der Partikel, die u.a. von der Partikelgröße r abhängt, der Spannung U, der Strömungsgeschwindigkeit v des Aerosols durch das Meßgerät, und geometrischen Abmessungen (h,d) des Meßgeräts selbst.

Insbesondere fällt auf, daß Teilchen mit einer Beweglichkeit b, für die gilt

$$b \geq \frac{vd^2}{Uh} \tag{8}$$

zu 100% detektiert und somit aus dem Aerosol herausgefiltert werden. Dies beschreibt einen Sättigungseffekt (siehe [5]).

Setzt man nun voraus, daß das Gerät nicht im Sättigungsbereich betrieben wird und daß nur eine Partikelgröße $r = R$ vorherrscht, so ergibt sich:

$$i = \frac{lh}{d} U b q_T N \tag{9}$$

Im Sättigungsbereich ergibt sich jedoch, ebenfalls nur eine Partikelgröße $r = R$ vorausgesetzt:

$$i = l d q_T N v \tag{10}$$

Es sei darauf hingewiesen, daß diese Gleichung eine explizite Abhängigkeit von der Strömungsgeschwindigkeit v beinhaltet.

Ob man im Sättigungsbereich messen will oder nicht, läßt sich u.U. bei Vorkenntnissen über die auftretenden Beweglichkeiten, d.h. indirekt über die Partikelgrößenverteilung, entsprechend Ungleichung (8) durch geeignete Wahl der Spannung U festlegen. Da die Beweglichkeiten und Partikelgrößen jedoch bei einem Feuer in weiten Bereichen streuen, ist eine scharfe Trennung kaum möglich.

In einer weiteren Abschätzung kann P_D angenähert werden durch

$$P_D \approx \begin{cases} 1, & \frac{bUh}{vd^2} \geq \frac{1}{2} \\ 0, & \text{sonst} \end{cases} \tag{11}$$

Bei Annahme eines Zusammenhangs (vgl. [6])

$$b(r) = c\frac{1}{r} \tag{12}$$

führt Gleichung (4) unter Verwendung von Ungleichung (8) auf

$$i = K \int_{r=0}^{r_0} q_T(r) \mathrm{d}N(r) \tag{13}$$

mit

$$r_0 = 2c\frac{Uh}{vd^2} \tag{14}$$

Das bedeutet, daß nur Partikel kleiner als r_0 eine wesentliche Rolle spielen. Damit ist gezeigt, daß das Meßgerät im Wesentlichen auf *kleine* geladene Partikel reagiert.

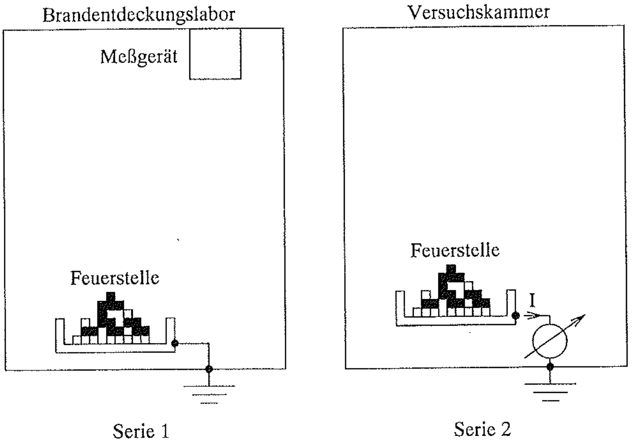

Abbildung 2: Meßanordnungen

Meßergebnisse

Es wurden zwei Serien von Messungen durchgeführt (Bild 2):

1. Messungen mit Testfeuern 1, 2 und 6 nach EN54/9 mit oben beschriebenem Meßgerät und
2. Messungen des Ausgleichsstroms zwischen Feuerstelle und Erde in einer elektromagnetisch abgeschirmten Versuchskammer mit ca. $80 dm^3$ Volumen.

Testfeuer 1 nach EN54/9 (offenes Holzfeuer)

Dieses Testfeuer wurde wie die beiden nachfolgenden im Brandentdeckungslabor des Fachgebiets Nachrichtentechnik bei einer Deckenhöhe von 4m durchgeführt. Die Messungen fanden auf dem 3m-Kreis mit dem oben beschriebenen Meßgerät statt. Zusätzlich wurde die Luftströmung durch das Meßgerät mit einem geeigneten Instrument gemessen und aufgezeichnet. Bild 3 zeigt die Anfangsphase (etwa die ersten 5 Minuten) des Testfeuers. Die tendenzielle Übereinstimmung der Meßkurven für den den Ladungstransport beschreibenden Strom i und die Strömungsgeschwindigkeit v bestätigt einen Zusammenhang $i \sim v$. Da jedoch die weiteren Größen in Gl. 4 ff. nicht zeitlich konstant sind, können die Kurven nicht exakt übereinander gelegt werden.

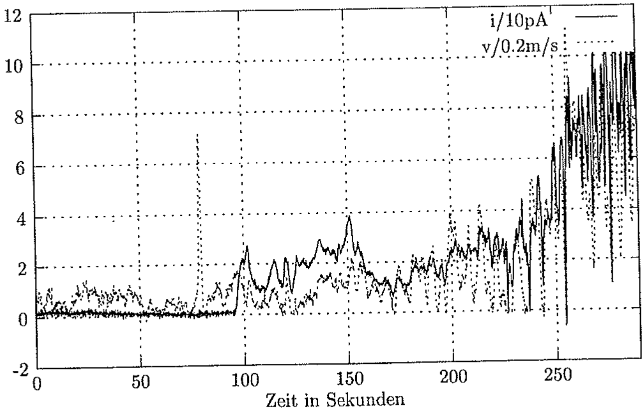

Abbildung 3: Testfeuer 1 (offenes Holzfeuer)

Testfeuer 2 nach EN54/9 (Holzschwelbrand)

Der Holzschwelbrand zeigt, solange das Holz nur schwelt, so gut wie keinen Einfluß auf das Meßergebnis (Bild 4). Der wellenförmige Verlauf rührt von Eindringen von Wind von außen in den Versuchsraum her (das Labor besitzt eine offenbar nicht völlig dichte Außentüre). Die Messung ist hier zusätzlich um den Faktor 10 verstärkt wiedergegeben. Einzig der Zeitpunkt, zu dem sich das schwelende Holz entzündet, ist bei etwa 740s deutlich zu erkennen.

Testfeuer 6 nach EN54/9 (Spiritusfeuer)

Das Spiritusfeuer zeigt von den durchgeführten Versuchen die größte Strömungsgeschwindigkeit und den höchsten Ladungstransport (Bild 5).

Papierfeuer in Versuchskammer

Die folgenden drei Versuche, in denen der Ausgleichsstrom zwischen Feuerstelle und Erde gemessen wurde, mußten in einer abgeschirmten Versuchskammer durchgeführt werden, um Störeinflüsse (z.B. 50Hz-Einstreuung vom Lichtnetz) zu vermeiden. Bild 6 zeigt das Meßergebnis für ein brennendes Stück leicht zusammengeknüllten Papiers. In der Anfangsphase (bis ca. 100s) brennt das Papier noch nicht richtig. Hier beobachtet man einen Ausgleichsstrom mit positivem Vorzeichen. Danach, wenn das Papier mit großer Flamme brennt, wird der Ausgleichstrom negativ.

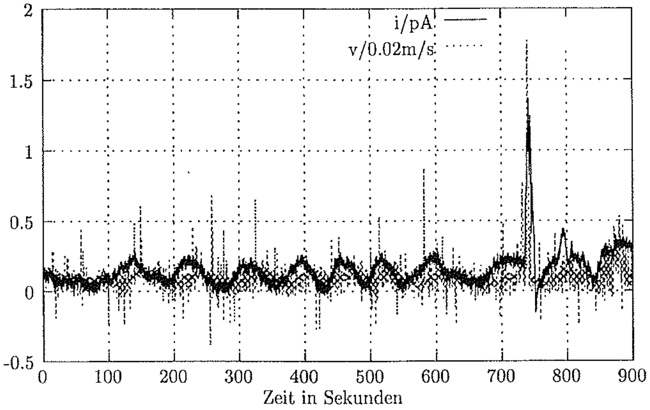

Abbildung 4: Testfeuer 2 (Holzschwelbrand)

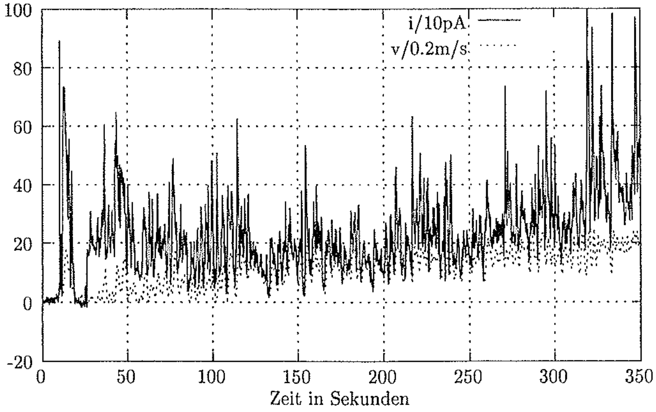

Abbildung 5: Testfeuer 6 (Spiritusfeuer)

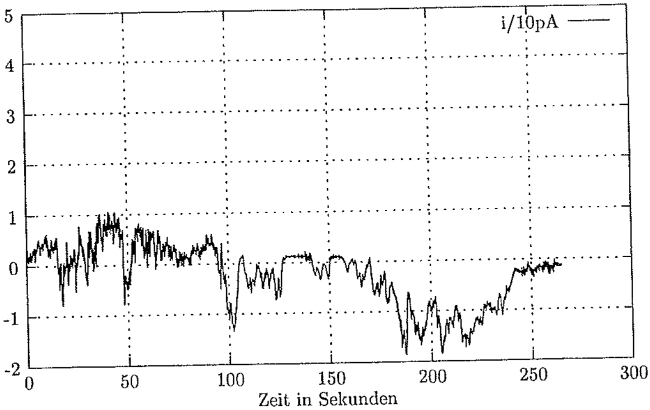

Abbildung 6: Papierfeuer in Versuchskammer

Spiritusfeuer in Versuchskammer

Das Experiment wurde mit Spiritus wiederholt (Bild 7). Es zeigt sich, daß durchweg ein im Vergleich zu den anderen Versuchen dieser Serie hoher, positiver Ausgleichsstrom fließt. Hierbei sei noch einmal deutlich darauf hingewiesen, daß das Vorzeichen des Stroms entgegengesetzt zu dem beim stark brennenden Papier ist.

Holzfeuer in Versuchskammer

Das Holzfeuer wurde mit Hilfe von Spiritus gezündet. Der zeitliche Verlauf des Ausgleichsstroms (Bild 8) zeigt deutlich, daß bis ca. 80s nach dem Start der Messung nur der Spiritus brannte (deutlich positiver Ausgleichsstrom). Ab etwa 80s beginnt das Holz zu brennen. Bei ca. 180s ist der Spiritus vollständig verbrannt und es brennt nur noch das Holz (negativer Ausgleichsstrom).

Schlußfolgerungen

Die Ergebnisse zeigen, daß das vorgestellte und theoretisch beschriebene Meßgerät prinzipiell zur Ladungsmessung bei Testbränden geeignet ist. Weiterhin zeigen die Ergebnisse, daß bei Bränden nicht davon ausgegangen werden kann, daß auf den entstehenden Partikeln exaktes Ladungsgleichgewicht herrscht. Vielmehr muß ein Ausgleichsstrom zwischen Feuerstelle und Erde in die Ladungsbilanz mit einbezogen werden.

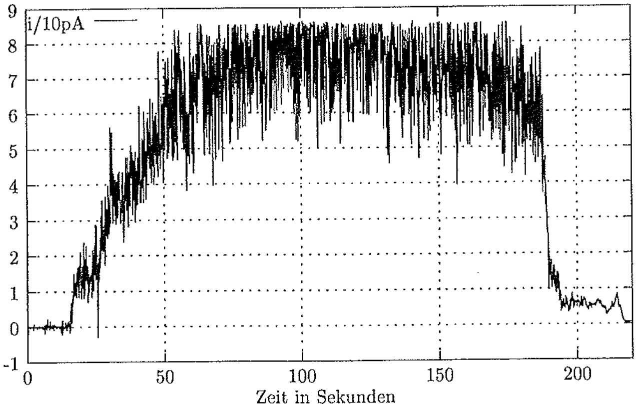

Abbildung 7: Spiritusfeuer in Versuchskammer

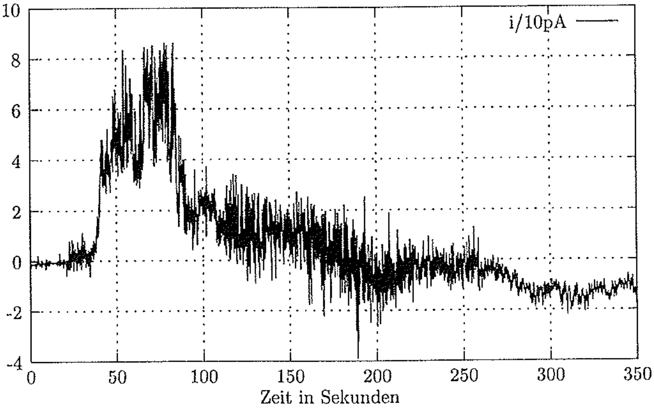

Abbildung 8: Holzfeuer in Versuchskammer

Die Ergebnisse bezüglich des Ausgleichsstroms zwischen Feuerstelle und Erde legen die Vermutung nahe, daß mit zwei Messungen, nämlich einmal einer Messung der positiven und gleichzeitig einer Messung der negativen Ladung auf den beim Brand entstehenden Partikeln aus den Unterschieden der beiden Messungen auf die Zusammensetzung des brennenden Materials geschlossen werden kann. Inwieweit dies tatsächlich möglich ist, bleibt noch zu untersuchen.

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A New Flame Detector using the latest Research on Flames and Fuzzy-Wavelet Algorithms.

Abstract

The detection of a fire with a flame detector relies upon the analysis of the flame flickering at several wavelengths. In order to improve the quality of the detection, a number of open questions have been addressed: What is the physical effect responsible for the flame pulsation of a diffusion flame? How does the main frequency depend on the location of the fire? How does a flame from a pool fire respond to air currents? We present new results that furnish a new insight into these questions. We have found out that the flickering spectrum of the flame possesses some features that permit to distinguish a flame from a potential source of false alarms. The new Waverex flame detector integrates these new results into the algorithms using a combination of wavelet and fuzzy techniques that has been developped in our laboratories.

1. Introduction:

It is well-known that, under laboratory conditions, a diffusion flame pulsates regularly with a frequency that depends essentially on the flame's diameter at its base. There are, nevertheless, a number of questions that have not been addressed experimentally and that are of central importance to flame detection:

-What is the main pulsation frequency for non-circular fire bases ?
-What happens if the fire develops close to a wall ?
-How does a flame respond to air currents ?

We have analyzed and modeled these problems, both under laboratory and real world conditions. The new „Waverex" flame detector integrates the obtained new results into the algorithms. The detection algorithms rely essentially on the combination of wavelet and fuzzy techniques, a method invented and patented by our laboratories, which is known today under the name „Fuzzy-wavelet“ [1]. In this detector, the light emitted by a flame is analyzed with 3 sensors working each at a different wavelength. The algorithms in the detector combine the informations obtained in the spectral domain with the results of a time-frequency analysis (Fuzzy-wavelet). The detector is capable with these new algorithms to recognize the fingerprint of a flame and to exclude possible false alarms due, for instance, to the flickering of the sun reflected on a water surface.

2. Dependance of the main pulsation frequency of a pool fire under different conditions.

2.1 Circular burner

Diffusion flames, jet flames and nonreacting flows of preheated helium [2-4] exhibit self-sustained low frequency oscillations (0.5-15 Hz) often described as flame flickering. For circular pool fires, a very simple empirical relation is found between the pulsation frequency f and the burner diameter D, provided that a single pulsation frequency f is dominant:

$$f = 1.5\ D^{-1/2}. \qquad (1)$$

2.2 Rectangular fire base

We have studied the dependance of the pulsation frequency of a flame as a function of the dimensions of a rectangular burner. Though studies of flames' height on rectangular burners have been carried out, we do not know of any study on the dependance of the pulsation frequency on the burner dimensions. We have found the pulsation frequency of a flame to be independent of the length of the burner l, as l was varied between w and 5w. The pulsation is in first approximation a function of the burner width only:

$$f = 1.25\, w^{-\frac{1}{2}} \tag{2}$$

This approximation is particularly good for large fires (w>10cm).

If the long side of the rectangular burner is adjacent to a wall (figure 1, left side), then the flame pulsates as if its width were 2w:

$$f = 1.25\, (2w)^{-\frac{1}{2}} \tag{3}$$

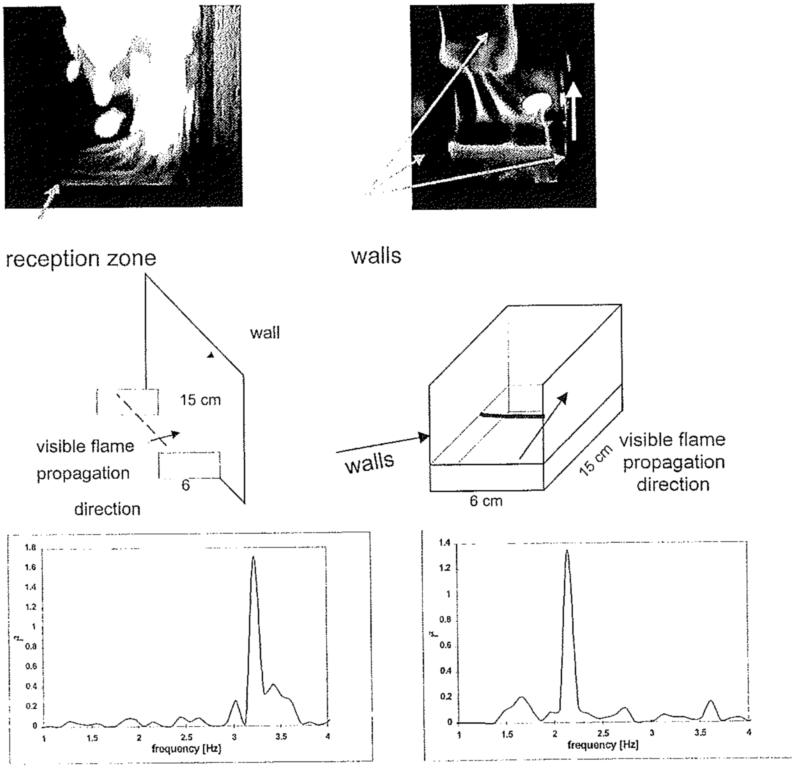


Figure 1: Left: The pulsation frequency of a flame against a wall is inversely proportional to the root of twice the burner's width. Right: The flame is confined through 3 walls and the pulsation frequency depends then on the burner length. A visible flame propagates almost horizontally close to the burner's surface.

We observe a strong correlation between the propagation direction of the visible flame close to the burner and the shedding frequency. In the configuration of figure 1 (left side), a visible flame is observed to form close to the burner rim (the reception zone) and to propagate into the direction of the wall, almost horizontally. In this configuration the main shedding frequency depends on the burner's width. If the burner is constrained with 3 walls (figure 1, right side), then the visible flame propagates along the long axis of the burner and the main shedding frequency is determined by the length of the burner (The shedding frequency of a 15x6 cm burner is, for instance, about 2.3 Hz. This corresponds with eq.(2) to the shedding frequency of a 15 cm wide burner). This suggests strongly that geometry is central to the understanding of the flickering of diffusion flames in pool fires.

3. A new explanation for the relationship relating the shedding frequency to the burner dimensions.

Theoretical predictions of the pulsation frequencies are generally based on scaling arguments [6]. To the best of our knowledge, no model or computer simulation gives a satisfactory physical explanation of the $D^{-1/2}$ dependence of the pulsation frequency as a function of the burner diameter D. The mechanism behind flame pulsation in pool fires is still considered as non-elucidated, an important open question in fluid dynamics [6] (In jet flames, the situation is different, model do predict correctly the pulsation frequency [4]. A Tollmien-Schlichting instability is at the origin of the instability). We assume that the main flickering frequency is the result of a resonance phenomena between the visible wave of wavelength λ [m] and the burner width: $\lambda = w$. Eq.(2) can be written:

$$f = 1.25\ \lambda^{-1/2} \tag{4}$$

which is almost equal to the relation

$$f\,[\mathrm{Hz}] = (g/2\pi)^{1/2}\,\lambda^{-1/2} \qquad (5)$$

Eq.(5) is the equation relating the wavelength to the frequency of a gravity wave. Is it a mere coincidence? We believe it is not. Let us recall first, that a gravity wave corresponds to a wave developping at the interface of two fluids of different density.

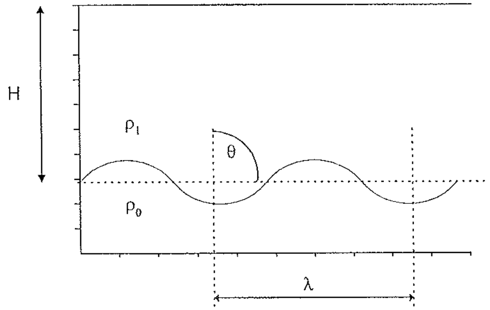
In a two layers model with the hot flame forming the first layer and the air supply forming the second layer (figure 2), the frequency of the internal gravity wave can be estimated from Euler's equation for inviscid flow (see [6] for justification of the inviscid approximation), together with the approximation that the flow is irrotational and the continuity equation:

$$\rho\, \partial \underline{u} / \partial t = -\underline{\nabla} p + \underline{g}\rho \qquad (6a)$$

$$\underline{\nabla u} = 0 \qquad (6b)$$

Looking for wavelike solutions, periodic in both space and time:
one obtains to the first order [7,8]

$$\omega = \sqrt{g k_x (\rho_1 - \rho_0) / \rho_1} \qquad (7)$$



if $\rho_1 >> \rho_0$ and $H > \lambda$ then

$$f = \frac{1.25}{\sqrt{\lambda}}$$

Figure 2: Explanatory sketch of a gravity wave

For $\rho_1 >> \rho_0$, eq.(7) corresponds to eq.(5). Let us estimate the error of estimating eq.(7) with eq.(5). The correction factor to eq.(5) due to the density is estimated to be of the order of 0.8. On the other hand, equating λ with w is also a rough estimate: λ of the order of ¾ w seems from video recording (figure 1) more realistic. This results into a correction factor of 1.15. Also, the gravity wave does not propagate perfectly horizontally. If the angle θ in figure 2 is different from 90°, eq.(7) is corrected by a factor $\sin(\theta)$ [7]. This leads to a correction factor of typically 1.1. Finally assuming $H > \lambda$ seems acceptable ($H = \lambda/2$ would result into a correction factor of 0.9). From the above discussion, we expect eq.(5) to describe a gravity wave at the interface between the hot flame and the cold air layer above it, within an error of ±20 % for a large fire.

In conclusion, we propose that the main shedding frequency is related to the propagation of a gravity wave. This gravity wave propagates almost horizontally close to the burner's surface. It triggers the development of the main puff, which as it raises amplifies the resonance mechanism through feedback coupling.

4. On the flame response to air currents.

Certainly one of the most important questions from the point of view of applications is how does a flame from a pool fire respond to air currents? In unwanted fires, air currents do often perturb the regular pulsation of the flame. Under real conditions, the flame becomes turbulent under the influence of strong air currents. We have analyzed and modeled this problem, both under laboratory and real world conditions. We have shown that an excited flame may be modeled as a parametrically forced van der Pol oscillator.

4.1 The model

We have found that a parametrically forced van der Pol oscillator describes qualitatively very well the behavior of flame from a pool fire excited by an external perturbation. The parametrically forced van der Pol oscillator is given by

$$X'' + \omega_0^2 X + b\,(X^2 - K)\,X' = (\text{external perturbation})\,X \qquad (8)$$

with X representing the measured signal radiation of the flame, ω_0^2, b, K constant that will assume to depend only on the burner dimension. The main idea behind this equation is to describe the regular flame pulsation of a flame with the prototype equation of a self-excited oscillator, namely the van der Pol oscillator. The effect of the external perturbation is found to couple parametrically through the term to the right. (This result is consistent with Markstein [5], that has shown that the coupling between a flame and acoustic wave in a tube is parametric). We have found out based on many real world experiments and on simulations with eq.(8) that the flickering spectrum of the flame possesses some features that permit to distinguish a flame from a potential source of false alarms. More specifically, we have shown that a flame perturbed by air currents has a number of features in its frequency spectrum that may be regarded as a fingerprint of a flame.

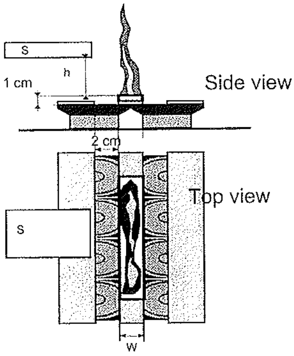
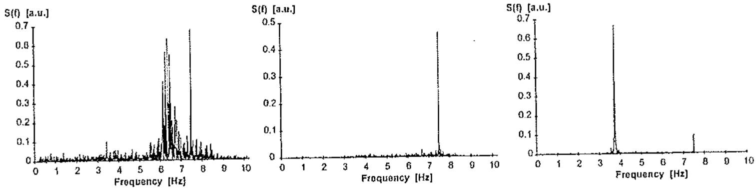


Figure 3: Sketch of the experimental configuration with the pyroelectric sensor S, measuring the flame radiation at a wavelength of 4.3 μm corresponding to a CO_2 emission line. The air flow is excited with vibrating membranes on each burner side (side view and top view).

This model predicts also a number of effects that could be verified experimentally, such as period doubling, nonlinear resonant effects and transitions to chaotic states. We will present two examples below as illustration.

Example 1: External perturbation = F sin ω t

A flame was perturbed with a number of vibrating membranes as sketched in figure 3. In the first example, the membrane vibrates at a single frequency. Depending on the amplitude of the acoustic excitation, the flame's pulsation frequency corresponds to its natural pulsation frequency or locks either on the excitation frequency or its subharmonic. At low excitation amplitude F, the power spectrum of the flame consists essentially of the power spectrum of the natural flame together with a peak at the excitation frequency (figure 4a). Figure 4b shows the flame response at a slightly higher excitation amplitude. The peak corresponding to the natural flame pulsation frequency has disappeared and the power spectrum has a very narrow resonance peak at the excitation frequency. Figure 4c shows the flame response at still higher excitation amplitude, the main resonance peak corresponds to half the excitation frequency. Period doubling is a characteristic feature of eq.(8) and the above described effect is well described by this equation.



a) b) c)

Figure 4: Power spectrum of an ethyl alcohol flame radiation in the experimental set-up of fig. 1 with a 6 cm wide burner and an excitation frequency of 7.6 Hz for increasing forcing (The amplitude F of the input signal to

the loudspeakers is used to quantify the excitation); a) low excitation (F= 2V), b) at the synchronization threshold (F= 4 V), c) above the threshold for period doubling (F= 12V).

Example 2: External perturbation = F (sin $\omega_1 t$ + sin $\omega_2 t$)

If the the flame is excited at two different frequencies, then the power spectrum essentially consists of peaks at integer or half integer multiples of f_a, f_b, f_b-f_a, $2f_a$-f_b. Figure 5 shows an example of a flame excited at two frequencies that are in a 4:5 ratio (10 Hz and 8 Hz). The peaks at 2 Hz, 4 Hz, 6 Hz correspond to integer multiples of 2 Hz. These effects are also well-described by eq.(8).

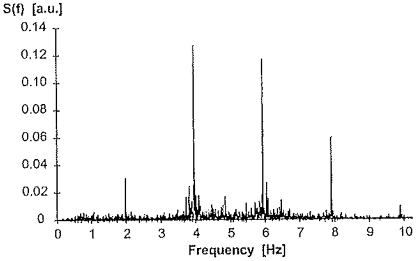


Figure 5: Power spectrum of an acoustically excited flame. The flame' s radiation is measured with a pyroelectric sensors at a height h= 9 cm above a 6 cm wide burner. The input signal to the loud-speakers is the sum of two sinusoidal perturbations of same amplitude and frequencies 8 Hz and 10 Hz.

5. Fuzzy-wavelets

The translation of the knowledge on flames into new powerful algorithms in the detector has taken much effort. In particular, it has been necessary to invent new techniques, called Fuzzy-wavelets. Fuzzy-wavelet techniques have been employed both during the development stage and also in the detector itself. Fuzzy-wavelet combines wavelet techniques with Fuzzy logic. Without the invention of these techniques, we can quite surely state, that it would have been very difficult to translate the latest research results on flame detection into performant algorithms.

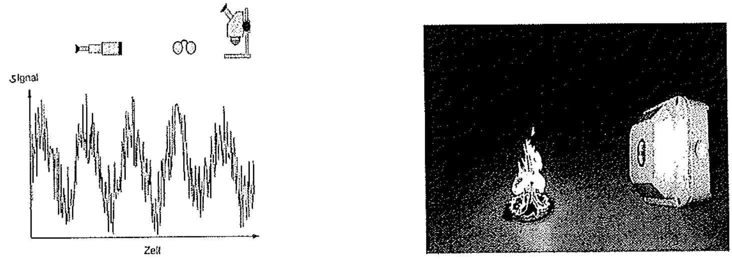


Figure 6: A wavelet decomposition consists of an analysis of a signal at different resolutions. The new Waverex flame detector combines fuzzy logic and wavelet techniques.

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Observation of Early Stage Fires by a Multi Spectrum Camera

1. Abstract

In National Research Institute of Fire and Disaster, data contributes to improve the technology of fire detection has being gathered by performing physical and chemical analysis of particles and gases and analysis of radiating situations of electromagnetic waves. These products of combustion and electromagnetic waves are generated by early fire when organic substances such as paper, lumber and plastics, which are causes of catching fire in many actual building fires, are under various conditions. For this study purpose, a new video camera system, that is purposed to monitor the light radiated from fire origin, has bee developed. The video camera system named 'Multi-Spectrum Camera System' is capable of monitoring and recording three different ranges, i.e. infrared range, visible range and ultraviolet range, without parallax and time delay. For the ease with extracting combustion area from infrared range image, basic consideration was made concerning fire detecting method using image processing, and summarized the concept of smoldering fire detection.

2. Introduction

Establishing the technology of early and reliable fire detection contributes greatly to improve secure life of citizens. For the purpose of improving technology of fire detection, in National Research Institute of Fire and Disaster, study of grasping and understanding the radiation of substances and forms of energy in early fire has being conducted. In this study, physical and chemical analysis of particles and gases, and analysis of energy radiating situations of sound waves and electromagnetic waves generated under various conditions in early fire by organic substances such as paper, lumber and plastics, which are causes of catching fire in many actual building fires, has being performed. Additionally, in tandem with this, application of the data from this research to new approach for detecting fire is under study.

This report introduces the Multi-Spectrum Camera System that is capable of monitoring radiation from fire origin in 3 different bands (infrared band, visible band and ultraviolet band) in early fire, and explain a concept of system development of detection of smoldering fire using heat image.

3. Multi-Spectrum Camera System

It is evident that radiation of infrared and ultraviolet occur by combustion of substances and detectors for the radiation have already been commercialized. Although it is important to know spacious distributions of radiation for reliable early detection of fire, these existing detectors do not consider the spacious distribution and can not grasp that from which radiation the detector had reacted. Therefore, in National Research Institute of Fire and Disaster, the Multi-Spectrum Camera System (Figure 1) has been developed. This system is capable of monitoring light radiation generated by combustion of substances from infrared to ultraviolet and in comparison with visible band image. Figure 2 shows configuration of the Multi-Spectrum Camera System and Figure 3 shows the internal configuration of the camera part.

Following are features of the Multi-Spectrum Camera System.

(1) No parallax in pictures of the 3 different bands: CCD cameras of each band share one fluorite object lens, therefore no parallax occurs. The extent of image sensing wave lengths are infrared:1100nm-800nm, visible:800nm-400nm, ultraviolet:320nm-160nm.

(2) No time delay for recording of 3 images of infrared band, visible band and ultraviolet band: Images of each band are treated as RGB signal and the RGB video recorder records the input, therefore no time delay occur.

(3) Compose the image of each band into pseudo color and display it as color: The image taken by Multi-Spectrum Camera is displayed as pseudo color, i.e. red monotone for infrared image, green monotone for visible image and blue monotone for ultraviolet image, on color display.

(4) Image of each band can be selected display or non-display by RGB switcher.

For above features, combustion of substances can be compared by images of 3 bands that are the same time and the same direction, and easily extract the feature of each band image. As the example of monitoring by Multi-Spectrum Camera, figure 4 (a),(b),(c) shows combustion of n-heptane and methanol. In visible image, it is difficult to capture combustion of methanol for it only emits light shade blue flame, however, it can be clearly seen in ultraviolet image of Multi-Spectrum Camera. In addition, figure 5 is a picture of weld heating electric hot plate. Visible image (figure 5(a)) displays not only electric plate but also surrounding objects, on the other hand, infrared image (figure 5(b)) only display heating element.

4. Detection of smoldering fire by infrared image

As shown in observations of Multi-Spectrum Camera, visibility and invisibility of objects depend on different sensing light band. Noting that visible objects become invisible, image processing of extracting certain object can be done in great ease. Concerning fire detection, image processing can be easily done by using infrared band image that only displays heated area as seen in above mentioned electric plate.

Fire detection using image processing does not get influenced by air movement, etc., therefore, it is effective in air conditioned room and high ceiling space, etc. During the study detecting method of smoldering fire using infrared image will be examined. The smoldering fire was set as focus of detection, for it was considered that smoldering fire detecting system that will not be influenced by air movement has to be developed as flame detector of flaming fire detection.

4.1 Principle of smoldering fire detection

Smoldering fire detection detect the expansion and movement of high temperature area of smoldering fire and determine the phenomena as fire. By putting expansion and movement of high temperature area as conditions of fire detection, it is possible to identify fire from heating of cooking instruments and heater. From sensing of smoldering stage of cotton cushion by thermal camera, it was understood that early smoldering fire can be detected if temperature monitored at about 200 °C. Figure 6 (a),(b),(c) are smoldering conditions of cotton cushion taken by thermal camera.

4.2 Functions necessary for image processing

Following are functions needed for the image processing for smoldering fire detection.

(1) Preprocessing of image: Rejecting distortion of images, compensating loss of permeation light, noise reduction and thresholding of high temperature band and normal temperature band will be performed. Rejection of distortion of image and loss compensation of permeation light will be converted by corrective functions pre-set as intrinsic properties of the camera. Noise reduction will be processed by averaging of each pixel of multiply sampled images. Thresholding of high temperature band and normal temperature band will be manipulated by drawing comparison with threshold

temperature.

(2) Extraction of high temperature cluster: Definition for 'high temperature cluster' is high temperature pixel (Figure 7) surrounded by normal temperature pixel. Number of pixel and the center of gravity coordinates of every high temperature cluster within the display will be registered.

(3) Follow-up increase and decrease of high temperature cluster: Follow-up on the basis of discriminating separation or fusion of high temperature cluster from time series image, and calculates the time varying size and location.

(4) Smoldering fire detection: Separate and reject heat from cooking instruments and heater by follow-up increase and decrease of high temperature cluster, and detect smoldering fire.

(5) Countermeasure to flaming fire: Shifting of smoldering fire to flaming fire needs to be considered. This problem will be met by usage of flame detector. However, study of image processing of flaming fire will be carried out.

4.3 Subjects for practical application

Following problems need to be solved, considering actual use in future.

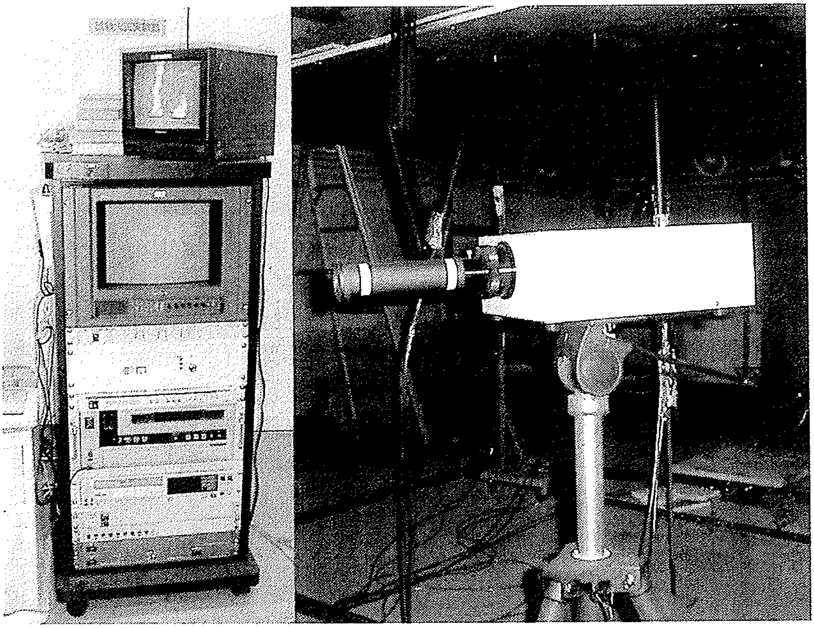
(1) Image input camera: The Multi-Spectrum Camera and thermal camera, used in this research, are expensive and therefore not practical for actual usage. Hence, application into commercial camera will be considered.

(2) Image input and processing: Usage of leased LSI and DSP will be considered.

(3) Performance evaluation: Performing operating test targeted various smoldering fire models in quest to optimize the hardware and software. In addition, evaluation of detecting performance of smoldering fire will be conducted.

5. Conclusion

New fire detecting method can be realized by monitoring fire phenomena with image and light excluding visible light. This report, as the outset, introduced the Multi-Spectrum Camera system developed by National Research Institute of Fire and Disaster and presented smoldering fire detecting method using effect of extracting high temperature area by infrared image.



VTR and Monitor

Camera Unit

Fig.1 Appearance of Multi-Spectrum Camera System

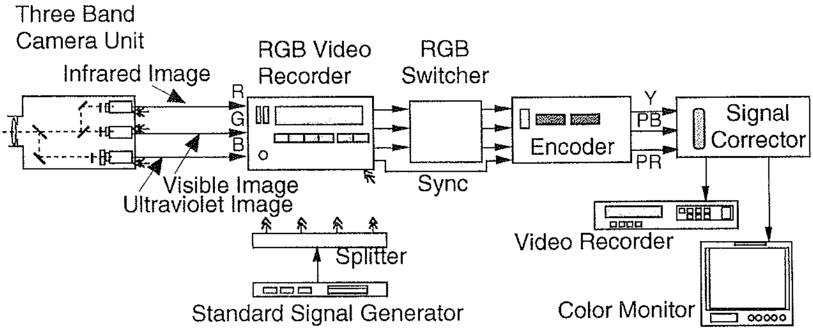


Fig.2 Configuration of Multi-Spectrum Camera System

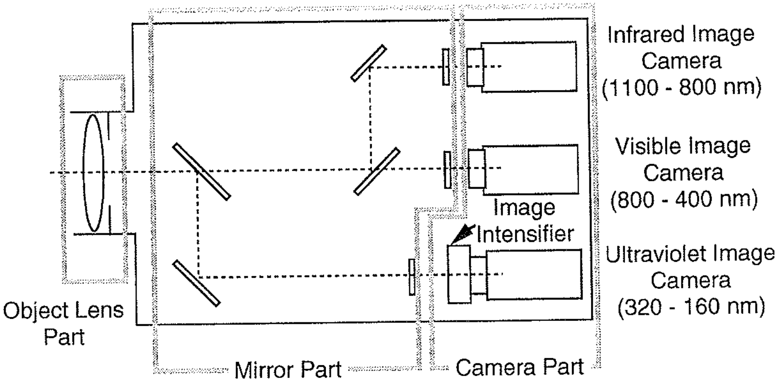


Fig.3 Internal Configuration of the Multi-Spectrum Camera

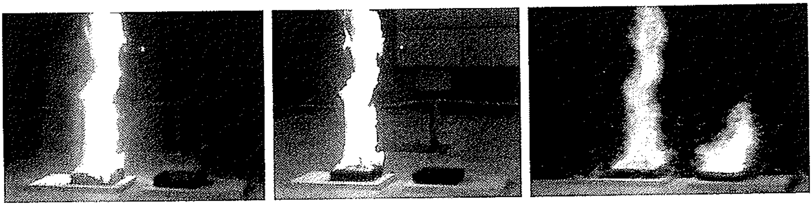

Infrared Image Visible Image Ultraviolet Image

Fig.4 Images from Multi-Spectrum Camera
(left:n-heptane, right:methanol)

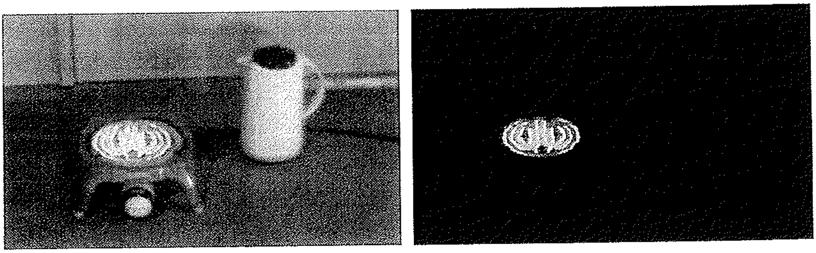
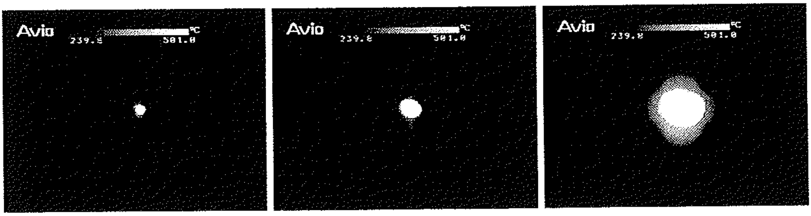

Infrared & Visible Image Infrared Image

Fig.5 Views of Electric Hot Plate



10 sec. 120 sec. 300 sec.

Fig.6 Growth of Smoldering Area in Silk Cotton Cushion

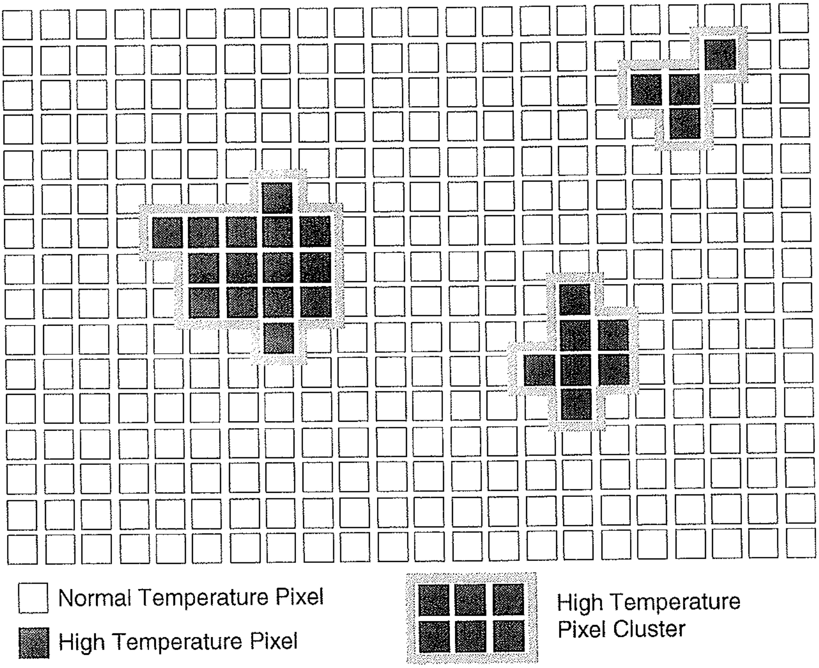


Fig.7 Definition of High Temperature Pixel Cluster

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Erkennung von Aerosolen nach dem Extinktionsprinzip auf kurzen Meßdistanzen

Abstract

Recognizing aerosols based on the extinction principle in short measuring distances

In fire detection technology usually concentrations of aerosols are measured with detectors based on the scattering light or the ionisation principle. Until now smoke detectors based on the extinction principle only work in large systems with a focused light beam and with a measuring length between 10 and 100 meters. Ionisation smoke detectors are better for recognizing small and unpolarized particles. But small particles arise only in later phases of a fire, when the fire has already developed flames. Scattering light smoke detectors are better in recognizing larger particles, which we find in earlier phases of a fire. But scattering light detectors are hardly able to detect open flames with small particles or fire emitting strong absorbant particles. Ionisation smoke detectors work with a radioactive americium source. This is a latent danger, even in case of a fire. Conventional extinction smoke detectors are expensive and are working only in „line systems" with a large extension, but not in the small housing of common smoke detectors.
Although the advantages of extinction smoke detectors have been known for a long time, we don't find this principle in common smoke detectors. The reasons are unsolved technical problems and the restrictions in fire detection technology like the need for cost constraints and the limitations in power consumption. We have therefore developed a small extinction smoke detector with a power consumption of less than 20 mW and a path length of 62,5 mm able to recognize particle concentrations of less than 0,3 dB/m and a partictle size of 0,1µm to 5µm.

Einführung

Eine übliche Rauchkonzentration hat eine Partikelkonzentration von ca. $10^5 cm^{-3}$. DieTeilchen haben dabei eine Größe von 0,1-5µm, je nach Art und Alter des Rauches. Die Rauchpartikel haben unterschiedliche Konsistenz, können auftreffendes Licht unterschiedlich stark absorbieren, brechen oder beugen. Streulichtrauchmelder messen diese Partikelkonzentrationen mit folgenden Anordnungen:

Die Streufunktion an einem kugelförmigen Partikel gemäß der strengen Lösung nach

Mie ergibt sich aus der Funktion

$$\mathbf{i = i\,(\theta,\phi,d,\lambda,m)},$$

und ist somit abhängig von θ=Streuwinkel, ϕ=Polarisationswinkel, d=Teilchendurchmesser, λ=Meßwellenlänge und m= komplexer Brechungsindex.

Der Partikeldurchmesser d und die Meßwellenlänge λ ergeben den dimensionslosen Parameter

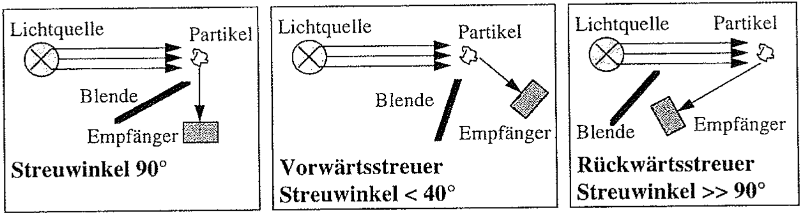
$$\alpha = \frac{\pi d}{\lambda}$$

Für Partikel, deren Durchmesser deutlich größer ist, als die durch π geteilte Meßwellenlänge, ergibt sich für unpolarisiertes Licht der Streulichtkoeffizient gemäß der Formel

$$\mathbf{Q_{ges}(\theta,\alpha,m) = Q_{Beugung}(\theta,\alpha) + Q_{Reflexion}(\theta,m) + Q_{Brechung}(\theta,m)},$$

der in die Streufunktion eingeht. Dies bedeutet, daß der gesamte Streulichtanteil sich aus Einzelanteilen, die auf den Effekten von Beugung, Reflexion und Brechung beruhen, zusammensetzen (Abb.2) [3].

Der durch Beugung gewonnene Anteil $Q_{Beugung}$ ist unabhängig von den optischen Eigenschaften der Partikel. Dieser Streuanteil nimmt jedoch mit Winkeln in Richtung Vorwärtsstreuung (0°) stark zu und ist zusätzlich von der Partikelgröße abhängig.



Streuwinkel 90°

Vorwärtsstreuer Streuwinkel < 40°

Rückwärtsstreuer Streuwinkel >> 90°

Abb. 1: Anordnungen von Streulichtmeldern

Der reflektierte Streuanteil $Q_{Reflektion}$ ist bezogen auf den Winkel unabhängig von der Partikelgröße, jedoch abhängig von den optischen Eigenschaften des Partikels, d.h. daß gerade dieser Anteil stark abhängig von der Absorptionseigenschaften bzw. der Transmission des Partikels (bezogen auf die Meßwellenlänge) ist. Somit ist dieser Anteil bei weniger absorbierenden Partikeln („heller“ Rauch) groß, bei stark absorbierenden Partikeln (Ruß) nur gering.

Der auf Brechung basierende Streulichtanteil $Q_{Brechung}$ ist ebenfalls von den optischen Partikeleigenschaften abhängig und kann für Brechungsindizes von ca. 1,5 nur in einem Winkelbereich von 0 bis ungefähr 90° gemessen werden.

Betrachtet man die Streufunktion in Abhängigkeit vom Streuwinkel (Abb. 1 u. 2), so kann man erkennen, daß aufgrund der einzelnen Streuanteile für verschieden absorbierende Partikel - insbesondere bei Streuwinkeln zwischen 15° und 90° - die resultierenden Signale aufgrund unterschiedlicher Brechungsanteile stark schwanken. Bei Brandmeldern ist dies ein nicht erwünschter Effekt, da dies bei verschiedenen Bränden unterschiedliche Alarmschwellen bedeuten würde.

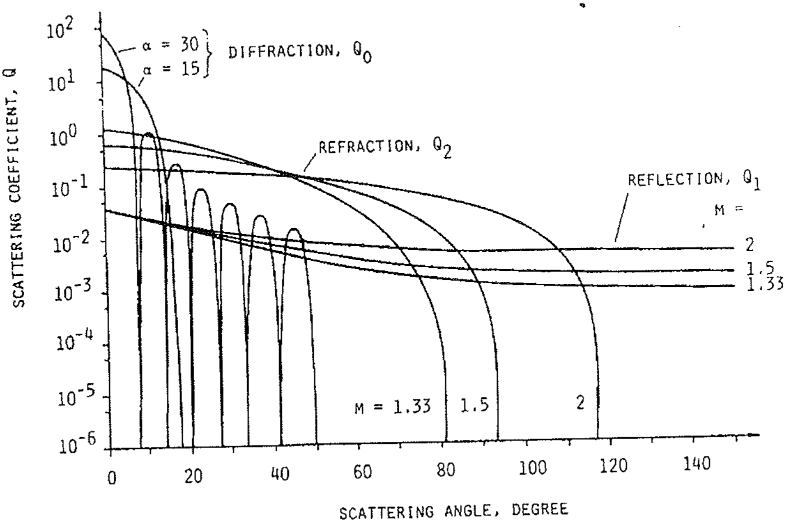


Abb. 2: Winkelverteilung der Streuanteile in Abhängigkeit vom Streuwinkel [3]

Bei einem Durchlichtsystem wird die Transmission, d.h. das Verhältnis von extingierter Lichtintensität zu primärer Lichtintensität, gemessen. Der Logarithmus des Kehrwertes der Transmission, der sogenannte Extinktionskoeffizient, wird zur Konzentrationsbestimmung herangezogen. Für konstante Partikeleigenschaften wie Größenverteilung, Form, Material und die gerätespezifische Eigenschaften verhält sich der Extinktionskoeffizient linear zur Partikelkonzentration.

Die breitbandigeren Eigenschaften des Extinktionsprinzips sind auf die Dämpfung des Lichtstroms durch Absorptionseffekte **und** Verluste durch Streuanteile zurückzuführen. Insbesondere die Beugungseffekte der extremen Vorwärtsstreuung bewirken eine zusätzliche Dämpfung, weil die Strahlung abgelenkt und nicht mehr auf die Empfänger fokussiert werden kann. Bei absorbierendem Partikelmaterial erhält man beim Durchlichtprinzip eine Verstärkung des Meßeffektes, beim Streulichtmelder führt dies zu einer Schwächung des Meßeffektes, da weniger Strahlung reflektiert oder gebrochen wird.

Die Extinktion wird über das Lambert-Beer'sche Gesetz durch den Extinktionskoeffizienten C_{ext}

$$\tau(\lambda) = \frac{\phi_{1\lambda}(\lambda)}{\phi_{0\lambda}(\lambda)} = e^{\overline{-C_{Ext}} \cdot z \cdot l}$$

beeinflußt.

Für Partikel << 0,4 λ gilt:

$$C_{ext} \approx \pi \frac{d^2}{4} \left\{ 4 \frac{\pi d}{\lambda} \left(\frac{\overline{n}^2 - 1}{\overline{n}^2 + 2} \right)^2 + \frac{8}{3} \left(\frac{\pi d}{\lambda} \right)^4 \left(\frac{\overline{n}^2 - 1}{\overline{n}^2 + 2} \right)^2 \right\}$$

$$C_{ext} \approx \pi \frac{d^2}{4} \left\{ E_{absorb} + E_{streu} \right\}$$

Durch Ausmultiplizieren sieht man, daß der Beitrag aus der Absorption mit d^3 und der Beitrag aus Streueffekten mit d^6 in den Extinktionsquerschnitt eingeht. Daraus ergibt sich der Vorteil des Extinktionsprinzip gegenüber dem Streulichtprinzip, da für kleine Partikel der Streuanteil proportional d^6, der Absorptionsanteil jedoch nur mit d^3 abnimmt. Für Partikel >> 0,4 λ gilt

$$C_{ext} \approx \pi \frac{d^2}{4} * 2$$

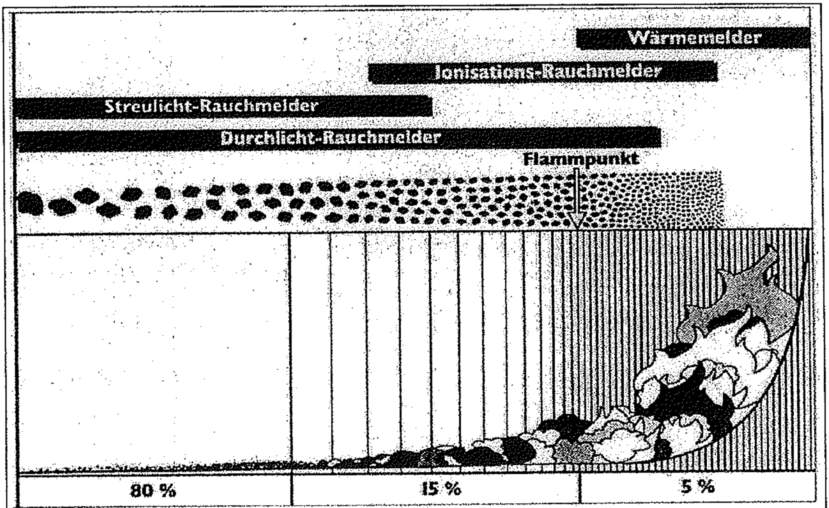


Abb 3: Einsatzbereich von Brandmeldern / Partikel-größenverteilung im zeitlichen Brandverlauf

Die untere Nachweisgrenze wird durch das Signal-Rauschverhältnis bestimmt.

Aus Abb. 3 kann man erkennen, daß die meisten Brände im Frühstadium große Partikel erzeugen. Diese Partikel können von Streulichtmeldern ebenso gut wie vom Durchlichtmelder erkannt werden, sofern der Rauch nicht absorbierend ist. Ein Melder nach dem Streulichtprinzip ist gegenüber kleinen Partikeln aus späten Phasen weniger empfindlich.

Der Durchlichtmelder hat dagegen wesentlich breitbandigere Detektionseigenschaften als bisher verwendete Typen.

Das angestrebte Entwicklungsziel, die Detektionseigenschaften für Partikel, die sehr viel kleiner sind, als die Meßwellenlänge üblicher Streulichtmelder (ca. 880nm) sind und die gerade bei offenen Bränden (TF1) auftreten, konnte erreicht werden. Auf einen Einsatz bisher verwendeter radioaktiver Ionisationsrauchmelder kann somit verzichtet werden. Bei großen Partikeln, wie sie bei Schwelbränden auftreten, zeigt sich eine Empfindlichkeit, wie sie vom Streulichtmelder bekannt ist.

Technische Realisierung

Es wurde ein punktförmiger Durchlichtrauchmelder mit einer Meßstrecke von 62,5 mm bis zur Serienreife entwickelt. Aufgrund der sehr geringen Meßdistanz läßt sich der Sensor in einem in der Brandmeldetechnik üblichen, runden Gehäuse eines punktförmigen Rauchmelders unterbringen.

Das Meßverfahren ist ein Referenzmeßverfahren mit einer dem Rauch zugänglichen Meßkammer und einer rauchdichten Referenzkammer. Die gesamte Kammer besteht aus zwei Kunststoffspritzteilen, einem kastenförmigen, länglichen Außenteil, welches an den Endseiten die Parabolspiegel enthält und einem Kunststoffeinsatz, mit dem die Kammer in Meß- und Referenzkammer geteilt wird. Dieser Einsatz enthält auch die Fenster, durch die Meß- und Referenzstrahl durchtreten. Die Parabolspiegel erhält man durch partielles Bedampfen der Innenflächen des Außenteils. Die komplette Meßkammer wird mit Schnapphaken und Haltebolzen auf der Leiterplatte fixiert, so daß eine Seitenwand des Kammersy-

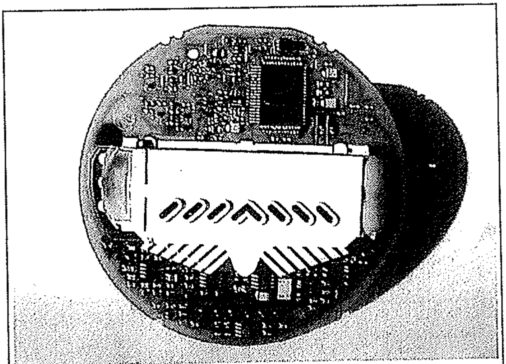


Abb 4: Durchlichtmeßkammer auf Leiterplatte

stems durch die Leiterplatte gebildet wird.

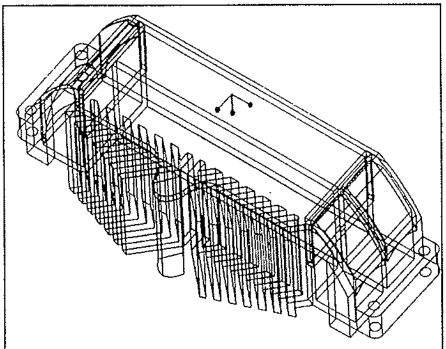


Abb. 5: 3D-Ansicht der Kammer mit eingesetzter Trennwand

Durch diese einfache Konstruktion des optischen Systems und die Möglichkeit sämtliche (opto-) elektronischen Bauteile einseitig in SMD-Technologie bestücken zu können, konnte den extremen Kostenanforderungen in der Brandmeldebranche begegnet werden.

Teure integriert optische Konstruktionen auf Basis von mikrosystemtechnischer Lösungen oder Lasermeßverfahren wurden ebenfalls in Erwägung gezogen, jedoch gegenüber dieser einfachen Konstruktion, nicht nur aus Kostengründen, fallengelassen: Der Durchtrittsquerschnitt des Lichtes beträgt ca. 1 cm^2. Der Melder ist somit hinsichtlich Verschmutzung der Optik weniger anfällig. Ablagerungen größerer Partikel in einem miniaturisiertem Strahlengang könnten leicht ein Signal erzeugen, welches die Alarmschwelle einer Brandsituation übersteigt.

Auf der Leiterplatte befindet sich in der jetzigen Ausführung im Fokus des Sendeparabolspiegels eine rot strahlende LED. Der Sendeparabolspiegel ist so dimensioniert, daß das Licht parallel und möglichst zu gleichen Teilen durch Meß- und Referenzvolumen auf die zwei Empfangsparaboloiden gebündelt wird, mit denen das Licht auf die beiden Fotoempfänger fokussiert wird. Es ist dabei nicht entscheidend, daß genau die gleiche Lichtmenge auf Meß- bzw. Referenzempfänger fällt, da der Sensor bei der erstmaligen Inbetriebnahme automatisch abgeglichen wird.

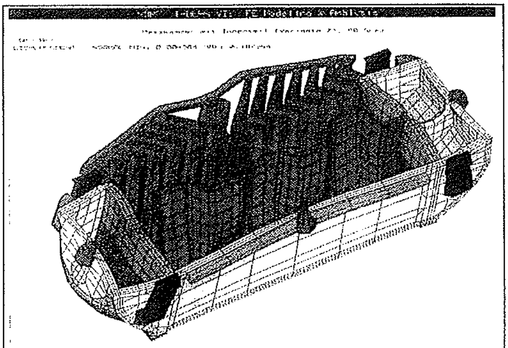


Abb. 6: FEM-Analyse der Meßkammer

Ein Verschmutzungsausgleich, sowie der Ausgleich von Alterungsprozessen des gesamten

optoelektronischen Pfades erfolgt durch einen kontinuierlich arbeitenden, kombiniert aktiven und rechnerischen Ausgleich. Diese Kompensation erfolgt bis zur Nachführgrenze des Systems. Bei Erreichen dieser Grenze signalisiert der Melder eine Störung an das übergeordnete System.
Untersuchungen, u.a. durch FEM haben ergeben, daß der festgestellte Temperaturgang der Sensorsignale durch Verformungen der prinzipiell bedingten asymmetrischen Kammerkonstruktion hervorgerufen wird. Dies bewirkt Nichtlinearitäten im Meßsignal. Temperaturänderungen bewirken mechanische Verformungen der Spiegelgeometrie bzw. der Spiegelaufhängung und somit eine Änderung der Abbildungen der Sende-LED auf die beiden Photoempfänger. Diese Nichtlinearitäten wurden durch geeignete Materialwahl, durch die Geometrie der Empfängerspots, geeignetes Leiterplattenmaterial, sowie einen nachgeschalteten Softwarealgorithmus kompensiert. Verbesserungen des Temperaturganges konnten dadurch erreicht werden, daß die Kunststoffteile glasfaserverstärkt wurden und ein Kunststoff gewählt wurde, der den gleichen Längenausdehnungskoeffizienten besitzt, wie das Leiterplattenmaterial.
Ein Ziel der Entwicklung war es, die Analogsignale der Photoempfänger möglichst unmittelbar dem Prozessor zuzuführen, die Signale digital weiterzuverarbeiten und somit Einflüsse durch EMV und Temperatur gering zu halten. Differentiell arbeitendende Meßverfahren sind a priori gegenüber Störeinflüssen durch EMV weniger anfällig, da Gleichtaktschwankungen auf das Meßsignal keinen Einfluß haben. Zusätzlich können die den Photodioden nachgeschalteten Transimpedanzverstärker aufgrund der gegenüber Streulichtmeldern sehr viel geringeren Verstärkung niederohmiger ausgelegt werden, so daß sich auch hier Vorteile gegenüber Störeinflüssen ergeben. Bei der Feldbeeinflussung gemäß IEC 801-3 wird dadurch leicht eine Störfestigkeit bis 50V/m erreicht.

Die Auswertung der Meßdaten übernimmt ein 8-Bit-Mikroprozessor mit integriertem AD-Wandler. Mit ihm wird die Aufbereitung der Rohsignale, die Signalanalyse mittels Fuzzy-Logic und die Datenübertragung durchgeführt.
Für die Entscheidungsfindung Brand/Nicht-Brand und die Datenübertragung werden 16 Kbyte Programmspeicher benötigt. Mit digitalen Filtern wird der Meßwert geglättet und von Ausreißern und Störspitzen befreit. Die Signalfunktion, die Anstiegsgeschwindigkeit und anormales Verhalten werden ermittelt. Gleichzeitig wird auch eine Driftkorrektur vorgenommen, mit der durch Verschmutzungs- und Alterungseinflüsse hervorgerufene langsame Grundsignaländerungen kompensiert werden. Die aufbereiteten Signale werden dann einer Fuzzy-Logic zugeführt, mit der typische Brandverläufe unter Be-

rücksichtigung des Meßsignal-Mittelwertes, der Anstiegsgeschwindigkeit und rascher Signalwechsel als Brände erkannt und Störeinflüsse ausgeschaltet werden. Über die Fuzzy-Logic werden auch Hinweise über Verstaubung oder Voralarmzustände, die einen Hinweis auf eine sich im Entwicklungsstadium befindliche Brandsituation geben können, erkannt. Signale die nicht auf einer realistischen Veränderung der Umwelt beruhen können, wie z.B. EMV-Störspitzen, temperaturbedingte Änderungen der optischen Signale oder Betauung von Fenstern im optischen Strahlengang werden als solche erkannt und unterdrückt. Durch diese intelligente Logik können Fehlalarme wesentlich reduziert werden.

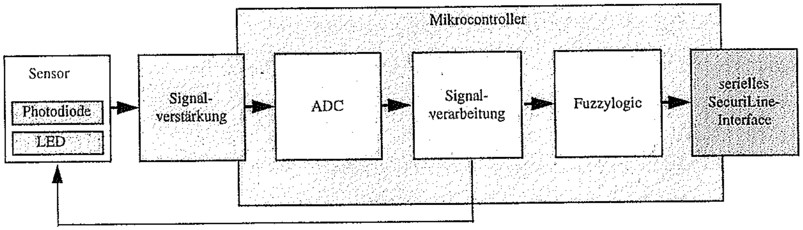


Abb. 7: Blockschaltbild der Signalverarbeitung

Zum Ausgleich von Alterungs- und Verschmutzungsvorgängen wird der Strom der Sende-LED in Abhängigkeit vom empfangenen Signal am Referenzkanal geregelt. Ein Abgleich zwischen Meß- und Referenzkanal nach Fertigung des Melders ist nicht erforderlich.

Der Melder wird über eine 2-Draht-Ringleitung an eine Brandmeldezentrale redundant betrieben, die auf einer Länge von 1200 m bis zu 126 Teilnehmer abfragen bzw. steuern kann. Die Informationsübertragung wird auf die Spannungsversorgung aufmoduliert. Jeder Durchlichtmelder kann seine Informationen zyklisch innerhalb 2 Sekunden an die Zentrale übertragen. Die Art der Datenübertragung verhindert den Einsatz von Standardschnittstelleneinheiten, so daß diese kurzen Abfragezyklen eine ständige Betriebsbereitschaft des Prozessors für den Pollingbetrieb der seriellen Datenübertragung voraussetzt. Dies steht einem Einsatz von stromsparenden Stand-By-Betriebsarten entgegen. Durch geeignete Verfahren im Powermanagement wird für den gesamten Melder eine Leistungsaufnahme von nur ca. 20 mW bei 24 V erreicht.

In der jetzigen Melderkonstruktion wird als Lichtquelle eine rote LED verwendet. Untersuchungen haben gezeigt, daß künftig durch Einsatz einer multispektralen Strahlungsquelle die Empfindlichkeit und somit das Ansprechverhalten nochmals deutlich verbessert werden kann. Zusätzlich können dann noch Aussagen über die Partikelart getroffen werden.

Ergebnisse

Aufgrund des breiten Detektionsbereiches des punktförmigen Durchlichtrauchmelders können Partikelkonzentrationen mit einem Teilchendurchmesser zwischen 0,1µm und 5µm erkannt werden. Unter Testbedingungen nach EN54/7 werden Rauchmelder verschiedenen Testfeuern (TF1-TF5) unterzogen.

TF 1:	offener Zellulosebrand , (Buchenholzbrand, kleine helle Partikel)
TF 2:	Pyrolyse-Schwelbrand, (Buchenholz-Schwelbrand, große helle Partikel, keine Thermik)
TF 3:	Glimm-Schwelbrand (Baumwolle-Schwelbrand,große helle Partikel)
TF 4:	offener Kunststoffbrand (Polyurethanmatte, graue Partikel)
TF 5:	Flüssigkeitsbrand (n-heptan, große schwarze Partikel, starke Thermik)

Um die Detektionsbandbreite des Durchlichtsystems zu verdeutlichen wurden Empfindlichkeitsmessungen in Abhängigkeit der Aerosolpartikelgröße durchgeführt. Die Messungen wurden mit einem Aerosolgenerator der Firma Palas in einem EN54 konformen Rauchkanal durchgeführt. Zum dimensionslosen Vergleich der Messergebnisse wurden diese in Relation zueinander auf das Gerät RM41, eine Norm-Durchlichtstrecke mit weißem Licht der Fa. Sick, bezogen. Die Meßergebnisse sind in Abb. 8 dargestellt. Aufgrund der Normierung ist das Signal des RM 41 immer konstant 1.

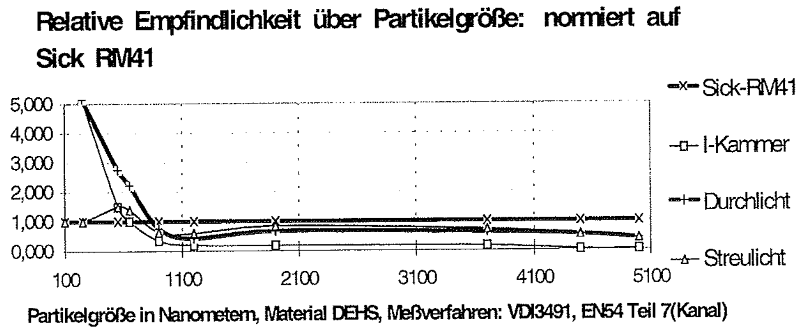


Abb. 8: Detektionsbandbreite des Durchlichtmelders

Man erkennt den Vorteil des Ionisationsmelders erst unterhalb einer Partikelgröße von (und dunklen) Rauchpartikeln als auch insbesondere offene (Cellulose)-Brände mit kleinen Rauchpartikeln zu erkennen.

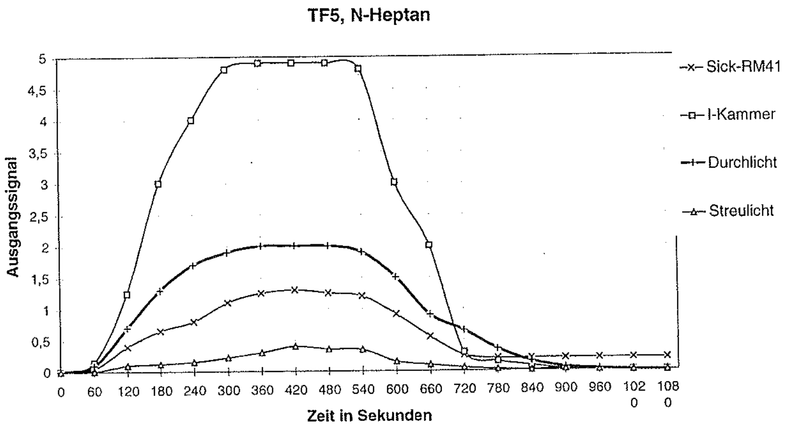


Abb. 9: Verhalten des Melders bei TF 5 n-Heptanbrand

Die Vorteile dieses Melders zeigen sich gegenüber dem Streulichtmelder bei absorbierenden Partikeln (schwarzer Rauch), wie sie bei TF 4 und 5, dem Polyurethanbrand und n-Heptanbrand, entstehen (Abb. 9). Als Signaländerung kann der Melder die Strahlungsdifferenz, die sich aus den Verlusten von Absorption und Streuung ergibt ausnutzen. Auch bei offenen Bränden, bei denen kleine Partikel entstehen, zeigt sich die relative Stärke der Detektionseigenschaften. Der Durchlichtmelder liefert immer noch ähnliche Ergebnisse, wie sie von Ionisationsmeldern bekannt sind (Abb. 10). Durch Verkür-

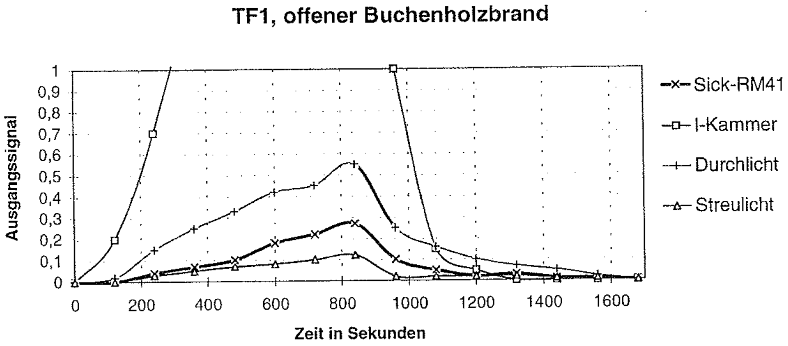


Abb.10: Verhalten des Melders bei TF 1 offener Buchenholzbrand

zung der Meßwellenlänge könnten die Ergebnisse nochmals verbessert werden, da für Teilchen, die deutlich kleiner als die Meßwellenlänge gilt, daß die Absorption ungefähr proportional der Masse der Teilchen ist.

Bemerkungen

Die grundlegenden Neuerungen dieses Melders sind mit Patenten gesichert. Für zwei dieser Patentanmeldungen wurden dem maßgeblichen Entwicklungsingenieur im Dezember 1995 der erste Preis des „Prix Européen d'Inventions" verliehen.

Der Durchlichtrauchmelder SecuriStar® wurde auf der Messe „Sicherheit 95" in Zürich als Weltneuheit vorgestellt. Das Projekt wurde vom BMFT als Entwicklungsvorhaben im Förderschwerpunkt „Mikrosystemtechnik" gefördert.

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Smoke Detection by Ultrasound – Determination of Particle Mass Concentration

Abstract

This paper discusses a Smoke Detection Device that uses Ultrasound as a detection principle. The heart of the device is a Double Layer perforated Matrix Board which facilitates a unique perturbated flow pattern in a transitory smoke plume at laminar velocities, that enables the Ultrasound medium to readily detect the presence of Smoke Particulates and to determine the Particle Mass Concentration.

Introduction

The Ultrasound Smoke Detection device described in this work uses a Double Matrix Board System, which has two main properties that enable the detection apparatus to be sensitive to smoke plumes at low relative air velocities. When the two properties combine in tandem, their synergy increases the sensitivity of the detection system by several factors when compared to either property operating alone. Broadly two particular properties are as follows:

[a] Induces a disassociated flow pattern (pseudo-turbulence) in the smoke plume as it enters the double matrix layer (strainer effect) at laminar velocities when the detector system has a low Reynolds Number. And when the smoke plume exits the double matrix layer, a rapid reassociation is induced within the plume and a cohesive and structured laminar flow pattern is reformed.

[b] A spatial resonance is formed when the combination of the critical dimensions of the double layer matrix array are similar to a function of the half-wave ($\frac{1}{2}\lambda$) of a time varying Ultrasonic wave emanating through the detector equipment.

Speed of Sound

Mednikov [1977] postulated that the local Speed of Sound in an aerosol like a smoke plume, is related to Speed of Sound of the gas or gases in the suspension thus,

[1]

$$\frac{c_0}{c} = \sqrt{\left(1+\frac{k}{\rho_g}\times Z\right)}$$

k = particle mass concentration

ρ_g = gas density

$$Z = \frac{\omega_2 \tau_d^2}{1+\omega^2 \tau_d^2} + (\gamma - 1)\frac{c_{pp}}{c_{pg}} \times \left(1 - \frac{\omega^2 - \tau_t^2}{1+\omega^2 \times \tau_t^2}\right)$$

ω = angular velocity of the incident soundwave

τ_d = dynamic relaxation time of the particle

γ = specific heat ratio of the gas at constant pressure volume

c_{pp} = specific heat of the particle at constant pressure

c_{pg} = specific heat of the gas at constant pressure

τ_l = particle thermal relaxation time $= \tau_\infty \dfrac{3Prc_{pp}}{2c_{pg}}$

Pr = Prantl's number (for aerosols like smoke $Pr \cong 0.70\text{-}0.73$)

For non-saturated aerosols like smoke particulates in air suspension when $\frac{kZ}{\rho_g}$ is small, equation [1] above can be rearranged thus,

[2]

$$\frac{c_0}{c} = 1+\frac{1}{2}\,k\frac{Z}{\rho_g}$$

If the distance travelled by the incident Ultrasound wave = 1, at time t in smoke and t_0 in air-only,

[3]

$$\frac{l/t_0}{l/t} = \frac{t}{t_0} = \frac{t_0+\Delta t}{t_0} = 1+\frac{\Delta t}{t_0} = 1+\frac{1}{2}k\times\frac{Z}{\rho_g}$$

Or put another way we get,

[4]

$$\Delta t = t_0\times\frac{1}{2}k\times\frac{Z}{\rho_g}$$

Rearranging still further,

[5]

$$k = k_0\,\frac{\rho_g}{\rho_0}$$

Particle Mass Concentration

Where k_0 and ρ_0 are the particulate concentration and the density of the gas or gases, at STP (i.e., 760mm Hg @ 0 ^{0}C), we have,

[6]

$$\Delta t = \frac{t_0\times k_0\times Z}{2\rho_0}$$

And where,

[7]

$$k_0 = \frac{2\Delta t \times \rho_0}{t_0 \times Z}$$

The Particle Mass Concentration can be determined from observing the "Group Frequency Shift" (τ_g) and the "Phase Shift" (τ_p), at the single point piezo detector mounted just after the Double Layer Matrix Board as shown in Figure 1. The single point piezo detector receives the Ultrasound signal from each aperture across the whole area of the matrix board at different time intervals. Therefore, the composite signal received at the single point piezo detector is the algebraic sum of all the Ultrasound signals from each aperture. The will be a modification in the local speed of sound (C) for the transition condition from "air only" to "smoke/air mix" which will correspondingly cause the composite signal to be phase shifted to some degree. This will affect the speed of propagation of the incident soundwave.

In the case of the "Group Frequency Shift"(τ_g) this will usually be a transient single event if there is only single density change from one transition to another. However, where varying densities of smoke are present with time in the flow, an undulation of Group Frequency shift then predominates. This can be characterised by the following.

[8]

$$\tau_g = -\frac{\delta\phi(\omega)}{\delta\omega}$$

The "Phase Shift" (τ_p) will be similarly affected as for the Group Frequency Shift (τ_g) above, and will modulate for a changing smoke density causing a frequency bandwidth change in the composite signal at the point detector, which can be characterised thus,

[9]

$$\tau_p = -\phi(\omega) / \omega$$

So in conclusion both the "Group Frequency Shift" (τ_g) and the "Phase Shift" (τ_p), can be described as near constants at a constant frequency and density @ STP, and can be expressed in the following Taylor series expansion,

[10]

$$\phi(\omega) \approx -\omega\tau p(\omega_0) - \tau p(\omega_0)[\omega - \omega_0]$$

Experimental Method

The apparatus as described in Figure 1 below was subjected smoke test for a 5-minute duration. The results of the experiment are shown later in the Graph in Figure 2 and the data included in Table 1. The smoke source was placed remotely from the experimental area, to minimise the temperature affects of the initial combustion process. The material used to produce the smoke was 10 gm.'s of tried tobacco leaves. The material once ignited was left to continue in smouldering combustion to produce smoke particulates. The following parameters were measured during the experimental procedure.

[a] Optical obscuration %/m., for the optical density of the smoke plume entering the Lower Matrix Board.

[b] Air velocity 50mm below the Matrix Boards.

[c] Amplitude of the detector voltage (p-p).

[d] Amplitude of the transmitter voltage (p-p).

[e] Average frequency bandwidth of the algebraic sum of the signals at the point detector.

[f] Incident sound intensity of 89dBA, @ 160khz, at a sinusoidal waveform.

[g] The start and end temperatures of the experiment, both above and below the Matrix Boards.

Prior to start of the experimental procedure the whole apparatus was left undisturbed for a period of 1 hour to allow for temperature and pressure stabilisation. To reduce the possibility of the apparatus contaminating the results the transmitter and all the measuring devices were turned on and allowed to temperature stabilise for a period of 15 minutes. Following the ignition of the smoke producing material measurements were taken continuously at 1-minute intervals for a period of five minutes.

The data collected is tabulated in Table 1 and on the graph in Figure 2. The temperature remained relatively stable throughout the test period only varying 2.2%. The air velocity commenced at 0.01m/sec and reached 0.02m/sec at it's highest. The detector volts broadly varied downwards on an increase in smoke density. The frequency modulation closely shadowed the increase in smoke density, as can be seen from the graph Figure 2. The frequency modulation is the average frequency bandwidth with time at the detector position. During the "air only" condition the bandwidth was recorded at 2kHz, and rose to 4khz at the highest smoke density.

It can be seen from the experimental results and the theoretical factors described earlier generally agreed in a few important areas.

Firstly, the degree of amplitude attenuation predicted at the point detector is also air velocity dependent. Since the initial velocity was small and only increased marginally during "smoke" conditions, greater sound absorption might be expected under higher velocity conditions.

Secondly, the frequency modulation followed quite sharply the increase in smoke density and occurred independently to a degree from the air velocity.

Thirdly, the apparatus showed that it was sensitive to smoke at some distance from the fire of origin, even when the vertical temperature gradient is very small.

The observations also demonstrated that the Double Layer Matrix Board System could form the basis of a practical smoke detector with further development work. The Author(s) also speculate that other research into the measurement of slow moving Two-Phase fluids might also find the method useful.

FIGURE 1

Ultrasound Smoke Detection
Apparatus

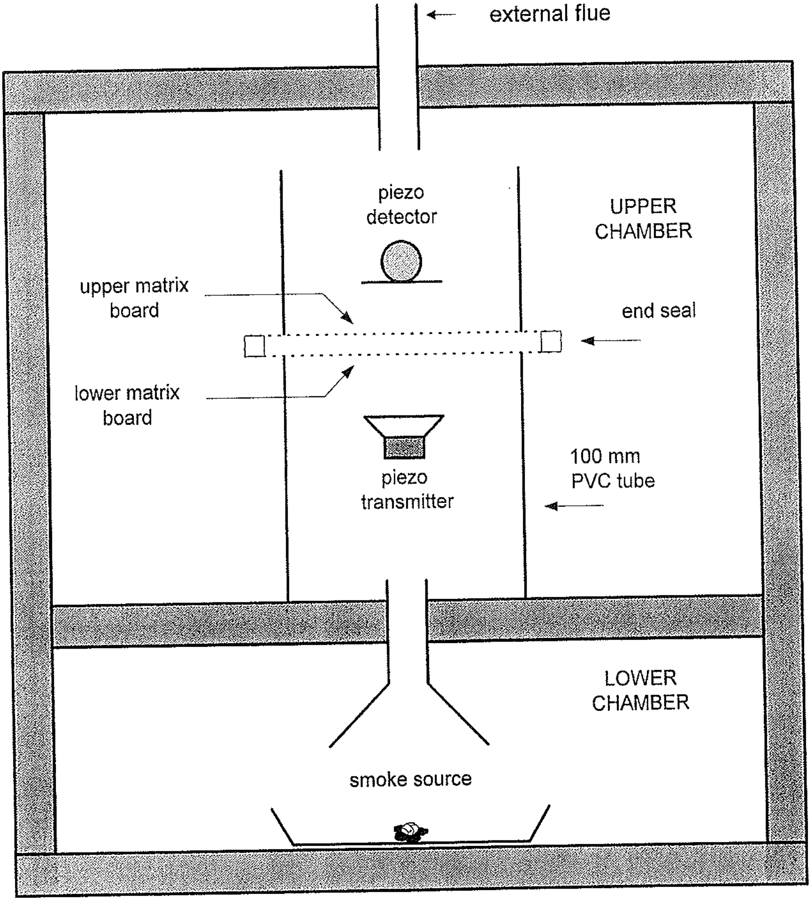


Figure 2 Smoke Detection by Ultrasound

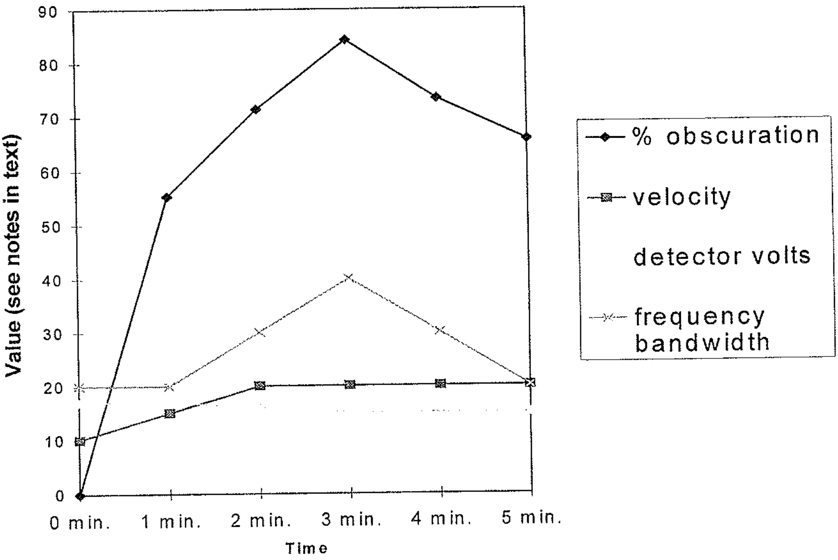
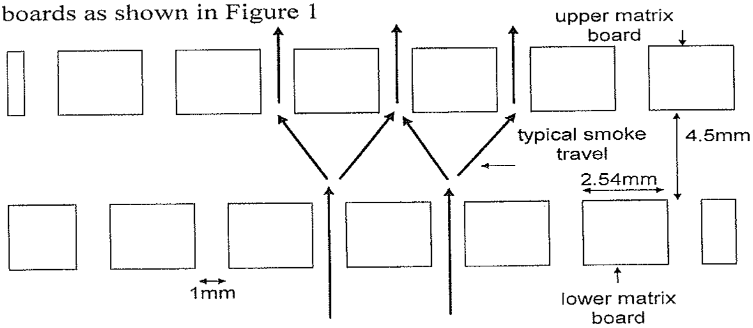


Table 1 - Experimental Results						
Duration	0 min.	1 min.	2 min.	3 min.	4 min.	5 min.
% Obscuration.	0	55.3	71.4	84.3	73.4	65.7
Air velocity 1×10^{-3} m/sec.	10	15	20	20	20	20
Detector voltage (p-p) 1×10^{2} mV.	17	17	16	15	15	16
Detector frequency bandwidth (average) 1×10^{2} Hz.	20	20	30	40	30	20

FIGURE 3

Typical section through the upper and lower matrix boards as shown in Figure 1



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The application of wavelet neural network in fire detection

Abstract

Wavelet neural network (WNN) is a special feedforward neural network. The structure and algorithm of wavelet neural network suitable to fire signal processing are proposed in this paper. The wavelet network adopts wavelet function and conjugate gradient algorithm. Experimental results indicate that wavelet neural network has good learning and detection abilities to fire signals. Faster and more accurate detecting against standard fires can be expected by applying this wavelet neural network.

Keywords: wavelet transform, wavelet neural network, fire detection

Introduction

Wavelet analysis[1],[2] is a developing mathematical method, and is considered as an important theoretical breakthrough following Fourier analysis. The wavelet transform has good localization in both time and frequency domains. Combining the good localization of wavelet and the auto-adaptive feature of neural network, the wavelet neural network gains quite good approximation and tolerance abilities. To apply wavelet network in signal approximation, it is essential to find a set of proper wavelet basis in wavelet feature space. For this purpose, either wavelet parameters or wavelet shape are iteratively computed as to minimize the error function.

In order to reduce the loses of human life and property, it is very important to detect a fire in early stage accurately. Research workers pay their attention to application of adaptation and self-organization of neural network in the field of fire protection and engineering. In Japan, BP network has been applied to fire detection[3]. A wavelet network used for automatic fire detection is introduced in this paper. Experimental data show that this network has good learning and detection abilities, faster convergent speed and better approximation in contrast to BP network .

Structure of wavelet neural network

Wavelet neural network based on wavelet theory is a special feedforward neural network used for approximation of functions in nonliner systems. The wavelet basis is better than sigmoid function in function feature[4]. Good approximation ability of wavelet and efficient initialized condition provided by wavelet parameters make the convergent speed of the wavelet network faster. Orthogonal stepwise selection is employed to initialize the wavelet network[5],[6]. The dilation and translation parameters of wavelet are adjusted through the back-propagation algorithm so that the mean square residuals of the expected output become the least. The network structure is shown in Fig.1.

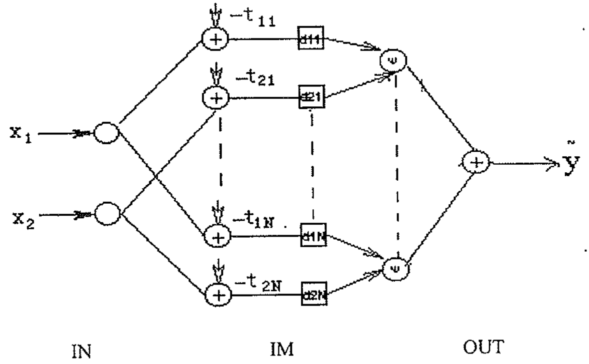


Fig.1 The structure of wavelet neural network

Let us apply this structure to fire signal processing. The two inputs x1 and x2 in input layer in Fig.1 represent the normalized values of optical smoke and heat sensors, and the region is between 0~1. The output y in output layer is fire probability. Wavelet neural cells are there in the immanent layer. General nonlinear sigmoid function is substituted by nonlinear wavelet basis in this wavelet network. The parameters t_{ij} and d_{ij} ($i=1,2;j=1,2,\cdots N$) are respectively the translations and dilations of the wavelet basis, and N is the number of wavelet basis. The weight between immanent layer IM and output layer OUT is w_k. The output of our wavelet network structure has following form

$$\tilde{y} = \sum_{k=1}^{N} w_k \psi(t_{1k}(x_1 - d_{1k}) t_{2k}(x_2 - d_{2k})) \qquad (1)$$

The initializing parameters are randomly selected in back-propagation network. This method is no longer effective for wavelet network because of highly nonlinear output and more adjustable parameters. In principle, the regular wavelet lattice and backpropagation algorithm can be used to initialize the system, but it would be a waste of computational resource for including too many futile wavelets. To avoid this, a combination of the regression analysis and back-propagation algorithm[5] is used to select the best wavelet function and to get a better initialized network structure in this paper. The parameters t, d and w can be optimized by minimizing the energy function

$$E = \frac{1}{2}\sum_{k=1}^{T} (y - \tilde{y})^2 \qquad (2)$$

where T is the number of the samples and $\tilde{y}$ is the expected output.

The following mother wavelet is adopted in Eq.(1):

$$\psi(x) = x^T x \exp(-\frac{1}{2} x^T x) \qquad (3)$$

The parameters w_k, t_{ik} and d_{ik} are optimized by conjugate gradient algorithm. The operation shall be repeated until the error E becomes less than a given value or the cycling is ended.

Training wavelet neural network

To accurately decide a fire by wavelet neural network, some training models are needed. We define here in our case 46 pairs of modeling sample against six kinds of European standard fire (EN54 Part9). These modeling sample pairs are used as training models. Eight pairs of modeling sample, including two inputs and one output for each, are here in Table1, where IN_1 and IN_2 are normalized outputs of optical smoke and heat sensors, and T is tutor signal representing fire probability.

Table 1 Part of training models

Sample pair number	IN1	IN2	T	Sample pair number	IN1	IN2	T
1	0.8012	0.0238	0.05	5	0	0.4286	0.95
2	0.8012	0.1333	0.2	6	0.8750	0.7214	0.7
3	0.6012	0.2643	0.5	7	0.8750	0.7095	0.5
4	0.2062	0.7690	0.9	8	1.00	0.8750	0.9

These 46 pairs of sample are fed into wavelet network for teaching or training the network. The network node number of immanent layer is 10, determined by the initialization algorithm mentioned above. The final learning results are given as follows:

t = [-0.0638 1.2430 0.0298 0.1262 -0.8822 0.7337 0.2513 0.4329 0.1191 0.1247;
0.8095 0.6298 -0.0567 0.6330 0.7086 0.0880 0.3071 0.1868 0.7927 0.8319]
d=[17.4163 3.8339 11.7722 12.6508 0.4619 0.6425 4.1298 8.5625 7.1742 11.8356;
5.4974 1.6577 28.7222 8.8117 2.3786 13.0157 6.3468 8.3721 2.4911 4.9044]
w=[0.4769 -0.3069 -0.6675 -0.3063 -0.1265 0.1413 0.2997 -0.2328 0.5455 -0.3137]

The learning results of approximating the tutor signal by wavelet network and BP network are plotted in Fig.2 and Fig.3. It is obvious that the learning ability of wavelet network is better than BP network. The mean square error is considerably less, compared with BP network. Furthermore the wavelet network reaches the desired results only by 100 times of learning iterations, while BP network by 1200 times of learning iterations with greater mean-square error remained.

(real line is the tutor signal, dotted line is the learning result)

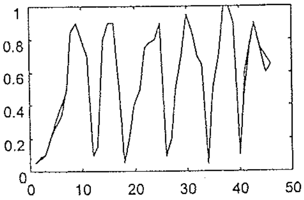


Fig.2 The learning results of WNN.

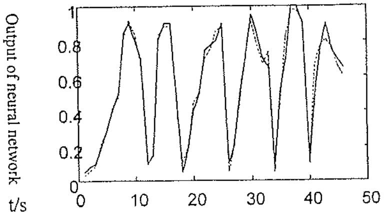
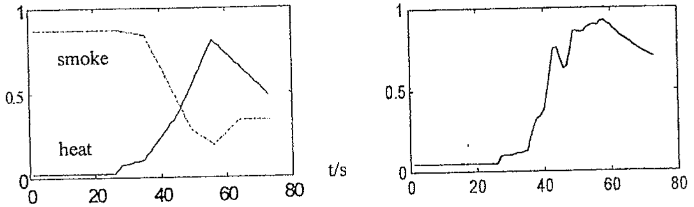


Fig.3 The learning results of BP

Experimental results against standard test fires and non-fire signals

This wavelet network was used to detect European standard test fires. Fig.4(a) shows the open wood fire (TF1) signals of smoke and heat sensors. The corresponding output of wavelet network is shown in Fig.4(b) which demonstrates rapidly increased fire probability.

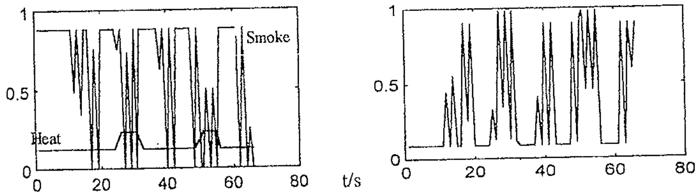
Fig.5(a) shows the response signals from sensors working in a harsh environment in non fire case. The data were collected from a hospital kitchen, where vapor, which is likely to produce some false alarms, may appear some times. The corresponding curve of wavelet network is plotted in Fig.5(b).It is clear that fire probability reflect the output signals of the sensors. The false alarm in this case can be eliminated by implementing some time delay and threshold values, as shown in Fig.5(c), where the time delay is 20s and the threshold value is 0.5.



(a)signals of detectors for TF1

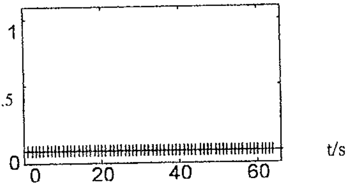
(b)output of wavelet network

Fig.4: The test result of TF1



(a) Signals of detectors in non fire case

(b) output of wavelet network



(c) Fire decision making

Fig.5: Non fire case in a hospital kitchen

Conclusion

The wavelet neural network discussed in this paper fully implements the approximating behavior of wavelet. Good initialized conditions, by selecting wavelet parameters, improves the convergent speed of the network. Experimental data demonstrates that the leaning and detecting abilities of the network are better than BP network.

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Detection In Difficult Environments

Abstract

Although the majority of early warning fire detection applications can be covered by optical and ionization detectors, these technologies are too sensitive for very dusty or dirty areas. Use of these standard types of fire detectors in such environments would result in a high occurrence of nuisance alarms. A detector for these applications needs to provide early warning while eliminating nuisance alarms and the need for frequent maintenance. This paper will describe one such implementation of an intelligent early warning detector that is designed for dusty or dirty locations.

Introduction

It's well known that smoke detectors just don't work in certain places. Dusty, dirty places like paper mills, lumber mills, cotton and textile mills, dry chemical processing plants or horse stables and other animal holding areas.

Until now, it was next to impossible to achieve "true early warning" of smoke in these dusty, dirty environments. No smoke detector could stand up to the punishment of dust. Anyone bold enough to try an optical smoke detector in such a place would report the same experience – frequent false alarms. Until now, specifiers could only choose between thermal, flame and spark detectors, thermal wire, beam detectors, or aspirating systems. Some of these alternatives could be effective, but are expensive and maintenance-intensive. Others, such as thermal detectors, could be slow to react.

Although these technologies can save lives, they may not respond early enough to prevent property damage. And prolonged extinguishing by water sprinklers or misters will actually increase property damage.

A smoke detector was developed that performs in the environments described above. Using a high-density filter and air intake system, airborne matter is removed before it reaches the smoke sensor. Dust, dirt, and insects are filtered out while allowing smoke in.

Detector Development

This smoke detector project had several objectives. The smoke detector must not alarm from dust, dirt, or insects. It shall withstand air velocities up to 20 meters per second. It shall be installed with standard mounting practices. It shall be designed for ease of maintenance. And the detector was to provide early warning compared to heat sensors, thermal wire, or sprinklers.

Many methods were evaluated. Algorithms were tried with optical, ionization, and thermal sensors, as well as with combinations of the sensors. It was found that nuisance alarms from transient conditions could be effectively eliminated. However, alarms still occurred when dust was present for a substantial period or a majority of the time. Also, the continuous presence of dust quickly contaminated the optical chamber and maintenance was required.

Gas sensors were also evaluated. Because of the limited selection of gas sensors available today, it was determined that a smoke sensor would have to be used in addition to the gas sensor. One could not depend solely on the response of the gas sensor to make a fire or non-fire decision. This technique did not perform per the objectives because of the susceptibility of the smoke sensor to dust.

Processing the data from several smoke sensors located throughout a room also proved ineffective. Again, they are all exposed to the dust so the necessary advantages are not gained.

It became apparent that the dust had to be kept away from the sensor. If the sensor was never exposed to the dust, then the dust could not cause an alarm. The sensor needed to be placed in a protective environment.

Two high-density filters were chosen and placed around the sensor. In order to overcome the airflow restriction of the filters, a fan was used to draw air into the sensor. The fan could be operated in either a continuous or pulsed mode. Operating the fan continuously would require the most power, but may not be necessary.

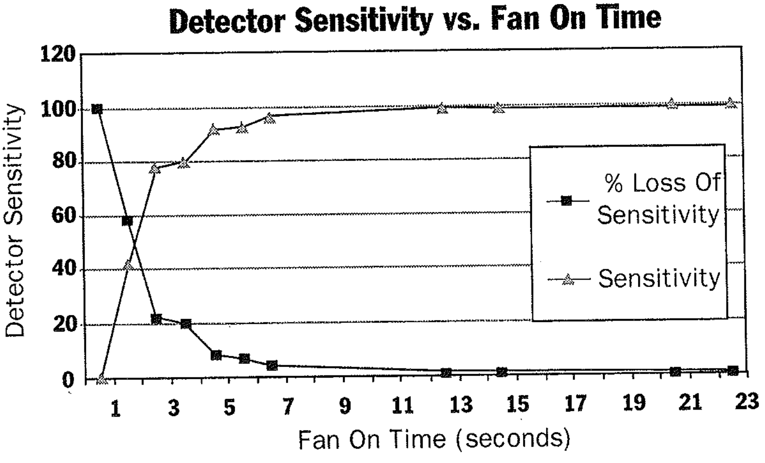

Figure 1. Detector Sensitivity

Figure 1 shows how the detector sensitivity increases with fan on time. Please note that the off time is a constant thirty seconds. At four seconds the sensitivity begins to level off. Below four seconds the sensitivity decreases quickly, probably because the fan rotor does not have enough time and inertia to reach full speed.

The sensitivity of sensors with the filtering system was compared to sensors without the filtering system. It was found that a system using a fan on time of five seconds and an off time of thirty seconds showed a decrease in sensitivity of approximately sixteen percent. This offset is eliminated through factory calibration so special settings are not required at the fire alarm control panel.

The new detector configuration was subjected to several nuisance tests. Three of the tests involved subjecting the detector to atmospheres containing cotton linters, Arizona test dust, and sodium bicarbonate (fire extinguisher grade). In all three cases the particulate was sufficiently filtered.

The filters are constructed of a special material that also restricts the migration of water mist. The detector can also sense smoke in the presence of water mist.

Figure 2 shows a typical sensor response with water mist and smoke. Notice that there is no change in signal level after the water

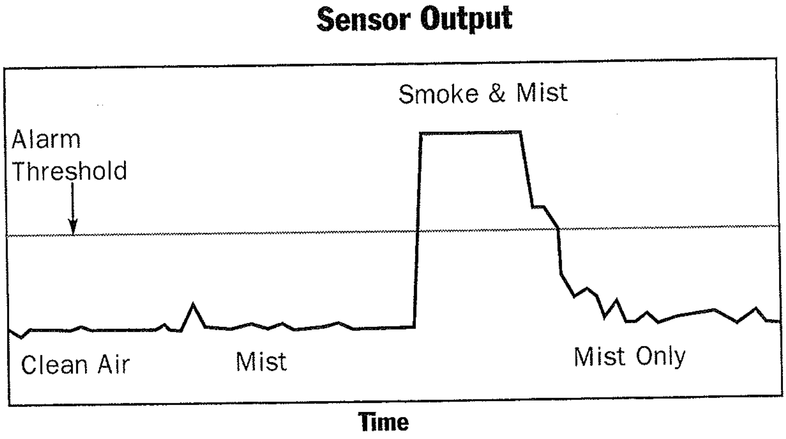

Figure 2. Typical Sensor Response

mist is activated. The output of the sensor remains consistent and stable. When smoke is introduced the sensor responds. While the water mist system is still activated the smoke source is removed. The sensor output signal returns to a level equivalent to that before either the water mist or smoke were introduced.

This would allow the detector to trigger a water mist system to extinguish a fire, monitor the smoke level during activation, and allow the water mist system to be turned off after the fire is extinguished, minimizing the amount of damage caused by water.

System Review

Figure 3 illustrates the operating principles of this new system. The fan draws in air which may contain smoke, dust, etc., enters through inlets in the cover of the detector. It then passes through two high-density micro-pore filters. After being filtered the air enters the optical chamber. From there it is exhausted through ports in the cover.

It is important to note that the operation of the fan and the state of the filters are monitored. The airflow through the fan is monitored to determine if the fan is functioning properly. If the fan fails to move or is not drawing in enough air a signal will be sent to the fire alarm control panel. Also, the airflow through the filters is monitored. If they start restricting the flow of air through them beyond a predetermined threshold, a signal will be sent to the fire alarm control panel.

Maintaining the detector is very simple. The detector need not be removed from the mounting base. The top of the cover, which contains the intake and exhaust ports, has one of the filters mounted in it. This part is field replaceable. Simply twist to remove and install

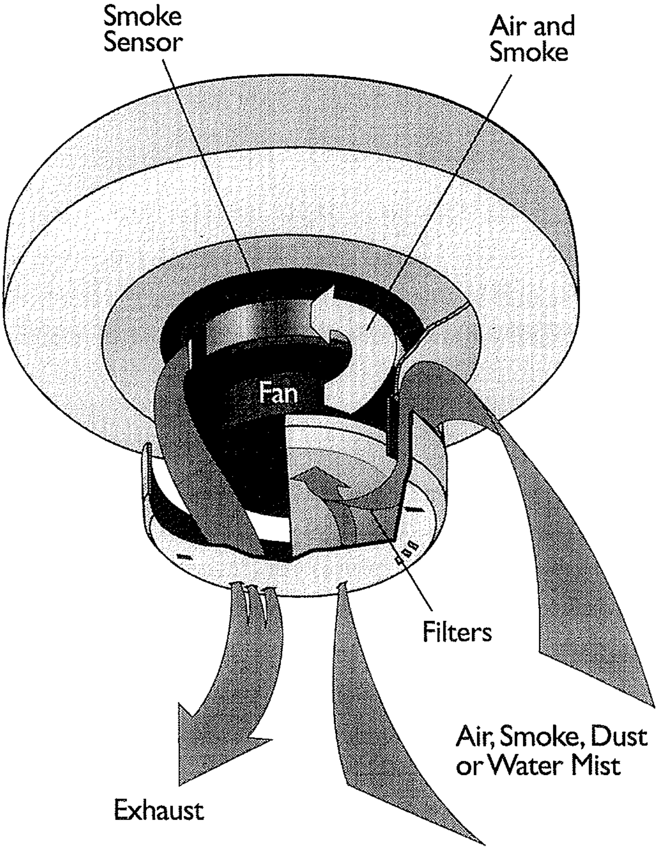

Figure 3. Operating Principles

a new filter assembly. The second filter is permanently attached to the housing. The function of this filter is to keep particulates from entering the sensor while the filter assembly is being replaced.

This detector has met the objectives set forth in the beginning of the project. It did not alarm from dust, or dirt, it functioned in airspeeds up to 20 meters per second, is installed using standard mounting practices, is easy to maintain, and provides early warning.

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Streulichtmelder mit mehreren Streuwinkeln

Abstract

The invention relates to an optical smoke detector with at least more than one scattering angle. As a result this detector is capable of measuring different kinds of smoke, as there is one scattering angle suitable for grey smokes and the other scattering angle for dark smokes, respectively. Furthermore this detector is able to distinguish between real smoke and particles as dust and steam, which are causing false alarms in conventional smoke detectors.

Gliederung:

1. Derzeitiger technischer Stand

In Brandmeldesystemen werden zur Branderkennung Rauch-,Wärmemelder oder Flammenmelder eingesetzt. Die Rauchmelder erkennen das Vorhandensein von Rauch und geben bei Überschreitung einer gewissen, fest eingestellten Schwelle ein Alarmsignal zur Zentrale weiter, die dann wiederum eine Feuermeldung generiert. Bekannte Rauchmelder arbeiten entweder nach dem optischen Streulichtprinzip, nach dem Durchlichtprinzip oder nach dem Ionisationsprinzip. Alle Prinzipien arbeiten nach unterschiedlichen physikalischen Verfahren und sprechen daher auf unterschiedliche Aerosole an.

Heutige Streulichtmelder erkennen dunkle Aerosole, wie sie meist bei Flüssigkeitsbränden entstehen z.B. Diesel, Öl, Benzin sowie schwere bzw. mittelschwere Kohlenwasserstoffverbindungen, schlechter als helle Aerosole, wie sie meist beim Verschwelen oder Verglimmen von z.B. Holz, Baumwolle entstehen. Um eine rechtzeitige Alarmauslösung in Streulichtmeldern bei dunklen Aerosolen sicherzustellen, reagieren diese Melder bei hellen Rauchsorten, z.B. Schwelbränden, sehr empfindlich. Dadurch können helle Aerosole, wie z.B. Wasserdampf, Zigarettenrauch, Dämpfe von Arbeitsprozessen, Stäube, Prozeßbedingte Aerosole, Abgase, Dämpfe durch heißes Fett zu einer unerwünschten Alarmauslösung führen.

Der Ionisationsrauchmelder kann sowohl dunkle als auch helle Aerosole gut erkennen. Der Nachteil liegt unter anderem darin, daß der Meßwert einer hohen Abhängigkeit von Luftströmungen unterliegt und daß eine Ionisationsquelle benötigt wird, die typischerweise aus einem Radionuklid besteht.

Lediglich Multisensormelder, wo verschiedene Sensortypen in einem Gehäuse vereint sind, z.B. Thermo- und/oder optischer- und/oder Ionisationsmelder, sind in der Lage, zwischen verschiedenen Brandgütern und damit verschiedenen Raucharten zu unterscheiden. Die Nachteile liegen in einem höheren Preis, daß ggf. ein Radionuklid verwendet werden muß und daß der Rauch nicht von allen Sensoren zum selben Zeitpunkt am selben Ort, innerhalb des Melders, gemessen wird.

2. Merkmale des Streulichtmelders mit mehreren Streuwinkeln

Aufgrund seines physikalischen Aufbaus, der im wesentlichen aus zwei unterschiedlich angeordneten Streulichtstrecken besteht, ist der Melder in der Lage, eine Unterscheidung von Rauchsorten zu ermöglichen. Diese Unterscheidung bezieht sich auf eine Hell-dunkel-Erkennung der unterschiedlichen Raucharten. Somit ist es möglich, für jeden Rauch einen bestimmten, charakteristischen Hell-Dunkel-Faktor zu ermitteln. Nimmt man nun eine Normierung dieses Faktors auf 100% vor, liefern helle Rauchsorten wie Paraffinnebel oder Zigarettenrauch Faktoren um 30%, während dunkle Rauchsorten wie

Diesel oder N-Heptan Werte um 70% ergeben. Wie oben schon erwähnt, kann ein herkömmlicher Streulichtmelder dunkle Rauchsorten schlechter erkennen als helle Rauchsorten. Seine Empfindlichkeit muß daher auf den Brand eingestellt werden, den er am schlechtesten erkennen kann, um eine sichere Alarmauslösung bei allen Testbränden zu gewährleisten. Daraus folgt aber, daß dieser Melder bei hellen Rauchsorten sehr empfindlich reagiert, da er diese sehr gut erkennen kann. Dieses führt zu einer erhöhten Fehlalarmrate bei dem Einsatz z.B. in Großküchen oder Sägewerken. Die dort entstehenden Stäube und Dämpfe kann ein herkömmlicher Streulichtmelder nicht von hellem Rauch unterscheiden und wird einen Fehlalarm auslösen.

Hingegen ist der O^2T-Melder in der Lage, eine Unterscheidung von Rauchsorten durch die Ermittlung eines Hell-Dunkel Faktors zu gewährleisten. Damit ist es möglich, die Empfindlichkeit des Melders durch eine analoge Gleichung je nach Helligkeit der Rauchsorte zu ermitteln. Wird z.B. ein kleiner Hell-Dunkel Faktor gemessen, liegt ein heller Rauch vor und die Empfindlichkeit kann herabgesetzt werden. Entsprechend wird bei dunklen Rauchsorten die Empfindlichkeit erhöht.

Als Resultat ergibt sich ein Melder mit einer gleichmäßigen Empfindlichkeit für alle Rauchsorten. Die Gesamtempfindlichkeit dieses Melders ist wesentlich geringer als bei herkömmlichen Streulichtmeldern, was sich in einer deutlich verringerten Fehlalarmrate bemerkbar macht.

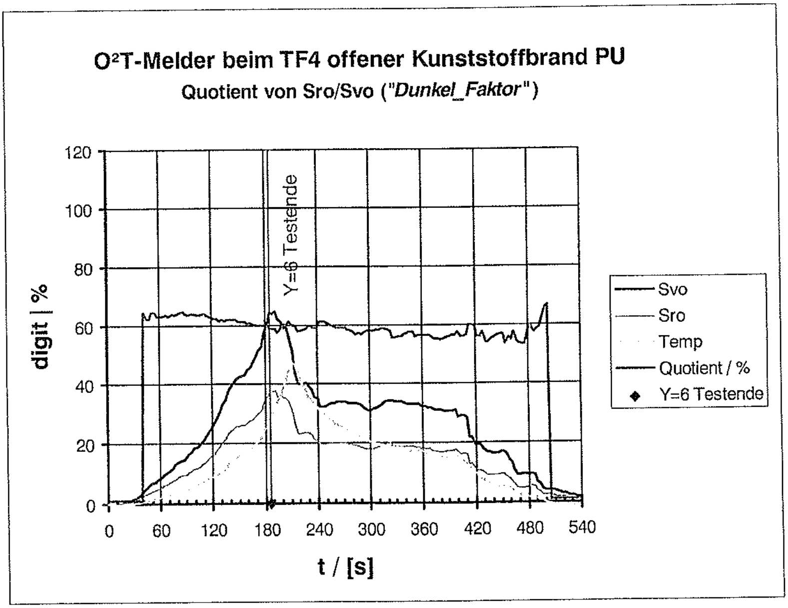
Zur Unterstützung des Melders bei unsichtbaren Aerosolen befindet sich in dem Melder noch ein Thermoteil, der die Alarmauslösung z.B. beim Spiritusbrand gewährleistet.

Insbesondere ist es möglich, bestimmte Täuschungsgrößen wie z.B. Wasserdampf oder Stäube und Dämpfe aus Arbeitsprozessen zu erkennen und diese eindeutig von Rauch zu unterscheiden. So liefert z.B Wasserdampf einen nur für Wasserdampf charakteristischen Faktor. Auch wenn diese Täuschungsgrößen in der gleichen Intensität wie Rauch im Falle eines Brandes vorliegen(z.B. Dämpfe in Großküchen oder Stäube in Sägewerken, o.ä.), wird der Melder keinen Alarm auslösen und ist damit auch in Umgebungen einsetzbar, wo konventionelle Melder aufgrund ihrer höheren Falschalarmanfälligkeit nicht einsetzbar sind.

Man könnte die Messergebnisse des Melders mit fest abgespeicherten Brandmustern vergleichen. In der Praxis in einem realen Brand treten jedoch immer Mischbrände auf, die sich nicht einklassifizieren lassen. Daher kann ein Vergleich mit einem abgespeicherten Brandmuster kein realistisches Ergebnis liefern. Der Erfindung liegt zugrunde, die Hell-dunkel Abstufung von Rauchsorten zu erkennen und den Streulichtmesswert stetig und gleichmäßig anhand dieses Helligkeitswerts durch eine mathematische Funktion zu bewerten. Damit kann jede Brandsorte erkannt und zugeordnet werden.

3. Präsentation der Messergebnisse

1. O^2T-Melder beim TF4 offener Kunststoffbrand PU



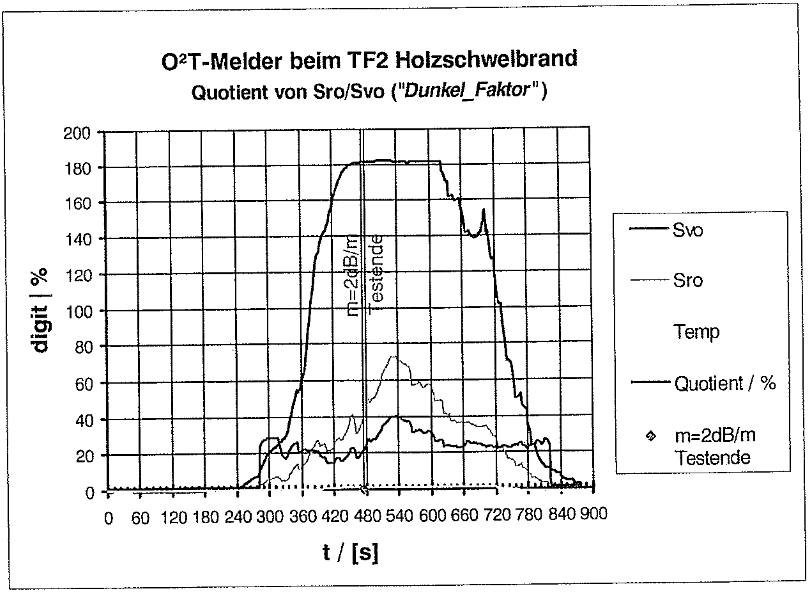
Auf der Y-Achse sind die Meßwerte des Melders in Digit, auf der X-Achse ist die Zeit aufgetragen. Die blauen und grünen Kurven sind die Meßwerte der beiden

Streulichtstrecken.

Die rote Kurve ist der Quotient der beiden Streulichtstrecken und wird benötigt, um den zur Alarmentscheidung erforderlichen Dunkelfaktor zu ermitteln. Die gelb eingezeichnete Kurve ist das Ergebnis der Temperaturmessung. Außerdem ist das Testende eingezeichnet, wie es in der Norm EN54, Teil 9 festgelegt ist.

Als Ergebnis ist festzustellen, daß der Quotient während des gesamten Brandversuchs ziemlich konstant bei 60% bleibt, obwohl die einzelnen Meßwerte stark schwanken. Damit ist dieser Rauch als dunkel einzustufen.

2. O^2T-Melder beim TF2 Holzschwelbrand

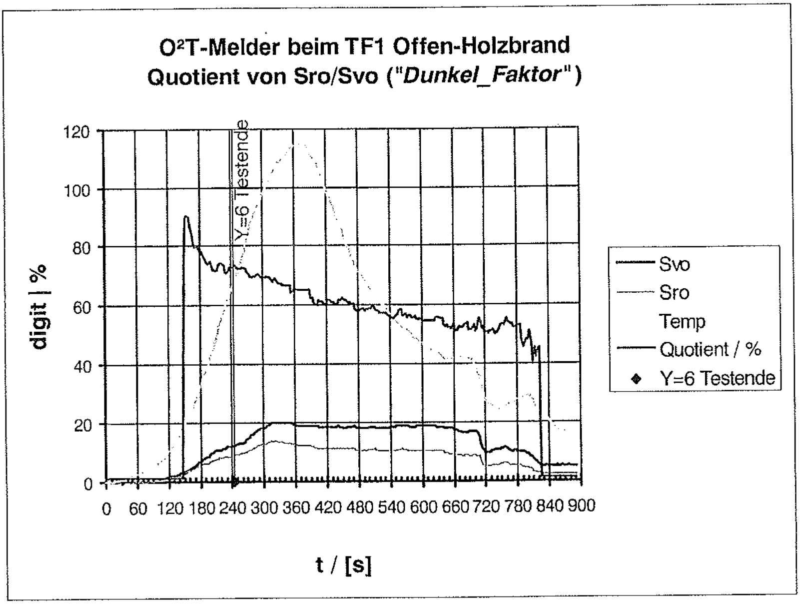


Auch hier ist das Ergebnis des Quotienten konstant bei etwa 20%.

Verfälscht wird der Faktor allerdings, weil eine der Streulichtstrecken (blau) ca. bei Testende die Aussteuerungsgrenze erreicht hat. Nachdem der Meßwert wieder in den

Analogbereich zurückkehrt, stimmt auch der Faktor von 20% wieder. Damit ist dieser Rauch als hell einzustufen.

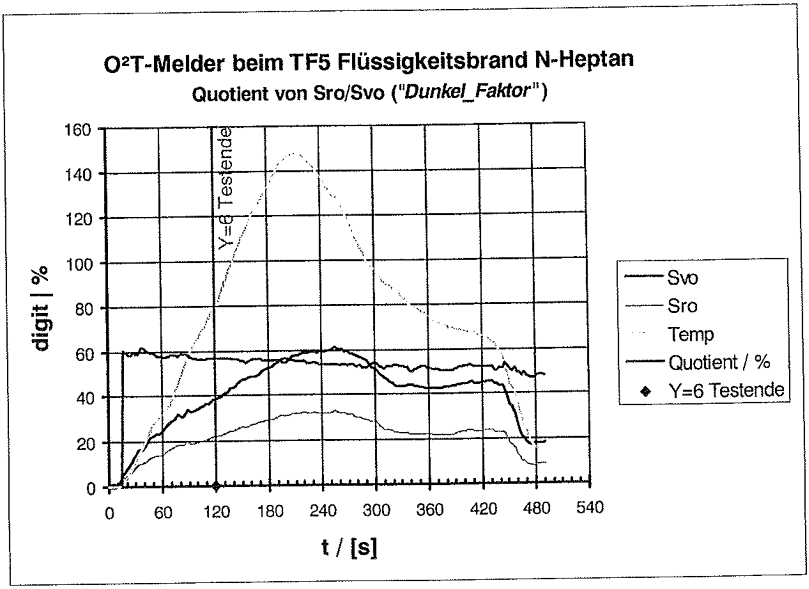
3. O^2T-Melder beim TF1 offener Holzbrand



Interessanterweise wird hier ein dunkler Rauch ermittelt bei einem Quotienten von etwa 70% vor dem Testende.

Man erkennt, daß beide Streulichtstrecken geringe Signale liefern, die einzeln selbst eine geringe Alarmschwelle nicht überschreiten würden. Der Quotient von etwa 70% würde zu einer Empfindlichkeitserhöhung führen, was bei diesem Brand angesichts der geringen Meßsignale auch sinnvoll ist.

4. O^2T-Melder beim TF5 Flüssigkeitsbrand N-Heptan



Hier ergibt sich ebenfalls als Ergebnis dunkler Rauch mit einem Quotienten von ca. 60%. Auch dieser Brand ist für herkömmliche Streulichtmelder aufgrund des dunklen Aerosols sehr schwer zu erkennen. Beim O^2T-Melder ergibt sich ein gut reproduzierbarer, konstanter Meßwert.

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SamDetect - Ein intelligenter Brand- und Gefahrstoffsensor

Abstract

Fire- and other hazardous events with release of volatile substances can be detected in an early phase by monitoring of a variety of off-gassing substances and products of thermal degradation. The concept of the smart pre-fire and harmful gas detector SamDetect makes usage of a multi-sensor array technology in combination with intelligent data processing (Neural Network).
It is intended to use the sensor especially for the detection and classification of smouldering fires and surveillance of working areas in complex contamination situations.

1. Einleitung

Allgemein stellt eine Verbrennung eine Oxidation eines brennbaren Stoffes mit Sauerstoff unter Wärmeeinfluß (geeignete Zündquelle) dar. Dabei tritt eine energetische Umwandlung auf, in deren Ergebnis Wärmeenergie als Form von Strahlung (UV, sichtbar, IR) sowie durch turbulente und laminare Konvektion abgegeben wird. Als remanente Umsetzprodukte der Verbrennung entstehen Ruß, Wasser und flüchtige Brandgase (Kohlendioxid, Kohlenmonoxid, Stickverbindungen usw.) sowie Rauch und Aerosole /1/.
Die Funktion gegenwärtig verfügbarer Brandmelder basiert zumeist auf physikalische Meßgrößen:

- Ionisationsmelder (Partikel, Aerosole)
- Optische Rauchmelder (Partikel, Aerosole)
- Flammelder (Strahlung)
- Temperaturmelder (Temperatur, Temperaturgradienten)

Voraussetzung für die Funktion dieser Melder ist ein entwickelter Brandprozeß, der in genügendem Maße Rauch, Aerosole und elektromagnetische Strahlung erzeugt oder einen starken Temperaturanstieg in der Umgebung verursacht. Zahlreiche Brandereignisse zeigen, daß diese Melder für eine Früherkennung in rauhen Industrieumgebungen, in denen naturgemäß Rauch, Staub, Aerosole und Wasserdampf vorhanden sind, nur bedingt geeignet sind. Auch durch Kombination verschiedener physikalischer Detektoren lassen sich diese Nachteile nur bedingt verbessern. Eine Identifizierung von Brandlasten und Brandverläufen über physikalisch wirkende Melder ist kaum möglich.

2. Lösungskonzept

Seit dem Ende der 80-ziger Jahre werden Meßsysteme beschrieben, die als "elektronische Nase" bezeichnet werden und die in der Lage sind, komplexe Gasgemische mit hoher Sensitivität zu erfassen und zu bewerten. Dabei handelt es sich um Geräte, welche mit elektronischen Mitteln die Funktionsweise der Geruchsorgane von Säugetieren nachempfinden. /2/, /3/, /4/.

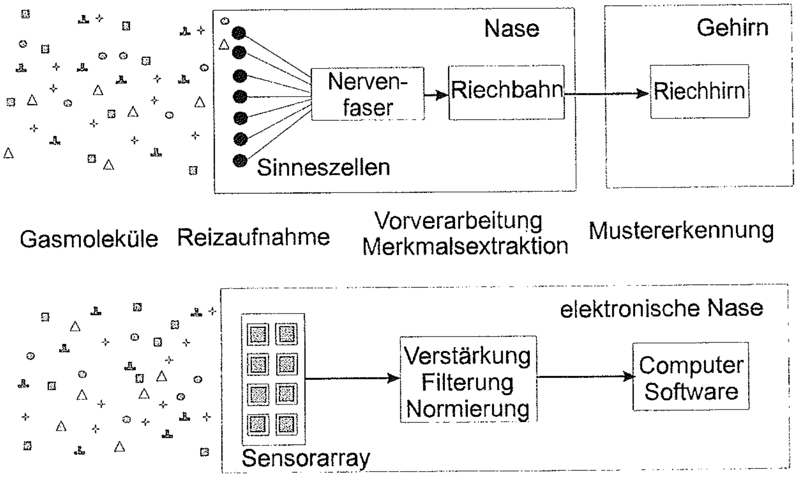

Abb. 2.1 Analogie der elektronischen Nase

Das Herzstück einer "elektronischen Nase" bildet ein Sensorarray mit einer der Meßaufgabe angepaßten Anzahl von teils selektiven, teils unselektiven chemischen Einzelsensoren. Diese Einzelsensoren erzeugen in Abhängigkeit von einer gegebenen komplexen Kontaminationssituation Antwortsignale aus denen ein Signalmuster abgeleitet werden kann, welches für das gemessene Gasgemisch charakteristisch ist. Dieser "Fingerabdruck" eines Gasgemisches kann mit modernen Verfahren der Mustererkennung analysiert und klassifiziert werden. Durch Trainieren des Systems mit Signalmustern typischer Stoffgemische ist eine Identifizierung von komplexen Gasgemischen und die Herstellung von Ähnlichkeitsbeziehungen zwischen bekannten und unbekannten Gasgemischen möglich.

Das Lösungskonzept des vorgeschlagenen Brand- und Gefahrstoffsensors sieht die Verwendung eines Arrays von chemischen Sensoren vor, mit dem die Detektion eines Brand- und Gefahrenereignisses mit hoher Sensitivität auf der Grundlage einer breiten Palette von gasförmigen Brandzersetzungsprodukten möglich ist. Durch Bewertung der Muster der Ausgangssignale des Sensorarrays sollen Aussagen abgeleitet werden, mit denen eine Klassifikation der konkreten Kontaminationssituation (Gefahrenereignis/Störung) sowie eine Charakterisierung des Gefahrenereignisses möglich ist (Brandverlauf, Brandlast) /5/, /6/, /7/.

3. Chemische Brandzersetzungsprodukte

In Verbrennungsprozessen entstehen üblicherweise zahlreiche gasförmige Verbrennungsprodukte, deren Vorhandensein und Konzentration von verschiedenen, den Brandprozeß bestimmenden Parametern abhängt /8/. Tabelle 3.1 stellt auszugsweise die Ergebnisse einer Literaturrecherche zu typischen Brandzersetzungsprodukten häufig verwendeter Materialien dar.

Brandbereich	**Brandlast/Material**	**Brandzersetzungsprodukte**
öffentliche Einrichtungen	Textilien, Papier, Holz, Duroplast Nylon Polyamid	CO_2, CO, Alkane, HCN, NH_3, NO_X, Isocyanat Nitrile, Alkene, arom. KW, Amine
Elektrische Anlagen	PVC, PE, PTFE, FEP, Füllstoffe, Weichmacher	CO_2, CO, Alkane HCl, Cl_2,Phosgen, Aldehyde, Alkane, Alkene, arom. KW,
Bergbau, Kohle	Braunkohle, Steinkohle, Koks	CO_2, CO, Alkane H_2S, H_2, SO_X, Alkane, Alkene
Trockneranlagen	Getreide, Futtermittel	CO_2, CO, Alkane Aldehyde, arom. KW
Erdölverarbeitung	Treibstoffe	CO_2, CO, Alkane
Reifenlager	Synthesekautschuk, Füllstoffe	CO_2, CO, Alkane H_2, SO_X, Alkene, PAK, BTX
Transformatoren	Triclorbenzol, Isolierungen	CO_2, CO, Alkane HCl, PCB
Schiffsmaschinenraum	Schweröl	CO_2, CO, Alkane, NO_X, SO_X

Tab. 3.1 Brandzersetzungsprodukte

Wesentliche Brandgase, die sowohl für die Detektion als auch die Klassifizierung von Brandereignissen durch eine "Elektronisch Nase" verwendet werden können, sind: /9/

Kohlendioxyd	300-20 000 ppm
Kohlenmonoxyd	10-1 000 ppm
Wasserstoff	10-500 ppm
Kohlenwasserstoffe	1-100 ppm
Ammoniak	1-50 ppm
Stickoxyde	1-10 ppm
Schwefeloxyde	1-10 ppm

4. Systemkonzept des Brand- und Gefahrstoffsensors

Das Systemkonzept des SamDetect zeigt Abb 4.1

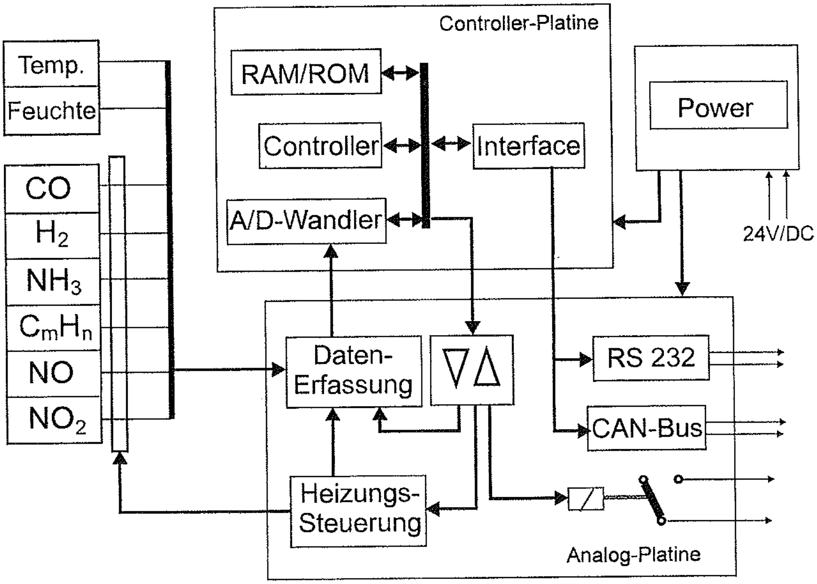

Abb. 4.1 Systemkonzept des SamDetect

Die gasförmigen Kontaminations- und Brandzersetzungsprodukte werden durch Konvektion zur Sensoreinheit transportiert. Ein Luftfilter am Eingang der Sensorbaugruppe verhindert eine Verschmutzung der Sensorelemente durch Staub und Aerosole. Durch die im Sensorarray integrierten chemischen Sensorelemente erfolgt die Erfassung der in der Atmosphäre vorhandenen Kontaminations- und Brandzersetzungsprodukte.

Der Micro-Controller ist die zentrale Rechen- und Steuereinheit des Sensorsystems (80C167mit 32 kB RAM und 132 kB ROM), über dem die nachfolgend genannten Funktionen realisiert werden:

- Erfassung der Ausgangssignale der Sensoren über A/D-Wandlereingänge
- Steuerung der Heizung des Sensorarrays
- Meßwertverarbeitung (Rekalibration, Normierung, Klassifikation)
- Implementierung und Steuerung der Interface des Sensors (RS 232, CAN-Bus, Relays-Kontakt)
- Systemtest aller Sensorbaugruppen

Die Entwicklung des SamDetect wurde auf Basis eines Arrays aus MOS-Sensoren ausgeführt. Ausschlaggebend für diese Entscheidung war das dynamische Verhalten der Sensoren, ihre gute Lebensdauer, ihre hohe Sensitivität auf typische Brandzersetzungsprodukte sowie ihre gute Integrierbarkeit und Verfügbarkeit am Markt zu niedrigen Preisen. Abbildung 4.2 zeigt das realisierte Muster eines Sensorarrays, bei dem 6 sensitive Schichten auf einem Keramikträger angeordnet wurden.

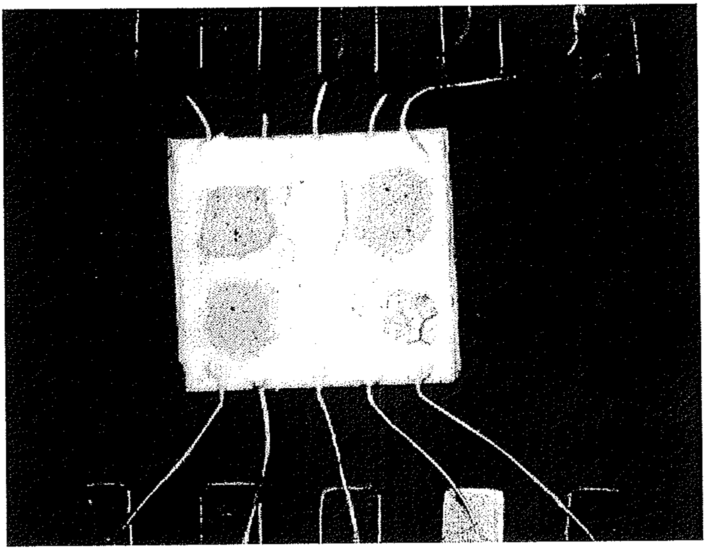

Abb. 4.2 6-fach Sensorarray

Das Konzept der internen Signalbearbeitung des SamDetect ist in Abb. 4.3 dargestellt.

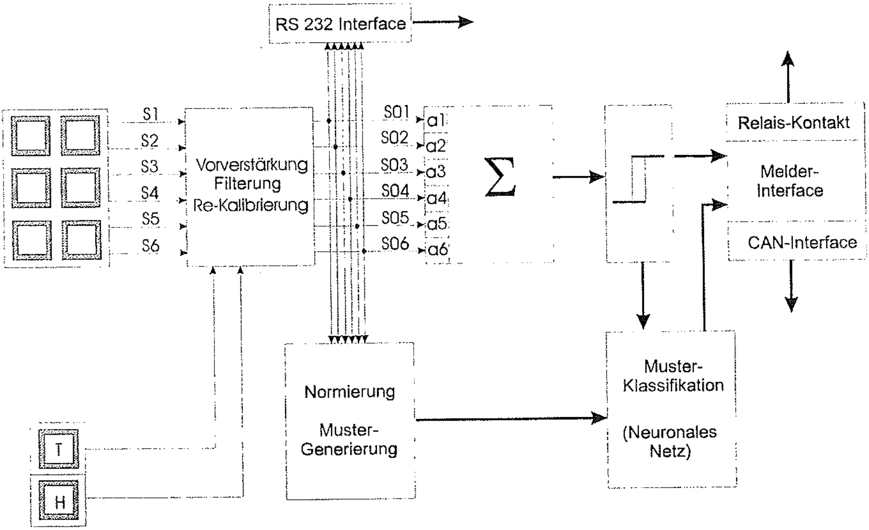

Abb. 4.3 Systemkonzept der internen Signalverarbeitung

Die Ausgangssignale des Sensorarrays sowie die Ausgangssignale des Temperatur- und des Feuchtesensors werden über A/D-Wandler in den µC eingelesen. Diese Signale werden in einer ersten Verarbeitungsstufe gefiltert und Re-kalibriert . Über eine weitere zeitliche Mittelwertbildung wird der Grundwiderstand für jedes Sensorelement des Arrays bestimmt, der sich im unkontaminierten Zustand an normaler Umgebungsluft einstellt. Alle Änderungen des Widerstandes der Sensorelemente durch gasförmige Kontaminationsstoffe werden auf diesen Grundwiderstand bezogen.
Alle Sensorsignale können über ein RS 232 Interface ausgelesen werden und stehen damit für Detailuntersuchungen und Fehlersuche zur Verfügung.

Die Beträge der relativen Widerstandsänderungen der Einzelsensoren werden gewichtet und zu einem Summensignal zusammengefaßt. Dieses Summensignal ist ein Maß für die Stärke einer auftretenden Kontamination. Bei Überschreitung eines vorgegeben Grenzwertes wird ein Neuronales Netz aktiviert, welches das Muster des erfaßten Kontaminationsereignisses klassifiziert. Erkennt das Neuronale Netz ein für einen Brand typisches Signalmuster (Schwelbrand, offener Brand, spezielle Brandlast) erfolgt eine unmittelbare Auslösung eines Alarmierungssignals, welches sowohl über einen Relaiskontakt als auch über ein CAN-Bus Interface ausgegeben werden kann. Bei Erkennung von Signalmustern, die für Störgrößen typisch sind (Zigarettenrauch, Lösungsmitteldämpfe, Autoabgase, ...) erfolgt eine Verzögerung bzw. Unterdrückung der Alarmgebung.

Abb. 4.4 zeigt einen Prototypen des SamDetect

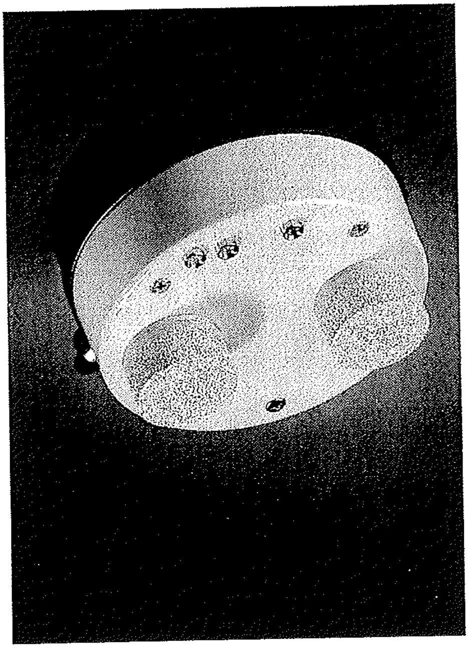

Abb.4.4 Prototyp SamDetect B1

5. Erprobungsergebnisse

Zum Nachweis der Leistungsfähigkeit des SamDetect wurde der Sensor definierten Testfeuern nach EN 54 Teil 9 (TF1-TF6) sowie häufig auftretenden Störgrößen in einem Brandraum ausgesetzt..
Als Störgrößen wurden Lösungsmitteldämpfe, Abgase einer Dieselmaschine, Zigarettenrauch und Rauchgas beim Gasschweißen untersucht:
Tabelle 5.1 zeigt einen Vergleich der Ansprechzeiten verschieder Melder /12/ .

	Ansprechzeiten der Melder in (min)			
	opt. Melder	**Ionis.-melder**	**CO-Sensor**	**SamDetect**
Schwelbrände				
Buchenholz	7	10	5	4
Braunkohle	9	15	5	5
offenes Feuer				
PUR	5	4	3	4
Buchenholz	33	15	11	6
Dieselkraftstoff	1	1	1	1
Spiritus	∞	∞	∞	5
Papier	∞	3	1	2
Textil	∞	3	3	3
Störgröße				
Zigarettenrauch	2	∞	2	∞
Laden Bleiakku (H_2)	∞	∞	180	∞
Schweißgas (Ethin)	∞	∞	4	∞
Theaternebel	3	2	∞	∞

Tab. 5.1 Ansprechzeiten der Melder

Insbesondere bei Schwelbränden ist ein deutlich schnelleres Ansprechen der CO-Sensoren und des SamDetect im Vergleich zu optischen Rauchmeldern und Ionistaionsmeldern festzustellen. Auch im Bereich der offenen Feuer sind die Melder auf Basis der chemischen Sensoren den konventionellen Meldern teilweise deutlich überlegen (Buchenholz, Flüssigkeitsbrände)
Bei den ausgeführten Experimenten mit Störgrößen konnte eine deutliche Überlegenheit des SamDetect insbesondere bei solchen Prozessen nachgewiesen werden, die mit einer Emission von Partikeln und Aerosolen verbunden sind.(Zigarettenrauch, Staub, Theaternebel). Auch im Bereich der gasförmigen Störgrößen konnte durch die Bewertung der Signalmuster des Arrays eine genügende Funktionssicherheit erreicht werden.

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Advanced Fire Detection Using Multi-signature Alarm Algorithms

Abstract

The objective of this work was to assess the feasibility of reducing false alarms while increasing sensitivity through the use of combined conventional smoke detectors with carbon monoxide (CO) sensors. This was accomplished through an experimental program using both real (fire) and nuisance alarm sources. A broad selection of sources was used ranging from smoldering wood and flaming fabric to cooking fumes. Individual sensor outputs and various signal conditioning schemes involving multiple sensors were explored.

The results show that improved fire detection capabilities can be achieved over standard smoke detectors by combining smoke measurements with CO measurements in specific algorithms. False alarms can be reduced while increasing sensitivity (i.e., decreasing the detection time for real fires). Patented alarm criteria were established using algorithms consisting of the product of smoke obscuration and the change in CO concentration. Alarm algorithms utilizing ionization detector smoke measurements proved to be more effective than measurements from photoelectric detectors.

Introduction

The objective of this work was to demonstrate the potential of a combined CO/smoke detection algorithm which is capable of discriminating between signatures from real fire and nuisance sources. The main goal was to provide faster response to real fire threats while providing better nuisance alarm immunity compared to conventional smoke detectors. The overall experimental work plan involved the development and testing of a prototype combined CO/smoke detector. This work was divided into several tasks which included evaluation of appropriate CO sensor technologies, measurement of multiple fire signatures from incipient fire and nuisance sources, detection tests with larger sources, detection tests in a UL217/EN54 test facility, and analysis of the data for development of signal processing algorithms. This paper presents the work based on the incipient fire and nuisance source testing.

Experimental Setup and Procedure

The majority of tests performed consisted of small incipient sources in a 49 m^3 (1730 ft^3) test room. The compartment was 5.87 by 3.43 by 2.44 m high (19.25 by 11.25 by 8 ft). Natural ventilation was provided through a 38 cm x 30 cm duct located at the floor in the front right corner of the room. The sources were located 0.61 m from the center of the right wall. Smoke detectors and sensors were mounted at the ceiling, centered in the compartment at a distance of about 4.57 m (15 ft) from the source. Smoke detectors consisted of Simplex ionization detectors (Model 4098-9716) and Simplex photoelectric detectors (Model 4098-9701). A specially designed hardware/software package was used to poll the detectors every 4 to 5 seconds and save the data to a computer file.

Other sensors included various CO sensors, such as a City Technology Limited 3ME/F CiTicel carbon monoxide sensor with a range of 0-100 ppm (electrochemical cell), and a Telaire Systems, Inc. Ventostat (R) 2001V CO_2 detector with a range of 0-5000 ppm (non-dispersive infrared). A gas sampling probe was located next to the detectors. Gas samples were analyzed by NDIR CO and CO_2 analyzers and a paramagnetic O_2 analyzer (Servomex 540A). The CO analyzer was a Horiba VIA-510 with a 100 ppm range and 1 percent of full scale accuracy.

The results presented below are based on CO measurements from the continuous gas sampling system which have been time-shifted for a 90 percent system response time of 30 seconds. Results using the real-time CO data from the City Technology electochemical cell sensor agreed very well with the time corrected NDIR measurements.

Smoke detector alarm conditions were set to be consistent with UL Standards 217 and 268 [1,2]. For the purpose of analyzing this data, the alarm criteria for the detectors was evaluated at typical values of 4.52 percent obscuration per meter (1.4%/ft) for ionization and 6.72 percent obscuration per meter (2.1%/ft) for photoelectric.

Selection of Test Sources

This phase of testing consisted of developing repeatable real alarm and nuisance sources which challenged the detection limits of the commercial smoke detectors used in the test series. The main purpose of these tests was to develop a data base which could be used to refine and evaluate multi-signature alarm algorithms. The two key criteria were to establish real alarm conditions for detector response time performance and also conditions which would cause commercial detectors to create nuisance alarms. A primary emphasis was placed on sizing the sources so that smoke levels and CO concentrations increased slowly with respect to time while maintaining test times to a minimum. The first column in Table 1 shows the sources that were tested.

Table 1. Summary of the Number of Alarms Signaled by Ionization and Photoelectric Smoke Detectors compared to the Alarm Algorithm (Ion · CO≥ 10)

Source [1]	Ionization	Photoelectric	Ion · CO = 10
Real Alarm			
Heptane	7/7	0/7	7/7
Alcohol	0/3	0/3	0/3
Gasoline	5/5	5/5	5/5
Polyurethane	3/3	0/3	3/3
Cardboard	3/5	0/5	5/5
Cotton fabric	3/4	0/4	4/4
Cotton wick	2/2	0/2	2/2
PVC cable (s)	0/3	3/3	0/3
Cotton wick (s)	0/3	3/3	3/3
Wood (s) 350 C	0/3	3/3	0/3
Wood (s) 425 C	0/3	3/3	1/3
Wood (s) 450 C	0/3	3/3	3/3
Polyurethane (s)	1/3	3/3	3/3
Cotton batting (s)	0/3	3/3	3/3
Upholstery fabric (s)	1/3	3/3	3/3
No. Detected / No. of Tests	25/53	29/53	42/53
No. Detected / No. of Sources	8/15	9/15	12/15
Nuisance Alarms			
Wesson oil (s)	0/3	3/3	0/3
Toast (s)	3/3	3/3	3/3
Cheddar cheese (s)	0/3	2/3	0/3
Bacon (s)	1/3	3/3	0/3
Propane burner	0/2	0/2	0/2
Propane burner with H_2O pan	0/2	0/2	0/2
Kerosene heater	0/2	0/2	0/2
Cigarettes	3/3	2/3	3/3
People smoking	0/3	1/3	0/3
Steam	2/3	3/3	0/3
No. Detected / No. of Tests	9/27	17/27	6/27
No. Detected / No of Sources	4/10	7/10	2/10

1. (s) indicates smoldering

General Development of an Alarm Algorithm

There are several advantages to developing a combined CO/smoke detector. One of the primary advantages is the ability of a combined sensor algorithm to reduce most nuisance alarms. Most nuisance alarms which are not related to hardware problems are the result of non-fire aerosols. Cooking aerosols, dusts, tobacco, and aerosol can discharges are examples of sources which cause nuisance alarms [3]. Cooking aerosols and steam (e.g., from a shower) are the most common nuisance alarm sources [4,5]. Of these examples, only tobacco smoke and possibly gas fired cooking are expected to contain carbon monoxide. This makes carbon monoxide an attractive fire signature for detection purposes. The fact that carbon monoxide is the causative agent in a majority of fire deaths further enhances the desirability of using CO as a fire signature. Given the toxic properties of CO, it can be argued that a "false" alarm due to the actual presence of CO in non-fire situations is not a false alarm at all. Actually, such alarms are desirable for the general safety of building occupants.

The key to this advanced fire detection technology is the development of a specific algorithm which can effectively combine a CO sensor output (i.e., ppm CO) with that of a smoke detector such that nuisance alarms are eliminated and detector sensitivity to real fire sources is at least equal to, if not better than, current smoke detectors. An example of the general approach is depicted in Figure 1 which shows a plot of smoke obscuration versus CO concentration. This plot illustrates several correlation strategies. Line 1 represents the alarm of a smoke detector set to 4.8 percent obscuration per meter (1.5 % per ft). Sources which produce detector outputs lower than this value are considered non-fire threats by the conventional ionization-type smoke detector.

Curve 2 represents the use of "AND/OR" logic by requiring that the sum of the smoke measurement AND the CO concentration OR the smoke measurement OR the CO concentration reach a preset value. For this example, the alarm value is 10 (i.e., Smoke + CO = 10), the smoke is measured in percent obscuration per meter, and the CO concentration is measured as parts per million (ppm). Compared to curve 1, curve 2 effectively reduces the sensitivity of the smoke detector when considered individually. The required smoke level for alarm is 10 instead of 4.8. Reducing detector sensitivity has been a common method for reducing nuisance alarms [3]. However, the reduced

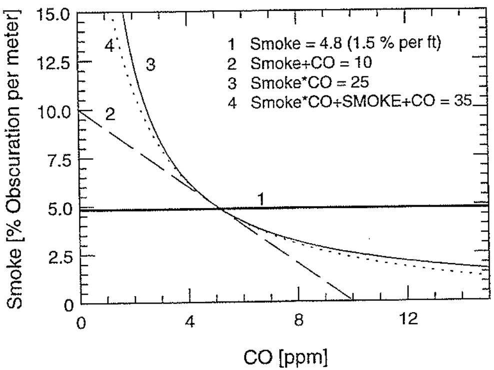

Fig. 1 - Smoke obscuration v. CO alarm criteria

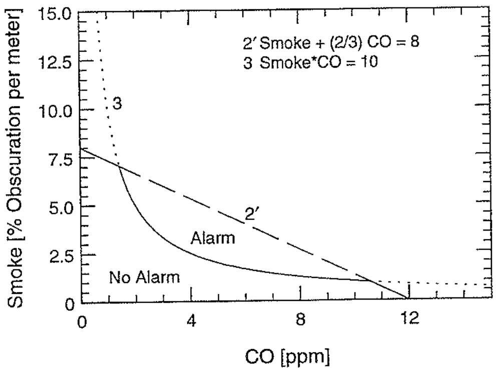

Fig. 2 - Smoke/CO alarm criteria using combined curves

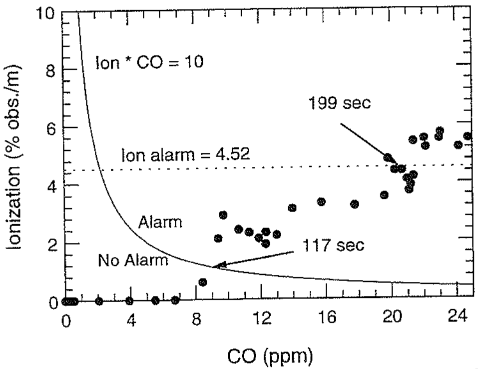

Fig. 3 - Example of improved sensitivity with algorithm for a cotton fabric fire

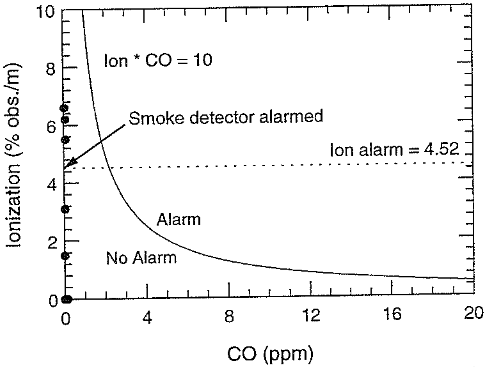

Fig. 4 - Example of improved nuisance alarm immunity when exposed to steam

sensitivity can also result in much longer response times for real fires. Since fire growth is exponential, longer response times can translate into fire deaths. The inclusion in the correlation of a change in the CO level serves to reduce this response time effect while maintaining the original objective of reducing nuisance alarms. For example, in order to have an alarm with a smoke measurement of 5 percent per meter, the measured increase in CO would have to be 5 ppm. Since most nuisance alarm sources do not produce CO, the correlation eliminates particle-producing, non-fire threat sources that fall below curve 2 in Figure 1. This type of correlation can also provide faster alarm responses for fire threats in which CO is detected much faster than smoke.

A second correlation technique is to take the product of the smoke and CO measurements. In Figure 1, curve 3 represents the product as a constant value of 25. For clarity, the curves in Figure 1 have been arbitrarily drawn with a common point of tangency. Due to the asymptotic nature of this curve, a nonzero value for both smoke obscuration and the change in CO concentration is required to signal an alarm for this correlation. This characteristic is not desirable since there are fire sources which can produce near zero changes in the measured CO concentration (e.g., smoldering PVC cable). Therefore, in actual practice, this correlation would be combined with an alarm limit for both smoke and CO. As an illustration, an alarm condition would exist for a product greater than 25 or if the change in CO was greater than 20 ppm or the smoke level was greater than 10 percent per meter.

This alternate method to eliminate the problem of near zero smoke or CO measurements is actually a combination of curves 2 and 3 using OR logic. A similar combination using AND and OR logic is represented by curve 4. For this example, the alarm level for both the AND and OR combination is 35. Therefore, the two conditions can be represented as a single equation. This type of correlation states that an alarm condition is reached when the product of the smoke and CO outputs plus the individual outputs equals a set value (AND logic). An alarm will also be signaled if the product or one of the individual signals equals the alarm value (OR logic).

By selecting different alarm thresholds and various combinations of these correlations using Boolean logic, an infinite number of alarm curves can be created. Figure 2 shows an example of an alarm curve created by combining curves 2 and 3 in Figure 1 using OR logic with different alarm levels and weighting coefficients. Curve 2 in Figure 1 has been changed so that the smoke measurement is weighted more in curve 2' of Figure 2 (i.e., a line from 8 percent smoke to 12 ppm CO instead of a line from 10 percent smoke to 10 ppm CO). This change is representative of decreasing the correlation sensitivity with respect to the CO component. This would tend to reduce nuisance alarms due to CO from tobacco smoke, for example.

The dashed and dotted lines in Figure 2 represent the individual curves for the two correlations. The solid line represents the alarm correlation which results from combining the two correlations using OR logic. An alarm is indicated if either condition 2' (Smoke+(2/3)CO>8) OR condition 3 (Smoke*CO>10) is true. This alarm correlation is more sensitive to fire sources that produce both smoke and CO than simply using curve 2'. And, it sets individual alarm limits for both smoke and CO, thus avoiding the asymptotic behavior of curve 3.

Example of an Alarm Algorithm

Overall, the test results of more than 600 experiments have shown that a single optimal fire alarm algorithm does not exist. Rather, the fire alarm algorithm used for a fire detection system is better tailored to the specific type of use (e.g., industrial, residential, kitchen, etc.). This is because certain applications place higher priority on improved sensitivity rather than reduced nuisance alarms, or vice-versa. Additionally, alarm algorithms differ depending on the type of smoke detector (ionization or photoelectric). Because of limited space in this paper and the large amount of data and analysis performed, this section only presents a summary of results for the incipient source tests and an example algorithm. The discussion focuses on an algorithm which has proven to be effective in meeting the two primary goals of this program (i.e., better fire/nuisance source discrimination and shorter fire alarm times). Preferred algorithms with greater performance capabilities have been developed. Additional information is provided in reference [7].

Table 1 presents a summary of the performance of the ionization and photoelectric smoke detectors in the 49 m^3 test compartment during the experiments using incipient sources. Table 1 shows for each test source the number of alarms signaled by each detector per the number of tests conducted for that source. The smoke detectors were considered to be in alarm at 4.52 percent obscuration per meter for the ionization detector and 6.72 percent obscuration per meter for the photoelectric. At the bottom of each column in Table 1 are two totals indicating the number of alarms signaled per total number of tests and the number of alarms signaled per total number of different sources.

As expected, the ionization detectors were better at detecting flaming fires, and the photoelectric detectors were better at detecting smoldering sources. For example, the ionization detectors were unable to detect the smoldering fires, such as PVC cable, cotton wick, and wood; the photoelectric detectors were unable to detect flaming fires of sources such as heptane, polyurethane foam, and cotton wick. (Although detection was not achieved for some sources in these incipient tests, given longer duration or larger size sources, alarms may result. Therefore, these results should not be taken as necessarily showing a limitation of each type of smoke detector.)

Numerous alarm algorithms were evaluated. Parameters that were studied included ionization and photoelectric smoke measurements, CO and CO_2 concentrations, and rate of rise of these variables. Generally, the algorithms that incorporated the ionization detector instead of the photoelectric detector signals were more effective overall. Some combinations of photoelectric and CO signals were able to detect more real sources than ionization and CO; however, this was accompanied by significant increases in nuisance alarms.

One algorithm that has proven to meet the goals of this program is based mainly on the criteria that if the product of the ionization detector output (% obscuration per meter) and the CO sensor (ppm) is greater than 10, a fire alarm is signaled. Table 1 also shows a summary of the fire detection and nuisance alarm performance of this algorithm (i.e., ION*CO $\geq$ 10) compared to the performance of the ionization and photoelectric smoke detectors. The use of the alarm algorithm results in 17 additional real source tests being detected (42 of 53 tests) compared to those of the ionization detector (25 of 53 tests). The additional fires that were detected consisted of both flaming and smoldering sources. These results show that the alarm algorithm provides an increase in fire detection sensitivity compared to both the ionization and photoelectric smoke detectors. An analysis of the response time results supports this conclusion as well.

The alarm algorithm detected the real fire sources faster than the ionization detector in all but two tests (i.e., flaming heptane and polyurethane). These two incipient size sources produced a maximum of 2 ppm CO while producing significant quantities of smoke. The low CO to smoke production ratio makes these sources difficult to differentiate from many typical nuisance sources that produce aerosols (i.e., simulate smoke) and no CO. The difference in response times between the combined CO/smoke algorithm and the ionization detector ranged from 4 seconds to 453 seconds (7.5 minutes) for real alarm sources. For many of the sources expected in a residential fire (e.g., smoldering fabric, polyurethane foam, and flaming cardboard), the combined alarm algorithm would afford the occupants several extra minutes of time to escape compared to smoke detectors alone. This additional time is significant in that most people typically have approximately 2 to 3 minutes to escape a fire after a smoke detector alarms [6].

Current smoke detectors can be made more sensitive to real fire sources, thus, reducing the time to alarm. However, this has been shown to be at the cost of creating more false alarms. The use of the alarm algorithm improved fire detection sensitivity while significantly reducing the occurrence of nuisance alarms. Table 1 shows that the alarm algorithm resulted in less nuisance alarms (6 out of 27 tests) than did the ionization detector (9 out of 27) or the photoelectric detector (17 out of 27). The important point is that improvements were observed for two of the most common residential nuisance sources, cooking (i.e., the frying bacon tests), and steam. Considering that nuisance alarms in industrial environments can be due to dust and process particulate matter which does not contain CO, the alarm algorithm would inherently provide nuisance alarm immunity in these environments where conventional smoke detectors may not.

Figures 3 and 4 demonstrate how the CO/smoke alarm algorithm is able to provide improved sensitivity (i.e., faster response to fires) and immunity to nuisance sources compared to conventional smoke detectors. Figure 3 shows how a real fire event will move diagonally away from the origin with time and cross the algorithm alarm level (at 117 s) before the smoke alarm (199 s). On the other hand, a nuisance source will tend to produce a signature that lies close to the y-axis (particulate only) and cross the smoke detector alarm level but not the CO/smoke algorithm alarm criteria (Figure 4).

Conclusions

Extensive testing and analysis has resulted in the development of a CO/smoke detector and multiple alarm algorithms which can be optimized for the specific application of the detector for optimal performance. However, compared to conventional smoke detectors, general algorithms do exist that will provide overall improved performance for a wide range of applications. For example, as presented in this paper, the CO/smoke detector with the alarm algorithm ($ION*CO \geq 10$) will significantly improve life safety. The detector will respond to real fire sources faster than a smoke detector, affording occupants up to several minutes more time to escape a fire. Additionally, the multi-sensor detector will eliminate many nuisance alarms.

Acknowledgments

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Multi-Sensor, Multi-Criteria Detectors are Better

Abstract

Studies have shown that most of the unwanted alarms from fire detection systems are caused by people's activities. Cigarette smoking and cooking cannot usually be distinguished from an early stage fire using a single sensor detector. This is due to the fact that these nuisance alarm sources produce variations of smoke concentration similar to a real fire.

In reviewing several studies of unwanted alarms, it is evident that the reduction of these alarms can be correlated to sensitivity settings. The lower the sensitivity setting of photo or ion detectors, the fewer the unwanted alarms. However, the sensitivity settings of detectors are determined by the test requirements at the various testing agencies and cannot be arbitrarily lowered to reduce unwanted alarms. Therefore, the challenge is to reduce the sensitivity and still have the detectors respond in a timely fashion to developing fires.

Reducing the sensitivity settings is one way to reduce unwanted alarms. Another is to use two different types of sensors that work synergistically to enhance detection of real fires, while further discriminating nuisance alarm situations.

Some multi-sensor, multi-criteria detectors can do both...pass all fire tests at low sensitivities and be more discriminating against nuisance alarm stimuli.

Background

From three studies that were reviewed, one can get quantitative insight as to causes of unwanted alarms. In a 1982 European study of industrial environments commissioned by Cerberus, it was found that welding caused the most unwanted alarms (34%). In a 1989 U.S. Department of Commerce study of hospital and nursing home environments, smoking was the greatest cause of unwanted alarms (33%). (Today, smoking would probably be replaced by dust and construction activities as the leading cause for unwanted alarms since smoking is currently allowed only in limited areas in these types of buildings.) A third study commissioned by the Pittway Corporation in 1997 covered commercial and residential buildings. The study was conducted in Naperville, Illinois and showed that cooking was the primary cause of unwanted alarms (29%).

If we differentiate "false" alarms (those not caused by smoke) from "nuisance" alarms (those caused by smoke), we learn from these three studies collectively that:

1. construction / dust creates the most false alarms (23%), while
2. smoking (18%), and
3. cooking (16%) caused most of the nuisance alarms.

If we could eliminate these three causes, we could reduce unwanted alarms by almost 60 percent.

Recommendations

In the three studies cited, recommendations were made for reducing nuisance alarms. They were:

1. Add Alarm Verification (resetting the system and looking for a second alarm condition before triggering an alarm signal),
2. Add the ability to lower the sensitivity of the detectors when people are present, and
3. Reduce detector sensitivity.

If these recommendations are implemented, what measurable benefits are attainable? In an anecdotal study of several systems that added Alarm Verification, the result was about a 10 to 1 reduction in unwanted alarms. In 2 other studies, 1 American and 1 European, improvements of about 5 to 1 and 13 to 1 respectively were found when the sensitivity was reduced when people were using the premises. Lastly, in a large study of over 30,000 detectors over several years, the benefits of reducing sensitivity became apparent and quantifiable. At .02% obscuration / ft. sensitivity, there were 43 unwanted alarms per 100 detectors per year. At 1.5% it dropped to 13; at 2.0% it dropped to 8. Extrapolating that data to 4.0%, the number of unwanted alarms dropped to .15 per 100 detectors per year. This is 100 times fewer alarms than if set to 1.5%, which is where most detectors are set today.

Single sensor detectors set at 4.0% cannot be relied upon to provide early warning to fires before major damage occurs. However multi-sensor, multi-criteria detectors, which combine ion, photo, and thermal sensors can. Examples of such detectors available today are the Edwards 4-D and the System Sensor OMNI detectors. They synergistically combine output signals from the ion, photo, and thermal sensors to give timely responses to developing fires even when set at 4.0%.

Test Results

In actual UL fire tests (comparing the OMNI detector to photo and ion units), the OMNI detector set at its least sensitive setting responded faster than the ion detector during a paper fire. In the smoldering fire test the OMNI, in the most sensitive mode, responded faster than the photo detector, while in the least sensitive mode, the OMNI responded almost 8 minutes faster than the ion detector. In the EN54 fire tests, the OMNI was typically faster or at least equivalent to the ion and photo detectors.

In 6 nuisance stimuli tests the multi-sensor, multi-criteria OMNI and ALGOREX detectors showed their superiority to ion and photo detectors. When tested in a small test room measuring about 8 ft. x 10 ft. x 8 ft., both detectors ignored steam generated by an electronic humidifier, frying of chicken and smoke from 20 cigarettes. Tests were conducted with and without a fan blowing in the test room. The detectors ignored these stimuli at all sensitivity settings.

The following table shows the benefits in delayed alarm indication times with multi-sensor, multi-criteria detectors. In the “toast” test, the bread was toasted beyond being edible, the “bacon” was cooked beyond being crisp and the welding went on continuously until all detectors were in alarm.

Added delay versus ion or photo before unwanted alarms are sent				
Test	Algorex PL	Algorex RE	OMNI 1	OMNI 5
Toast	+25 seconds	Ignored	+20 seconds	Ignored
Bacon	+125 seconds	+205 seconds	+165 seconds	+245 seconds
Welding	40% more time	120% more time	60% more time	100% more time

PL = People mode = most sensitive

RE = Real Estate mode = least sensitive

1 = most sensitive

5 = least sensitive

Conclusion

It is critical to have quick responding detection devices for life safety in fire situations. Reducing the sensitivity settings of single sensor detectors to make them less prone to unwanted alarm stimuli also causes these devices to respond slower to actual fires. The use of multi-sensor, multi-criteria detectors addresses both concerns. Multi-sensor, multi-criteria detectors give you more time against nuisance alarms, sometimes ignoring nuisance alarm causes completely. In addition, multi-sensor, multi-criteria detectors, such as the OMNI, have better or similar (within 5%) response times to fires versus single criteria early warning smoke detectors.

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Auswerteverfahren für die Multisensorik für eine sicherere Meldungsentscheidung bei Brandereignissen

Abstract:
This paper discusses the problems with sets of variety of signals of multi sensors to take a decision about a fire or non fire situation. Normally with only one measuring signal a threshold is used as a decision instrument. The location of the threshold gives the probability of a false alarm and the probability of a not recognized alarm as a fixed pair of figures. With the use of several signals in combination these spread out a feature vector. The single threshold emerges to multidimensional boundary surfaces. The outline of a such a boundary depends on the probability distribution of the wanted signal (fire signal) and the probability distribution of noise and delusion signals. The loss of practical data material leads to the difficulty to describe a statistic, so overview measurements and meaningful assumptions must help. Different methods can be used to optimize the decision area like neural networks, classification systems or statistic models. To prove the ruggedness of such methods, signal generators which simulate fire signals as well as sturgeon signals can be used.

Einleitung

Brandmelder werden in unterschiedlichsten Umgebungen eingebaut und sollen trotz der vielfältigen Einsatzbedingungen immer gleichmäßig, zuverlässig und störungsfrei funktionieren. Als Meßkriterium für die Detektion eines Brandes dient in aller Regel das Messen des entstehenden Brandrauches in der Umgebung. Man geht stillschweigend davon aus, daß im Nichtbrandfall die Aerosoldichte durch Umgebungseinflüsse keinen Wert erreicht, der dem eines Brandes entspricht.

Die Erfahrung zeigt, daß die Bewertung des Brandfalles auf Grund nur einer Kenngöße in kritischen Fällen zu Täuschungsalarmen führt. Zwar ist die Zuverlässigkeit heutiger Melder hoch, durch die große Zahl der eingesetzten Melder führt aber auch eine kleine Rate von Täuschungsalarmen zu einer absolut spürbaren Zahl von Falschmeldungen und damit unnötigen Einsätzen der Feuerwehren.

Verwertbare Signale

Bei der stofflichen Umsetzung im Brandfall entstehen, neben den durch die Thermik transportierten Aerosolen, Gase als weitere Verbrennungsprodukte. Die Nutzung solcher charakteristischer Merkmale wird wirtschaftlich sinnvoll möglich mit Gassensoren, die ausreichend empfindlich und stabil bei kleiner Energieaufnahme zu vertretbaren Kosten herstellbar sind [1].

Die im Brand entstehenden Gase sind abhängig von den verbrannten Materialien und der Brandart. Die auftretenden Konzentrationen können über die chemische Zusammensetzung und die Masse des Brandgutes abgeschätzt werden [2].

	CO/ppm	CO_2/ppm	NO_x/ppm
TF1		3000 ... 5300	5,1 ... 9,2
TF2	50		0,2 ... 0,5
TF3	480 ... 862		
TF4		242 ... 436	249 ... 449
TF5		2000 ... 3970	
TF6		3796 ... 6838	

Tabelle 1: Theoretische Abschätzung der Wertekonzentration von Gasen bei Testfeuern

Für die Testbrände nach EN54/9 sind die Konzentrationen wie in Tabelle 1 dargestellt zu erwarten. Gegenüber dieser Abschätzung zeigen Messungen aus unterschiedlichen Quellen folgenden Wertebereich:

	CO [4]	CO [3]	CO [5]	CO_2[5]	CO_2[3]	NO_2[3]
TF1	230		90	1800		
TF2	50	80	100	880	350	0,15
TF3	300	100	90	1560	600	0,03
TF4	15	19			1500	0,75
TF5	15	27			2100	0,9
TF6	5	25			2000	1,7

Tabelle 2: Gemessene Gaskonzentrationen bei Testfeuern

Eine Auswertung ist abhängig davon, mit welchen Typen von Gassensoren gearbeitet wird. Die Querempfindlichkeit der Sensoren spielt insbesondere bei Störgrößen und bei Vorliegen von Gasgesmischen eine Rolle. Auswerteverfahren sind somit nicht ohne weiteres von einem Sensortyp auf einen anderen übertragbar. Pauschal erkennt man jedoch, daß im Brandfall mit der Entstehung von signifikanten Gasanteilen zu rechnen ist. Für einen praktischen Einsatz in Brandmeldern ist jedoch die Unterscheidbarkeit des Auftretens solcher Signale von Brand und Nicht-Brand wesentlich. Eine Beurteilung dieser Unterscheidbarkeit kann über die Auftretenswahrscheinlichkeitsdichte solcher Signale im Brand und im Störfall erfolgen. Das Problem ist, daß solche Verteilungsverläufe aus der Praxis statistisch gesichert nicht vorliegen. Für eine erste Abschätzung kann man jedoch von modellhaften Annahmen zu solchen Verteilungen ausgehen, um die grundsätzliche Wirksamkeit abzuschätzen.

Häufigkeit von Störsignalen

Daten aus der Praxis herkömmlicher Melder sind z.B. über die Statistiken der Feuerwehren zu ermitteln (siehe Abb. 1).

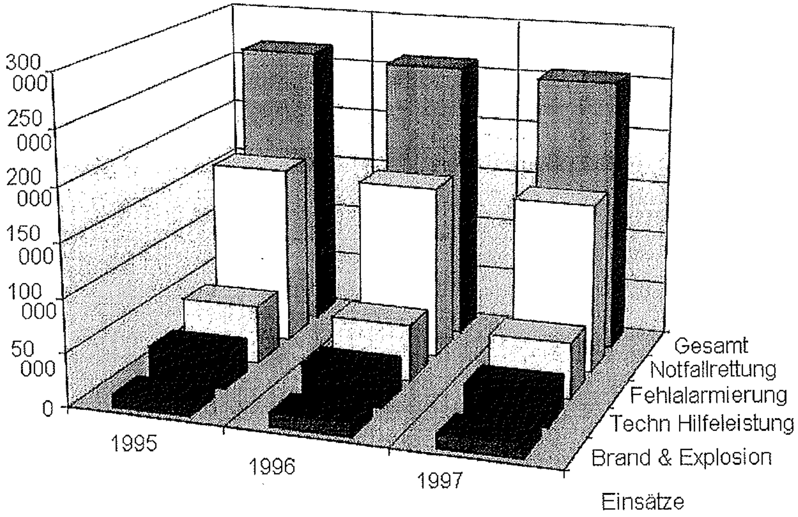

Abb. 1: Einsatzstatistik der Berliner Feuerwehr [6]

Diese Daten geben jedoch keine Auskunft über die Ursachen der Fehleinsätze. Es wird jedoch unterstellt, daß ein nicht zu vernachlässigender Anteil auf Grund von Täuschungsgrößen durch die Melder verursacht sind. An der absoluten Größe der Fehleinsätze läßt sich ablesen, daß eine Verbesserung des Melderverhaltens sich unmittelbar in einer Verbesserung des Verhätnisses Echtalarm/Fehlalarm auswirkt.

	1995	1996	1997
Brand- und Explosionseinsätze	**11.752**	**13.112**	**12.700**
Technische u. andere Hilfeleistungen	32.108	31.821	31.300
Notfallrettungseinsätze	166.937	162.264	158.500
Fehleinsätze	**55.328**	**53.222**	**52.500**
Gesamteinsätze	266.125	260.419	255.000

Tabelle 3: Feuerwehrstatistik der Berliner Feuerwehr [6]

Für eine Abschätzung der Störempfindlichkeit ist eine Liste möglicher Störungen aus realen Einsatzanwendungen von Brandmeldern hilfreich.

Kritische Einsatzfälle sind z.B.: Raucherbüros, Diskotheken, Stätten mit Staubbildung, Flusenflug, Lösungsmitteldämpfen, Dampfbildung, Schweißbetrieb, Autoabgase, der parallele Betrieb mit Einbruchvernebelungsanlagen u.v.a.m. Führt man Versuche mit den vorgenannten Einflußgrößen an Brand- und Gassensoren durch, so stellt man fest, daß keiner der Sensoren als Einzelsensor gegen das gesamte Spektrum von Störgrößen resistent ist. Das gilt auch für herkömmliche I- und O-Melder. Hier wird das Problem durch Festlegungen für die Einsatzgebiete abgegrenzt (z.B. keine Rauchmelder in Küchen) oder durch gezielte Abschaltungen von Meldern in Sonderfällen, z.B. bei temporären Schweißarbeiten.

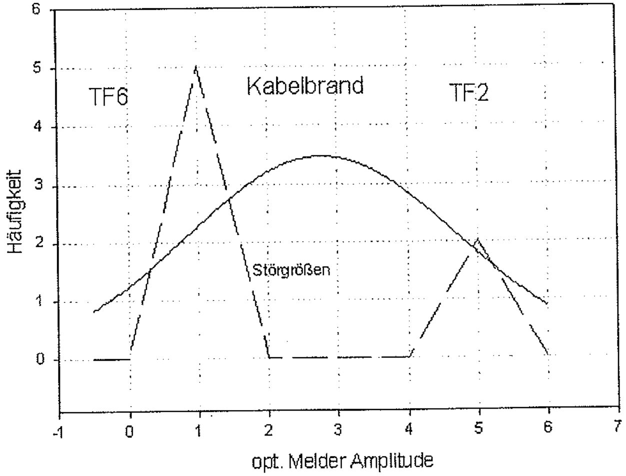

Abb.2: Amplitudenspektren über Testfeuer und Störeinflüssen für opt.Sensor

Abb.2 bis 5 zeigen schematisch die Überlappung von Brandsignal und Störsignalamplituden. Man erkennt, daß Temperatursensoren auf brandtypische Täuschungsgrößen kaum empfindlich reagieren, jedoch nur für Brandarten mit entsprechender Wärmeentwicklung einsatzfähig sind.

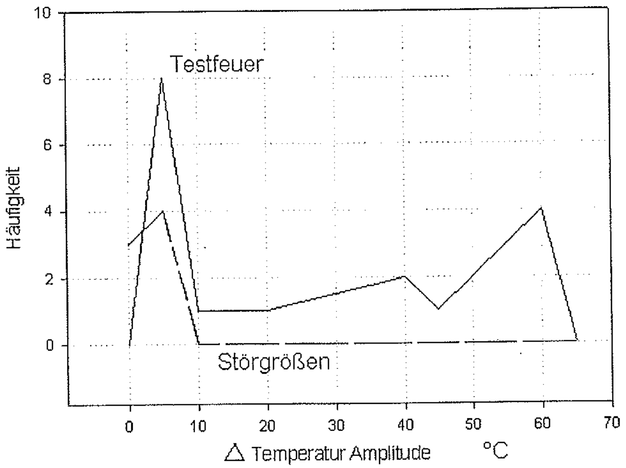

Abb. 3: Amplitudenspektrum über Testfeuer und Störgrößen für T-Sensor

Gassensoren sind sowohl auf typische Brände, aber auch auf typische Störgrößen empfindlich. Dies gilt insbesondere für Sensoren, deren Wirkungsweise auf der Reduzierung von Gasen basieren, und somit über die Querempfindlichkeit auf Störungen recht breitbandig reagieren.

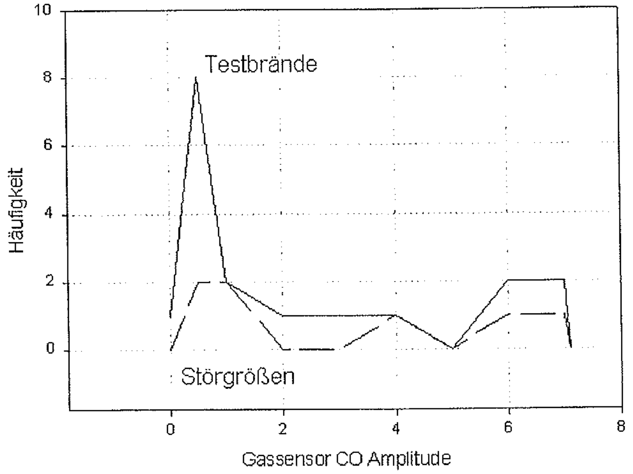

Abb. 4: Amplitudenspektren über Testfeuer und Störeinflüssen für CO Sensor

Hinzu kommt die Feuchteabhängigkeit vieler Sensoren, so daß sie auch bei Nebel deutliche Signalausschläge zeigen, was z.B. die Unterdrückung von Einflüssen durch Nebelmaschinen (Diskotheken) einschränkt.

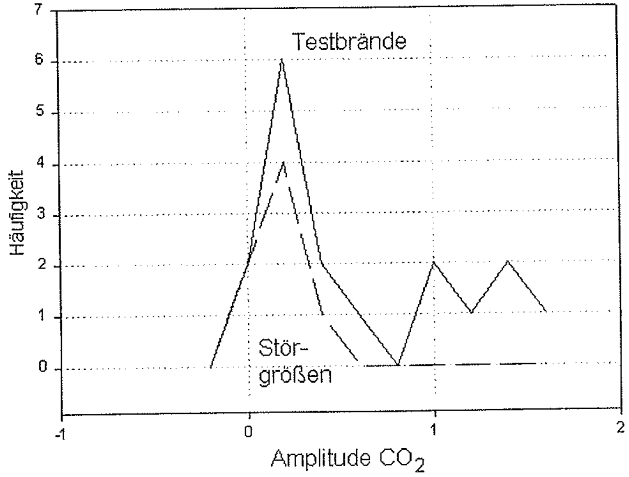

Abb. 5: Amplitudenspektrum über Testfeuer und Störeinflüsse von CO_2

Entscheidungskriterien

Die in [1] beschriebenen Sensoren reagieren hingegen sehr schmalbandig auf nur eine Gaskomponente und sind nahezu unabhängig vom Feuchteeinflüssen und sind daher für eine Kombination mit einem Rauchmelder gut geeignet. Auf Grund der Überlappung von Stör- und Nutzspektrum der einzelnen Sensorsignale muß nun überprüft werden, inwieweit durch die Betrachtung von zeitgleichen Sensorsignalensemblen die Überdeckung von Nutz- und Störsignal reduziert wird. Hierzu bildet man aus den einzelnen Sensorsignalen einen Signalvektor. Für ein Signalensemble aus einem Signal eines optischen Rauchmelders, einem Temperatursignal, einem CO-Signal und einem CO_2-Signal erhält man einen Vektor, der in einen 4-dimensionalen Ereignisraum zeigt. Betrachtet man bei einem einzelnen Signal nur ein Kriterium, z.B. die Amplitude, und nutzt dieses Signal zur Entscheidung über einen Gefah-renzustand, so geschieht dies üblicherweise über eine Entscheidungsschwelle (Abb. 6).

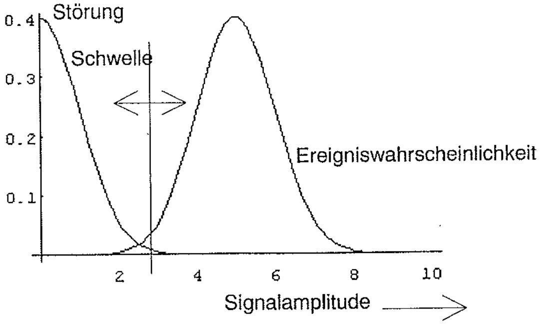

Abb. 6: Schwelle eines Melders mit einem Entscheidungskriterium

Geht man von einem Ensemble mit zwei Signalen aus und unterstellt man der Einfachheit halber eine Gauss'sche Verteilung sowohl der Störgrößen als auch der Brandkenngrößen, so erweitert sich die Kurve in eine Gauss'sche Glockenkurve und die Schwelle erweitert sich im Idealfall zu einem Kreis, den der zweidimensionale Vektor für einen Alarm überschreiten muß. Bei drei Sensorsignalen und vereinfachten Annahmen erhält man eine Kugel als Schwellwertgrenzfläche (Abb. 7).

Daß vereinfachte Annahmen für die Auftretenswahrscheinlichkeit nicht ohne weiteres zulässig sind, ist plausibel an einem einfachen Beispiel ersichtlich. Ein CO_2-Sensor kann als Wertepaar mit dem Signal eines optischen Sensors wahrscheinlich für einen Brand sein. Durch ein Störsignal (z.B. Autoabgas) kann der CO_2-Sensor ein singuläres Signal liefern, dessen Betrag deutlich größer ist als der Betrag des Vektors aus dem Wertepaar für ein Brandereignis. Schwellwertgrenzkurven werden für den praktischen Betrieb an die tatsächlichen Signalverteilungen anzupassen sein.

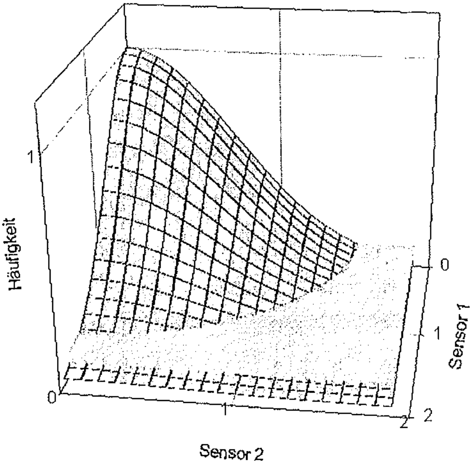

Abb. 7: Zweidimensionale Schwelle zur Entscheidung zwischen Alarm und Nicht-Alarm

Diese Grenzflächen sind unmittelbar abhängig von dem Verhalten der jeweiligen Sensoren und somit nicht pauschal anzugeben.

Gütenachweis über Simulation

Um eine Bewertung der Störsicherheit der Signale eines Sensorensembles vorzunehmen, muß die Schwellwertgrenzfläche in einem optimalen Abstand zwischen der vieldimensionalen Störvektorsignalverteilung und der Brandvektorsignalverteilung verlaufen. Ein Entscheidungsalgorithmus hat nun die Aufgabe im praktischen Betrieb die tatsächlichen Signalpaare gegen eine solche Grenzfläche zu bewerten. Für reale Melder muß ein solcher Algorithmus kostengünstig in einen Mikrocontroller implementierbar sein, was wiederum Anforderungen an Komplexität, Rechenleistung und Speicherplatz stellt. Für einen solchen Algorithmus muß der Nachweis der Wirksamkeit geführt werden. Man versucht einen solchen Nachweis mit Hilfe von Praxistest an speziell ausgesuchten Örtlichkeiten oder durch Labortests durchzuführen. Um einen solchen, im Vorfeld nicht unerheblichen Aufwand teilweise zu kompensieren, wird in Verbindung mit der Universität der Bundeswehr Neubiberg ein Testgenerator entwickelt, der in der Lage ist, erwartete Eingangssignale von Testbränden, Störgrößen und Mischsignale zu erzeugen und statistisch zu variieren (Abb. 8). Als Eingangssignale können Werte real durchgeführter Brände dienen oder aber der Brand durch Modellbildung von Bränden und Störgrößen simuliert werden. Die Einflüsse der örtlichen Gegebenheiten und das Übertragungsverhalten der verschiedenen Sensoren werden durch eine Gewichtsfunktion im Eingangszweig berücksichtigt. Damit ist es möglich, die Vielfalt erwarteter Eingangssignale einem Algorithmus zuzuführen und dessen Verhalten zu überprüfen. Eine Bestimmung der Entscheidungsgüte erfolgt nicht durch analytische Bewertung, sondern durch statistische Auswertung der Ausgangssignale, die der Algorithmus liefert. Mit einem solchen Instrument können ohne großen Aufwand Modifikationen am Algorithmus auf ihre Wirksamkeit überprüft werden und unterschiedliche Algorithmen miteinander verglichen werden. Der Einfluß von Sensorparametern, z.B. durch Hinzufügen eines weiteren Sensors oder durch Austausch eines Sensors durch einen anderen mit geänderten Eigenschaften, wird hierbei durch die Bewertungsfunktion im Signalgenerator berücksichtigt.

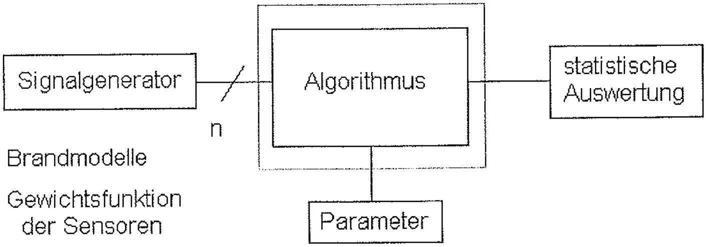

Abb. 8: Modell eines Testsimulators für die Überprüfung der Wirksamkeit von Algorithmen

Zusammenfassung

Der Einsatz von diversen Gassensoren in Branddetektoren hilft Störeinflüsse für die Meldungsentscheidung zu unterdrücken. Die Güte dieser Unterdrückung hängt von der Selektivität der Gassensoren ab. Zu Sensoren mit geringer Querempfindlichkeit zählen chemische Sensoren nach dem Schlüssel/Schloß-Prinzip, die in bestimmten Ausführungsformen mit einfachen Mitteln optisch meßbar sind. Ein Auswertemechanismus muß speziell an die Eigenschaften eines Sensorensemble angepaßt werden. Für den Nachweis der Güte unter bestimmten vorgegebenen Betriebsbedingungen bietet sich der Einsatz von Brandsimulationswerkzeugen an.

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A New Type of Intelligent Point Photoelectric Smoke-Heat Combined Fire Detector

ABSTRACT

A new type of intelligent photoelectric smoke-heat combined fire detector used in the Shenghua SH9400 distributing intelligent fire alarm system is introduced in this paper. Its technical features, operating principle, neural signal process and applications are presented in detail. Performances and levels of several typical fire alarm systems in world today are compared.

Key Words: Intelligent, Photoelectric, Fire detector, Neural signal process

INTRODUCTION

Shenghua SH9432 fire detector is the fourth generation product developed by Nanjing Fire (Group) Co.. It is an intelligent smoke-heat combined fire detector. It can be used together with SH9412 intelligent fire alarm controller, SH9421 fire central control system to form a fire detection, alarm and linkage control system. The system incorporates staged decision function and is widely used in different kinds of industrial and civil fire engineering projects.

Smoke and temperature values detected by SH9432 detector is processed by using neural techniques. It can give out three-level alarm signals for smoke, temperature, smoke-heat respectively according to the detecting site situation. When controller receives these alarm signals, it makes the second stage decision according to the detected site conditions (e.g. normal smoke and dust values, temperature range, fire risk etc.) and time (daytime, night, work time or holiday etc.), and send out different kinds of alarm signals with different urgent levels.

SH9432 has following features:

* It can respond to four test fires stipulated in national standards GB4715-93 and six test fires stipulated in European standards EN54.

* It has low false alarm rate and high reliability.

* It can set its detecting functions corresponding to different time and zones.

It meets the requirements of national standards CB4715-93 and GB4716-93, American standards UL217 and UL539, Australian standards AS1603.1 and AS1603.2. In December, 1996, it has passed the ISO9000 National quality certification and is doing American UL and Australian QAS certifications recently.

MAIN SPECIFICATIONS

Operating voltage: DC 24V, with communication signals

Operating current: 300 μ A in supervision state 600 μ A in alarm state

Sensitivity: I --III to four test fires stipulated in GB4715-93

Address code: 8bits range:1 ～ 256

Connection: two-wire bus no parity

Operating temperature: -10 ℃- +60 ℃(continuous)
-10 ℃- +80 ℃(non-continuous)

Closure protective class: IP42

Dimensions: Φ 102mm × 47m ;

Weight: 150g

Protection area: about 40-100m^2(calculated according to GBJ116-88)

OPERATING PRINCIPLE

Photoelectric smoke and heat sensing principle

SH9432 detector has two separated rooms for detecting smoke and heat. Generally, it is very hard to detect various fires by using one-sensor detector. SH9432 detector combines photoelectric smoke sensor and heat sensor together.

Ionic smoke detector has stable responses to gray, dark smoke and many other smoke of different spectrums. However, it will do harm to the environment and is easy to send out false alarm when in a damp environment.

Photoelectric detector has no such faults, but its response to the smoke spectrum is not so stable as that of the ionic detector. It has low sensitivity to the dark smoke. In most of the situations, fire is caused by solid materials, such as wood product, textile, paper and etc.. The performance of photoelectric detector is good enough and even better than ionic detector in detecting the invisible smoke sending out by these materials. When fire is caused by certain chemical products, the detecting performance of ionic detector is better than that of the photoelectric detector. Luckily, these kinds of materials will produce a lot of heat and increase the temperature apparently when combusting. So, detectors combining smoke sensor and heat sensor can detect almost all fires, even a heat only fire (such as ethyl alcohol fire) which ionic smoke detector can not detect. *Table 1* gives out the detection characteristics of photoelectric smoke detector, ionic smoke detector, heat detector and SH9432 smoke-heat combined detector to different test fires.

	Detector types			
Test fires defined in National and European standards	photo-electric	ionic	heat	smoke-heat combined
Pyrolysis firewood SH1, TF2	excellent	good	not suitable	excellent
Cotton string SH2, TF3	excellent	good	not suitable	excellent
Foam polyurethane SH3, TF4	pass	good	pass	excellent
Heptane SH4, TF5	pass	excellent	excellent	excellent
Free burning firewood TF1	not suitable	good	excellent	excellent
Heat only liquid TF6	not suitable	not suitable	excellent	excellent

Table 1 Performance comparison between multi-sensor and mono-sensor detector

Operating process

SH9432 consists of smoke sensor, heat sensor, signal amplifier, communication interface, power supply management, microprocessor, memory and etc., shown in *Fig.1*.

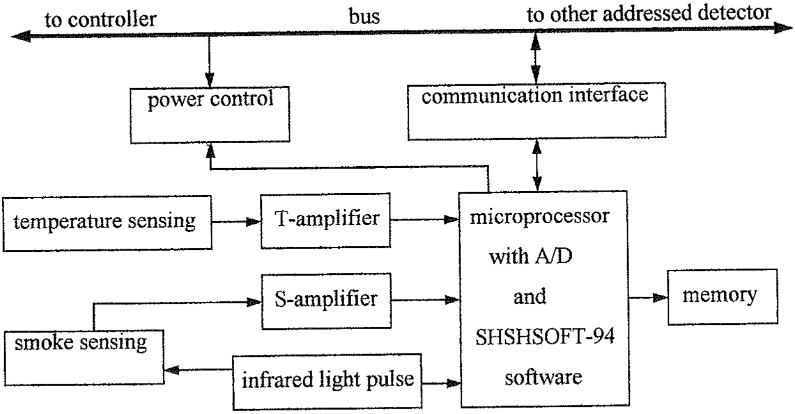

Fig.1 SH9432 Diagram

Smoke detecting room is a dark chamber specially designed using optical theory so that the environment light is reduced to a very small extent. When there is no smoke, photosensitive diode receives only the weak background light coming from the multi-reflection by the infrared light pulse in the dark chamber. When smoke getting into the chamber and reaching the sensitive zone, the infrared pulse ray will be scattered by the smoke particles, the scattered rays will be received and transformed to electric signal by photosensitive diode.

In the temperature detecting chamber, there is a heat sensitive component made up of a PN junction with small thermal capacity. This component can respond to the environment temperature change rapidly. It can work very well in detecting the open fires from woods, cotton and wool etc., dark fire from petroleum Carson, and also the heat only fire from flammable liquids like alcohol etc. Alarms will be given out in an early stage while no heavy lost is made. After being amplified, smoke and temperature signals are collected and processed by the microprocessor. Nine kinds of alarm signals with three levels (pre-warning, fire symptom, fire under pure smoke, pure heat and combined smoke and temperature modes. The power management unit gets power from the bus, and provides it to the amplifier circuit and infrared pulse generating circuits according to the microprocessor' s instructions. The communication interface unit transfers the inquiring, command and sync pulses on the bus to corresponding ports of the microprocessor, in the meanwhile transfers the return codes from the detector to the bus.

SHSHSOFT94 software

SHSHSOFT94 software manages the operating process of the whole detector. The communication program for the detector and controller is an interrupt subprogram.

Collection and process of smoke, temperature signals

The SHSHSOFT94 software controls the power supplying to infrared light emitting tube and amplifier, smoke and temperature signals collecting, and digital filtering process. After that, the software will judge and process the signals using various algorithms. It uses Neural network fuzzy logic method for smoke detect and uses the change rate and fix value algorithm for the temperature detect. It also uses combined fire algorithm for smoke and temperature combination algorithm, three levels combined fire alarm signals are given out.

Communication with the controller

SH9432 communicates with the controller using SHCP94 communication protocol. The data sent out by the controller includes start code, address, command and synchronous pulse for detector return code. The data is total 35 bits, show in *Tab.2* .

The codes sent back by the detector being called includes status, address, type, smoke value, temperature. These codes are in current values following the synchronous pulse.

Fault and maintenance

SHSHSOFT94 will monitor key circuits and the software itself, reset when abnormal status appears; on the other hand, when factors of environment, accumulated dust and aging of components etc. make the normal smoke and temperature values exceed predefined values, send out maintenance requirement signal.

start bit	address	command	space	status	priority interrupt	smoke value	address	space
1	2-9	10-12	13	14-17	18	19-26	27-34	35

Table 2 Communication code structure

NEURAL SIGNAL PROCESS

Fuzzy logic experiment system based on neural signal process

We use a kind of fire detecting technique that combines neural network and fuzzy system. The cascade network structure is used here, the pre-processed input signal will be processed in the neural network, its output is sent to the fuzzy system, there the fuzzy logic gives out fire or non-fire signals, shown in *Fig. 2*.

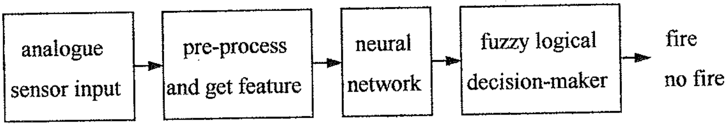

Fig.2 Neural network fuzzy detection system

Pre-process and neural network

The fire detection signal process is mainly done by neural network. The whole signal process of the automatic detection system also includes preprocess of input detector analogue value and fuzzy decision maker. To increase neural network fire detecting adaptability and network training convenience, the analogue values obtained by detectors usually are not used directly as the input of the neural network, but are normalized within the range of [0,1]. Preprocess also includes getting tendency features by using modification tendency algorithm.

Fuzzy logic fire decision-maker

We define the neural network output as the probability for open fire or heat only fire. When probability for open fire is higher than 0.8, it can be considered that there is a fire. If the number is less than 0.2, there is no fire. When the number is 0.5, it is a little difficult to make the decisions, the method we use is a kind of maximum belonging principle, the principle is:

$$\text{let } A_i \in F(U), i = 1,2,\ldots n, u0 \in U, \qquad A_i(u0) = \max\{A_1(u0), \ldots A_n(u0)\}$$

here the u0 can be considered belonging to A

Assuming u is the open fire probability, A(u) is fire fuzzy set, B(u) is non-fire fuzzy set. For a given u to decide whether there is a fire, what we need to do is just to compare A(u) and B(u). The key is to make out the belonging function. We choose a normal distribution function as the belonging function for A(u), B(u), after many times modification, a and b is 0.2 and 0.4 respectively.

$$A(X) = \left\{\begin{matrix} 0 \\ 1 - e^{-\left(\frac{X-a}{b}\right)^2} \end{matrix}\right\} \begin{matrix} X \le a \\ X > a \end{matrix} \qquad B(X) = \left\{\begin{matrix} 1 \\ e^{-\left(\frac{X-a}{b}\right)^2} \end{matrix}\right\} \begin{matrix} X \le a \\ X > a \end{matrix}$$

Training the neural network

From the principle of neural network detection, the neural network generates the belonging function by learning predefined independent samples. The training mode (input/output) definition and learning method of the neural network is very important for the intelligent fire detection system. The training mode definition is not arbitrary, it should be typical and can give out the essential features for the relationship to be constructed by the neural network, this needs to analyze the data carefully.

There are 6 input features in the experiment, assuming each feature has m training values, the training mode pair will be m^6. Even m is 3, the number of mode pair will be 729, this makes the input of training table very difficult. We use two BP neural network to replace the neural network used in the detection system. For network 2 and 3 , we define 36 and 18 training mode pairs respectively. Although the number of given training mode pairs is small, the neural network can deal with various inputs in the experiment, and can do very well, that is because that the pairs used are all typical and the network' s strong learning and reasoning capability.

Fire detection experiment and realization

This neural network fuzzy detection system has been experimented with standard test fires of Europe and China. *Fig. 3* shows the results for the simulation experiments. This detection system is also used to test some non-fire data, the false alarm probability is 0. *Fig. 3* shows the test of this system for kitchen data that usually causes false alarm by two ordinary fire detection systems, the neural network fuzzy system gives very low probability for open or heat only fire. So, no false alarm will be given out . The realization for the fire detection hardware is shown in *Fig. 1*.

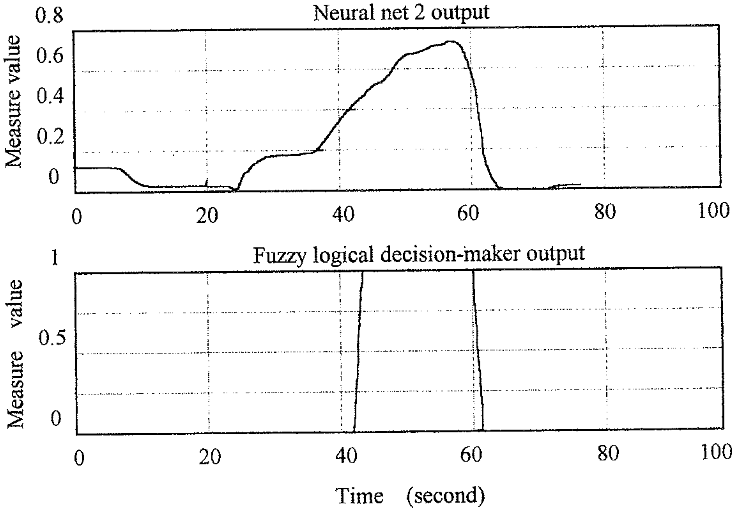

Fig. 3 (a) for TF1 in EN/54

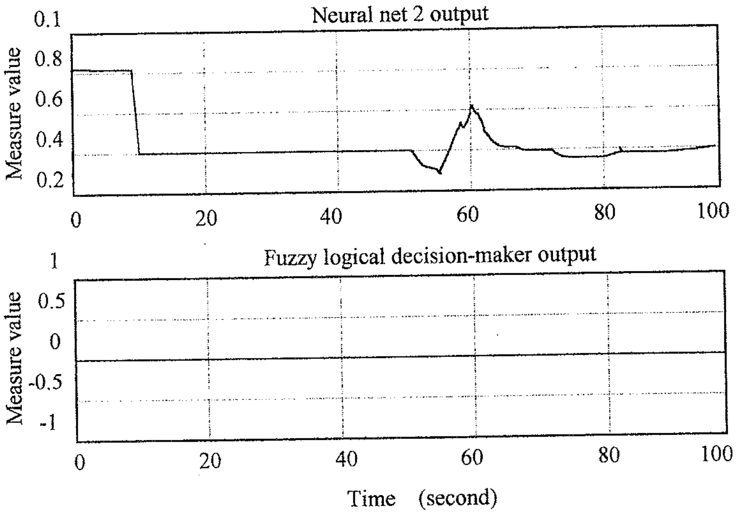

Fig. 3 (b) for TF2 in EN/54

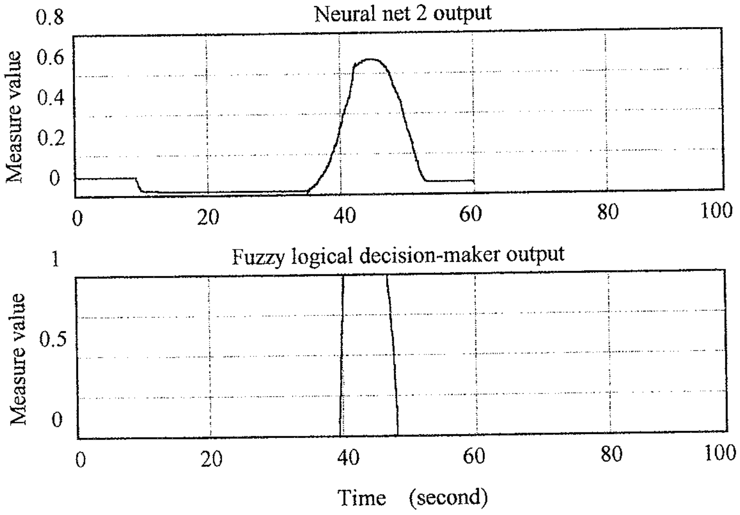

Fig. 3 (c) for TF4 in EN/54

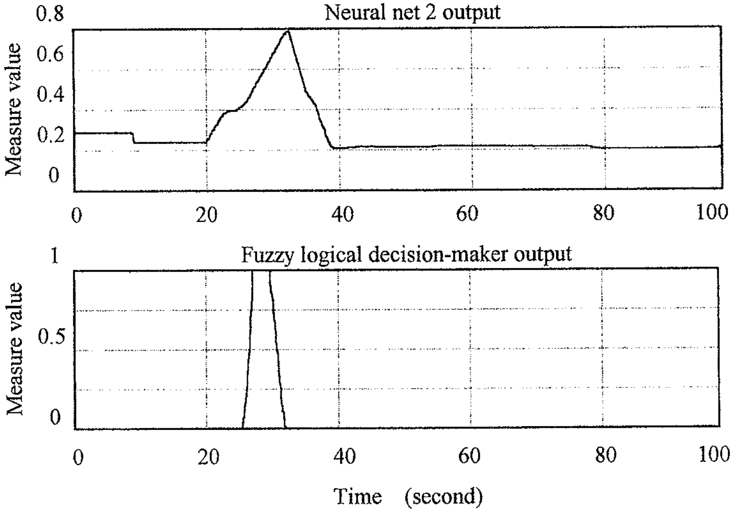

Fig. 3 (d) for TF6 in EN/54

APPLICATIONS

The system' s false alarm rate is nearly zero

This kind of fire detector, together with our company' s SH9412 intelligent fire detection controller, SH9421 intelligent fire central control system and other about 60 different products make up the fourth generation products of our company ---SH9400 fire alarm system. SH9400 fire alarm system went into market in 1996. By the end of July 30, 1998, forty large and medium projects have passed the check and acceptance of fire and the false alarm rate is nearly zero. One hundred and ten projects are in construction and one hundred and eighty projects are to be constructed. The largest number of addressable detectors is up to 8000.

Report from real fire places

There were three fires breaking out in three places including Nanjing Central Market in 1997. The SH9432 gave out precision alarms. After started and controlled by the linkage devices, the automatic fire fighting system put out the fires all in about 20 minutes.

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Die Auswertung der Brandkenngröße Kohlenmonoxidkonzentration in Multisensor-Detektorsystemen

Abstract:
With a simple detection algorithm, the advantage to be gained in regard of detectivity by using an additional CO-sensor in connection with a smoke sensor is demonstrated. Most of the victims in large-scale fires die because of CO-poisoning long before they may be killed by the heat. This fact is the motivation for the use of CO-sensors in fire detection devices.

1 Einleitung

Kohlenmonoxid (CO) entsteht als Folge unvollständiger Verbrennung bei nahezu jedem Feuer unabhängig von dem Material, das verbrannt wird, oder dem Stadium des Feuers. Kohlenmonoxid ist unsichtbar und geruchlos und daher nicht durch menschliche Sinnesorgane zu erfassen. Die häufigste Todesursache bei Brandopfern ist eine Kohlenmonoxidvergiftung. Vor diesem Hintergrund erscheint die Auswertung der Brandkenngröße Kohlenmonoxidkonzentration nicht nur als sinnvoll sondern geradezu als geboten.

Die in den letzten Jahren stark angestiegene Nachfrage nach kostengünstigen aber dennoch hochempfindlichen Gassensoren hat dazu geführt, daß heute CO-Sensoren erhältlich sind, die aufgrund ihrer geringen Baugröße und des geringen Energiebedarfes (< 70 mW) in Brandmeldern einsetzbar sind. Dies gilt inbesondere für die sogenannten Leitfähigkeitssensoren auf der Basis n-leitender Metalloxide, wie Zinnoxid (SnO_2).

Im folgenden wird ein Mehrkenngrößen-Mehrkriterien-Branddetektor vorgestellt, der die Brandkenngrößen Wärme, Rauchdichte und Kohlenmonoxidkonzentration auswertet. Der elektrische Aufbau des Prototyps dieses Detektors beinhaltet einen NTC-Widerstand zur Temperaturmessung, eines Streulichtsensor zur Messung der Rauchdichte sowie ein SnO_2-CO-Sensor zur Messung der Kohlenmonoxidkonzentration.

2 Kohlenmonoxid

Wie in der Einleitung beschrieben ist Kohlenmonoxid ein geruchloses, unsichtbares Gas, das bei nahezu jedem Schadensfeuer freigesetzt wird. Darüberhinaus besitzt Kohlenmonoxid ein geringeres spezifisches Gewicht als Luft. Daher erreicht das bei einem Brand freigesetzte Kohlenmonoxid einen an unter Raumdecke installierten Branddetektor auch dann, wenn wie im Fall eines Schwelbrandes die thermische Luftbewegung sehr gering ist.

Die Toxizität von Kohlenmonoxid ergibt sich aus der Tatsache, daß es sich mit dem Hämoglobin des Blutes zu Carboxyhämoglobin (COHb) verbindet. Dadurch wird die Fähigkeit des Blutes, Sauerstoff aufzunehmen, beeinträchtigt, was wiederum zu einer unzureichenden Versorgung des Körpergewebes, besonders des Gehirns, mit frischem Sauerstoff führt. Die Folge ist eine toxische Narkose.

Die Affinität von Hämoglobin zu Kohlenmonoxid ist sehr hoch, sodaß der Anteil von Hämoglobin in der Form des Carboxyhämoglobin immer weiter ansteigt, solange Kohlenmonoxid eingeatmet wird. Ein Anteil von $> 30\%$ COHb führt zur Bewußtlosigkeit, ein Anteil von $> 50\%$COHb um Tod [1]. Jede körperliche Anstrengung in einer mit Kohlenmonoxid angereicherten Atmosphäre führt aufgrund verstärkter Atemtätigkeit zur schnellen Zunahme des Carboxyhämoglobins. Viele Brandopfer, die im Schlaf von einem Feuer überrascht wurden, dieses aber noch bemerkten, wurden unmittelbar nach Verlassen des Bettes durch die dann verstärkte Aufnahme von Kohlenmonoxid handlungsunfähig und fanden den Tod.

3 Metalloxid Gassensoren

3.1 Das Detektionsprinzip von Metalloxid-Gassensoren

Das sensitive Material dieser Gassensor ist Metalloxid, im Fall im Prototyp verwendeten CO-Sensor Zinnoxid SnO_2. Wird ein Metalloxidkristall in sauerstoffhaltiger Atmosphäre auf eine Temperatur von mehreren hundert Grad erhitzt, so findet eine Adsorption von Sauerstoffatomen an der Kristalloberfläche statt. Durch diesen Vorgang werden an der Oberfläche Elektronen gebunden, was zu einer Verringerung der elektrischen Leitfähigkeit führt [2]. Die folgenden Gleichungen geben in verkürzter

Form die Stufen zur ionogen Bindung von Sauerstoff an.

$$\begin{aligned} O_{2(gas)} &\Longleftrightarrow O_{2(ads)} \\ 2e^- + O_{2(ads)} &\Longleftrightarrow 2O^-_{(ads)} \end{aligned}$$

Erreichen nun reduzierende Gase wie Kohlenmonoxid die Kristalloberfläche, kommt es mit dem in der Oberfläche adsorbierten Sauerstoff zu einer Verbrennung und die gebundenen Elektronen stehen wieder im Leitungsband zur Verfügung. Die elektrische Leitfähigkeit nimmt zu:

$$CO + O^-_{(ads)} \Longleftrightarrow CO_2 + e^-$$

3.2 Einige Eigenschaften von Metalloxid-Gassensoren

Metalloxid-Gassensoren besitzen gegenüber einer Vielzahl reduzierender Gase eine relative große Empfindlichkeit. Die Selektivität bezüglich eines bestimmten Gases läßt sich durch geeignete Wahl des sensitiven Material sowie der Betriebstemperatur optimieren.

Da das Detektionsprinzip von Metalloxid-Gassensoren beruht auf der chemischen Adsorption und Desorption von Gasen an der Oberfläche das Sensors. Daher werden die Reaktionsgeschwindigkeit und damit auch die sensitiven Eigenschaften eines solchen Sensor sowohl durch die Umgebungstemperatur als auch die Luftfeuchtigkeit beeinflußt.

3.3 Der CO-Sensor TGS 2440

Für der Aufbau eines Prototypes des Mehrkenngrößen-Mehrkriterien-Detektors wurde ein CO-Sensor des Typs TGS 2440 der Firma *Figaro Inc.* verwendet. Das sensitive Material ist Zinnoxid (SnO_2). Dieser Sensor besitzt neben anderen die folgenden Charakteristika:

- Geringer Energiebedarf (< 80mW)
- hohe Empfindlichkeit bezüglich CO im Bereich < 50ppm
- geringe Querempfindlichkeit gegen Ethanol
- geringe Baugröße (Durchmesser = 9mm, Höhe = 12mm)

4 Ein Mehrkenngrößen-Detektorsystem

In diesem Abschnitt wird ein Mehrkenngrößen-Mehrkriterien-Branddetektorsystem vorgestellt, das auf der Auswertung der Ausgangssignale eines Temperatursensors, eines Rauchdichtesensors sowie eines Kohlenmonoxidsensors basiert. Die folgende Abbildung gibt die Struktur der Signalverarbeitung für ein solches System mit n Sensoren wieder.

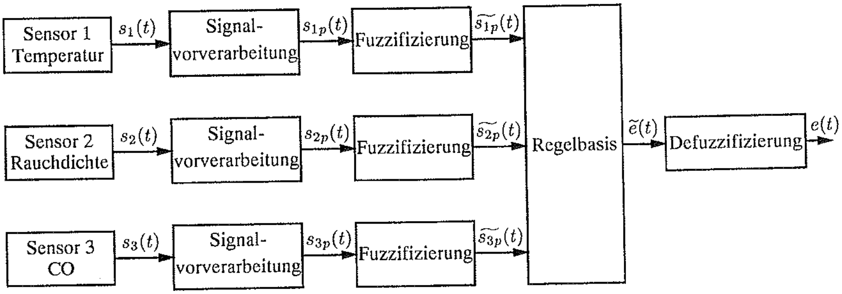

Abbildung 1: Prinzipielle Struktur eines Mehrkenngrößen-Detektorsystems

Für jedes der Sensorausgangssignale $s_i(t)$ $(i = 1, 2, 3)$ wird im Signalvorverarbeitungsblock eine Art Merkmalsextraktion durchgeführt. Die resultierenden Signale $s_{ip}(t)$ gelangen nach einer Fuzzifizierung, $s_{ip}(t) \rightarrow \widetilde{s_{ip}}(t)$ an einen Block, der ein regelbasiertes Fuzzy-Expertensystem beinhaltet, und werden entsprechend den dort definierten Regeln verknüpft. Das defuzzifizierte Ausgangssignal $\tilde{e}(t) \rightarrow e(t)$ dieses Blocks repräsentiert nach einen einfachen Schwellenwertvergleich den Alarm- oder Nichtalarmzustand des Detektors.

4.1 Die Signalvorverarbeitung

Grundsätzlich existieren zumindest zwei Wege, die Detektionseigenschaften eines herkömmlichen Branddetektors, der die Brandkenngrößen Temperatur und Rauchdichte sensorisch erfaßt, zu verbessern. Dies ist zum einen die Wahl einer aufwendigeren Signalvorverarbeitung und zum anderen der Einsatz zusätzlicher Sensoren zur Erfassung weiterer Brandphänomene.

Im Fall des hier vorgestellten Mehrkenngrößen-Detektors wurde der zweite Weg unter Einsatz einer vergleichsweise einfachen Signalvorverarbeitung beschritten.

4.1.1 Temperatursensor

Das Ausgangssignal des Temperatursensors wird ohne jede weitere Signalvorverarbeitung fuzzifiziert. Folglich gilt:

$$s_{1p}(t) = s_1(t)$$

4.1.2 Rauchdichtesensor

Basierend auf dem Sensorsignal $s_2(t)$ und einem daraus abgeleitetden gleitenden Mittelwert $r_2(t)$ wurde eine gewichtete Summe wie folgt definiert:

$$\begin{aligned} s_{2p}(t) &= \begin{cases} s_{2p}(t-1) + w(t) \cdot s_2(t) & \text{, if } s_2(t) - r_2(t) > d \\ 0 & \text{, else} \end{cases} \\ \text{mit } w(t) &= f\{s_2(t)\} \end{aligned}$$

Die Funktion $w(t) = f\{s(t)\}$ gewichtet die Signalwerte $s_2(t)$, die Konstante d dient als Schwellenwert. Es hat sich gezeigt, daß diese relativ einfache Signalvorverarbeitung die weitgehende Unterdrückung von Störimpulsen ermöglicht.

4.1.3 CO-Sensor

Für das Ausgangssignal $s_3(t)$ wurde eine Signalvorverarbeitung definiert, die vollständig der für den Rauchdichtesensor gewählten entspricht:

$$\begin{aligned} s_{3p}(t) &= \begin{cases} s_{3p}(t-1) + w(t) \cdot s_3(t) & \text{, if } s_3(t) - r_3(t) > d \\ 0 & \text{, else} \end{cases} \\ \text{mit } w(t) &= f\{s_3(t)\} \end{aligned}$$

Die im vorigen Abschnitt beschriebene Akkumulation von Kohlenmonoxid im Blut legt die hier erfolgende Aufsummierung der Signalwerte $s_3(t)$ nahe.

4.2 Die Regelbasis

Die vorverarbeiten Sensorsignale $s_{ip}(t)$ bilden die Eingangssignale für das auf Fuzzy-Regeln basierende Entscheidungsnetzwerk. Zentraler Bestandteil dieses Netzwerkes ist eine Regelbasis. Hier werden die Signalwerte $s_{ip}(t)$ miteinander verknüpft und eine Entscheidung über den Alarmzustand des Detektors getroffen. Die Regelbasis des hier diskutierten Detektors enthält fünf Regeln, die in vereinfachter Form wie folgt definiert sind:

$$\begin{array}{rll}
\text{if } s_{2p}(t) \text{ is } \mathit{low} & \text{then} & e(t) \text{ is } \mathit{low} \\
\text{if } s_{1p}(t) \text{ is } \mathit{low} \text{ and } s_{2p}(t) \text{ is } \overline{\mathit{high}} \text{ and } s_{3p}(t) \text{ is } \mathit{low} & \text{then} & e(t) \text{ is } \mathit{low} \\
\text{if } s_{2p}(t) \text{ is } \mathit{high} & \text{then} & e(t) \text{ is } \mathit{high} \\
\text{if } s_{2p}(k) \text{ is } \mathit{medium} \text{ and } s_{1p}(t) \text{ is } \mathit{high} & \text{then} & e(t) \text{ is } \mathit{high} \\
\text{if } s_{2p}(k) \text{ is } \mathit{medium} \text{ and } s_{3p}(t) \text{ is } \mathit{high} & \text{then} & e(t) \text{ is } \mathit{high}
\end{array}$$

Diese Regelbasis läßt sich wie folgt interpretieren: Der Detektor erreicht den Alarmzustand, wenn für eine hinreichend lange Zeitspanne eine hohe Rauchdichte gemessen wird, oder wenn für eine hinreichend lange Zeitspanne eine mittlere Rauchdichte in Kombination mit einer hohen Temperatur oder einer hohen Kohlenmonoxidkonzentration gemessen wird.

5 Experimentelle Ergebnisse

In diesem Abschnitt werden einige Ergebnisse vorgestellt, die auf bei Brandversuchen aufgezeichneten Sensorsignalen und anschließender Rechnersimulation beruhen, dargestellt.

5.1 Offenes Holzfeuer

Die folgende Abbildung zeitlich Verlauf der Ausgangssignale des Temperatursensors $s_1(t)$, des Rauchdichtesensors $s_2(t)$, des Kohlenmonoxidsensors $s_3(t)$ sowie das Ausgangsignal $e(t)$ des Detektors im Fall eines offenes Holzfeuers (TF1 gemäß EN54).

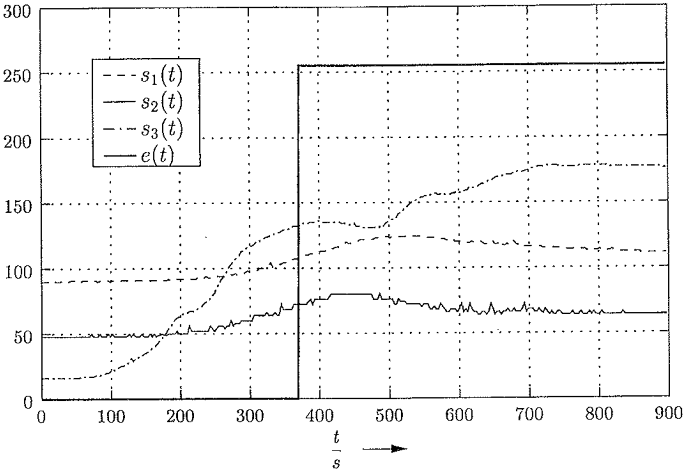

Abbildung 2: Zeitlicher Verlauf der Sensorausgangssignale $s_i(t)$ und des Detektorausgangssignals $e(t)$ im Fall eines TF1

In der Anfangsphase dieses Feuers basiert die Alarmentscheidung auf der Auswertung der vierten und fünften Regel der oben dargestellten Regelbasis. Bezogen auf den Zeitpunkt des Alarmierung ergibt sich aus dem Einsatz eines zusätzlichen Kohlenmonoxidsensors keinerlei Vorteil.

5.2 Holzschwelbrand

Die folgende Abbildung zeitlich Verlauf der Ausgangssignale des Temperatursensors $s_1(t)$, des Rauchdichtesensors $s_2(t)$, des Kohlenmonoxidsensors $s_3(t)$ sowie das Ausgangsignal $e(t)$ des Detektors im Fall eines Holzschwelbrandes (TF2 gemäß EN54). Darüberhinaus ist das Detektorausgangssignal $e'(t)$ dargestellt, daß aus einer Simulation mit "abgeschaltetem" CO-Sensor resultiert.

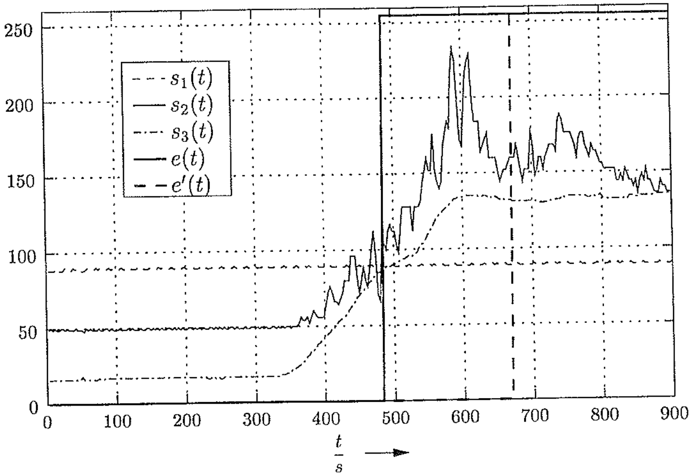

Abbildung 3: Zeitlicher Verlauf der Sensorausgangssignale $s_i(t)$ und des Detektorausgangssignale $e(t)$, $e'(t)$ im Fall eines TF2

In diesem Beispiel, einem Schwelbrand, erfolgt die Alarmentscheidung in der Anfangsphase des Brandes durch Auswertung der fünften Regel der oben dargestellten Regelbasis. Die vierte Regel liefert hier keinen Beitrag, da das Ausgangssignal des Temperatursensors $s_1(t)$ ausgehend von der gemessene Temperatur zu Beginn des Brandversuches (etwa 20°C) nahezu konstant bleibt.

Der Vergleich der Detektorausgangssignale $e(t)$ und $e'(t)$ (deaktivierter CO-Sensor) zeigt, daß die zusätzliche Auswertung der Brandkenngröße Kohlenmonoxid prinzipiell den Vorteil einer frühzeitigen Alarmierung bietet, ohne die Falschalarmsicherheit eines solch einfachen Detektorsystems zu beeinträchtigen.

Grundsätzlich ließe sich sich eine frühzeitige und falschalarmsichere Alarmentscheidung im Fall von Schwelbränden auch durch eine aufwendigere Signalvorverarbeitung erreichen. Der hier gewählte Weg, also die Auswertung der Brandkenngröße Kohlenmonoxidkonzentration, kann einen Beitrag zu einem verbesserten Personenschutz bieten. Dies gilt insbesondere für Detektorsysteme, bei denen zusätzlich ein Entscheidungsnetzwerk zu Kohlenmonoxidwarnung implementiert ist.

5.3 Nichtbrandversuch

Neben einer Reihe von Brandversuchen wurden auch einige Nichtbrandversuche durchgeführt, um die Eigenschaften des hier vorgestellten Mehrkenngrößen-Detektors zu untersuchen. Die folgende Abbildung zeigt den zeitlichen Verlauf der Ausgangssignale des Temperatursensors $s_1(t)$, des Rauchdichtesensors $s_2(t)$, des CO-Sensors $s_3(t9$, sowie das Detektorausgangssignal $e(t)$ während eines Nichtbrandversuches. Drei Mitarbeiten erklärten sich bereit, für diesen Versuch eine Zigarettenpause in den Brandversuchsraum des Fachgebiets Nachrichtentechnik zu verlegen. Die Deckenhöhe betrug 3,4 m. Die Versuchspersonen befanden standen unmittelbar unter dem unter der Decke installierten Detektorprototyp.

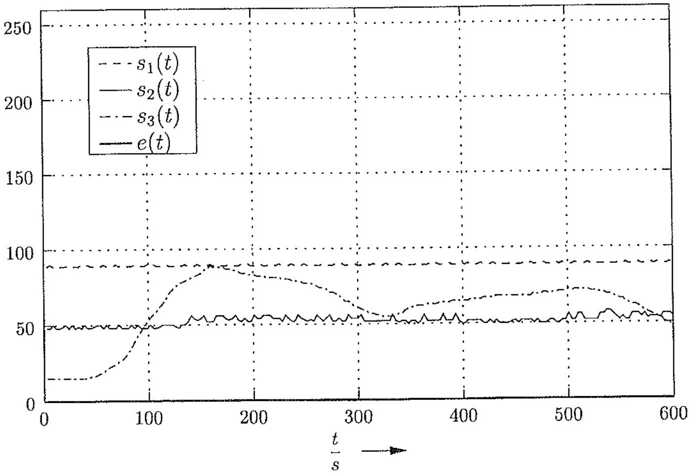

Abbildung 4: Zeitlicher Verlauf der Sensorausgangssignale $s_i(t)$ und des Detektorausgangssignal $e(t)$ während eines Nichtbrandversuches

Für das Ausgangssignal des Detektors gilt während der gesamten Dauer des Versuches: $e(t) = 0$. Der Grund hierfür ist die geringe gemessene Rauchdichte, sodaß trotz der zeitweise hohen Ausgangssignalwerte $s_3(t)$ des CO-Sensors die fünfte Regel der Regelbasis nicht zu einer positiven Alarmentscheidung führt. Die maximalen Signalwerte $s_3(t)$ liegen sind größer als diejenigen, die im Fall des oben dargestellten Holzschwelbrandes zum Auslösen des Alarms führten.

Der erneute Anstieg der gemessenen Kohlenmonoxidkonzentration im Bereich $t >$ 330s ist auf das Entzünden und Rauchen weiterer Zigaretten zurückzuführen.

6 Referenzmessungen

Die hinreichend vollständige Beurteilung von Kohlenmonoxidsensoren erfordert die Durchführung von Referenzmessungen. Zu diesem Zweck verfügt das Fachgebiet Nachrichtentechnik professionelles Gasanalysegerät, das eine quasi zeitkontinuierliche und genau Messung der Kohlenmonoxidkonzentration nach der optischen Absorptionsmethode erlaubt.

Die folgende Abbildung zeigt den zeitlichen Verlauf des Ausgangssignal des CO-Sensors $s_3(t)$ und die gemessene Kohlenmonoxidkonzentration am Ort des Sensors während eines offen Holzfeuers (TF1).

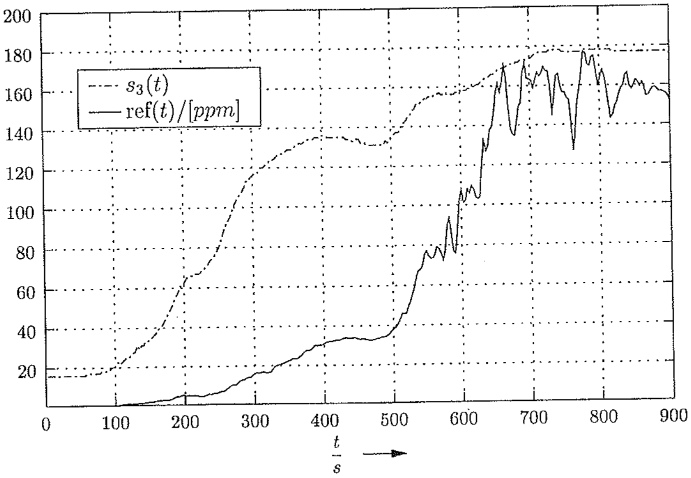

Abbildung 5: Zeitlicher Verlauf der Sensorausgangssignals $s_3(t)$ und der gemessenen Kohlenmonoxidkonzentration $ref(t)$ im Fall eines TF1

Die signifikante Anstieg der CO-Konzentration zum Zeitpunkt $t \approx 500s$ ist auf den Übergang von vollständiger Oxidation zur unvollständiger Oxidation (Pyrolyse) nach Erlöschen der Flammen zurückzuführen.

Der Vergleich der gemessenen Kohlenmonoxidkonzentration $ref(t)$ mit dem Ausgangssignal des CO-Sensors $s_3(t)$ zeigt ein relativ gute Übereinstimmung der Signalverläufe bis zum Zeitpunkt des Erlöschens der Flammen. In dem sich anschließenden Zeitraum weist das Ausgangssignal des CO-Sensors weniger Fluktuation auf als das Ausgangssignal des Referenzmeßgerätes. Grund hierfür sind der dann geringeren thermischen Luftbewegung einerseits und dem Eindringverhalten der konventionellen Detektorgehäuses andererseits zu suchen.

Das Referenzgerät verfügt über eine Ansaugvorrichtung zur aktiven Probennahme, sodaß thermische Luftbewegung und Eindringverhalten für die Messung keine Rolle spielen.

Die obengenannten Unterschiede, lassen sich auch bei einem Schwelbrand für die gesamte Dauer des Brandversuches beobachten, wie die folgende Abbildung am Beispiel eines Holzschwelbrandes (TF2) zeigt. Auch hier ist eine Art Tiefpaßverhalten der Kombination CO-Sensor und Detektorgehäuse festzustellen.

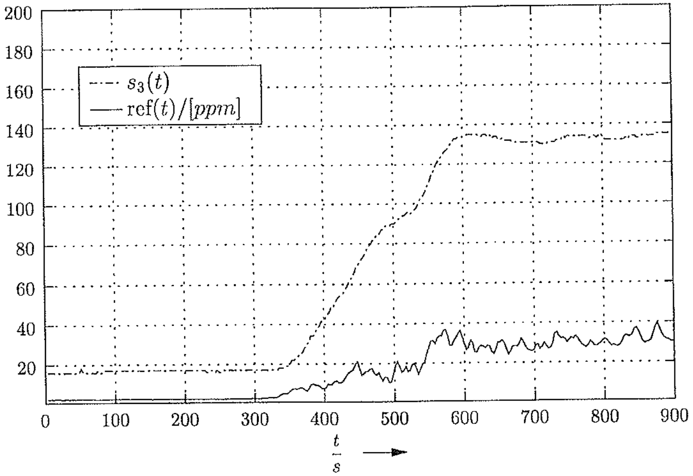

Abbildung 6: Zeitlicher Verlauf der Sensorausgangssignals $s_3(t)$ und der gemessenen Kohlenmonoxidkonzentration $ref(t)$ im Fall eines TF2

Die dargestellten Ergebnisse von Referenzmessungen machen neben den genannten Merkmalen deutlich, daß der verwendete CO-Sensor aufgrund seiner hohen Empfindlichkeit in einem Bereich < 50ppm zur Erkennung von Bränden in einem frühen Stadium geeignet ist.

7 Zusammenfassung

Im zweiten Abschnitt war auf das hohe Risiko hingewiesen worden, dem Menschen in einer CO haltigen Atmosphäre ausgesetzt sind. Die häufigste Todesursache von Brandopfern ist eine Kohlenmonoxidvergiftung. Dieser Umstand lieferte und liefert eine hinreichende Motivation zum Einsatz von CO-Sensor in Branddetektoren.

An Hand eines, bezogen auf die Signalvorverarbeitung, sehr einfachen Detektionsalgorithmus wurde gezeigt, daß der Einsatz von CO-Sensoren in Branddetektoren zumindest im Fall von Schwelbränden zu einer verbesserten Detektivität führen kann.

Literatur

[1] *The SFPE Handbook of Fire Protection Engineering*, Second Edition, Society of Fire Protection Engineers, 1995, S. 2-92ff

[2] *General Information for TGS Sensors*, Figaro USA Inc., 1996

History of development steps in gas sensor fire detection in RWE power plants for lignite and waste combustion

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A. Schwarz, A. Eberheim, V. Uwira, D. Kohl, Institut für Angewandte Physik, Universität Gießen

On March, 23, 1991, presumably an electrical shortcut in the 230-Volt-illumination circuit was the cause of an extended and desastrous fire in the Niederaußem power plant of RWE Energie AG, Fig. 1. Both the tilted bridge including the Eternit padding of its housing (cross section 8 m x 3 m) and the distributing station were severely damaged, Figs. 2, 3). The whole electrical wiring had to be replaced, too. The conveyors of the blocks A to E had to be stopped for 2 weeks and the production was reduced to a low level. The total cost of repair amounted to 2.4 million DM and the production loss to further 6 million DM. Triggerd by this event the already existing fire detectors, about 2800 ionization and optical detectors, of the power plant were reinvestigated and a search for more efficient fire detection was started. Dipl.-Ing. H. Petig guided this programme.

Mr. Petig found contact to activities started already in 1987 by Dr. Florschütz und Ober-Ing. Walther in the power plant Jänschwalde. In November 1987 Dipl-Ing. Karow (today: VEAG central administration, Berlin) started experiments with a gas sensor system, featuring only one tin oxide sensor and a simple detection circuit (fig. 4) which had been installed in the power plant of Jänschwalde to survey the conveyor belts. 12 prototypes of tinoxide sensors were prepared 1986/1987 by Dipl.-Ing. Tröger in the central laboratory of the VEB Energy "Kombinat" (since the reunion, 1990: Energie-Versorgung Sachsen AG) in Karl-Marx-Stadt (today: Chemnitz) for this purpose. After the reunion of Germany Dr. Kieswetter founded a start up company, called Umweltsensortechnik (UST) in Geraberg, using licenses from Chemnitz, to produce tinoxide gas sensor elements.

Experiments with this system in Niederaußem suffered from a lack of stability caused by humidity changes and temperature drift resulting in frequently occuring false alarms. Therefore this system was judged not to be applicable in connection with the central bus system of the power plant.

After some discussions starting in November 1991, on March, 30, 1992 RWE Energie asked formally the Institute of Applied Physics (IAP) of Gießen university to find out the most favourable gases to detect a smouldering lignite fire in the conveyor house by model experiments in the technical chemistry laboratories in Niederaußem, fig. 5. An electrochemical cell for CO, a chemically sensitive field effect sensors for hydrogen, a humidity- and a temperature sensor in a large sized box were used. Dipl.-Phys. Kelleter, IAP, performed first measurements of background gas concentrations on site.

It turned out that the ratio of hydrogen to carbon monoxide concentration originating from the smouldering fire reappears at the detector site, because diffusion is slow compared to the transfer time between source and detector, even at distances of up to 30 m [1-5].
This observation was the base for a first patent of an evaluation algorithm for the sensor signals, further patens followed [6-8].

On August, 14, 1992, in a second step of cooperation a mobile data acquisition system for the rough environment of the conveyor house was built in Gießen. Electrochemical cells and the FET had shown reliability problems and were replaced by three tinoxide sensor elements made by Umweltsensortechnik (UST) in Geraberg. In parallel the sensor elements were characterized in the IAP laboratory and the patents principle was supported by further on site measurements. Scenarios with artificial smouldering fires near the conveyor bands were used to get realistic data for optimizing the system. Such measurements in a running plant are connected with a high risk, so the fire brigade had to be present during these experiments. In addition vapours of halogenated hydrocarbons used for vulcanisation of defect conveyor belts were offered to the sensor set. To handle this condition a third sensor for solvents was implemented. The hydrogen sensor was modified according to an IAP proposal, since operation at different temperatures was not sufficient to be selective enough between CO and hydrogen. Later a special temperature cycle was used by Mr. Kelleter to optimize the selectivity of the CO sensor.

On April, 21, 1993 an internal presentation of the status of the new system was given in Niederaußem by Dipl.-Ing. Petig (RWE), Mr. Kelleter and Prof. Kohl (IAP), Dr. Kiesewetter (UST), and Dipl.-Ing. Hellmann (Siemens, Essen, possibilities of realizing a production of a microprocessor evaluation system). Main features of a proposed system were a sensor head with 3 oxide sensors with modified sensitive layers, made by UST protected by a sinter metal hood. Suppression of the influence of humidity changes. Signal conditioning featuring a microcontroller and SMD technique. Calibration by a gas mixture. The system was implemented in the central information and alarm bus system of the power plant.

On October, 12, 1993, a third step of cooperation was devoted to the developement of software with separate modules, switched automatically, for the fast detection of large fires, the reliable (slower) detection of small, but increasing glow nests and for the suppression of interfering influences. The apparatus should adapt itself to a certain surrounding to minimize false alarms. Furtheron recalibration procedures were investigated. Some of the sensor heads were used for long time stability tests. Within this package also experiments with standardized test fires in the laboratories of the "Verband der Sachversicherer, VdS" were used to qualify the system for more general applications (July/August 1993).. This cooperation turned out to be very fruitful. The solvent sensor was replaced by a double function sensor sensitive to solvents (conductance increase) and to NOx (conductance increase). Thereby also open test fires could be detected and discriminated from smouldering fires. Starting February, 2, 1994, three self contained compact sensor prototype units in a rugged housing including a microcontroller were built up in IAP and installed in the conveyor house for further tests. The package was finished in August, 1994.

On May, 9, 1994, RWE Energie asked IAP to explore the possibility to extend the application of the detector system to waste power plants. Again a search for the most characteristic gas components was necessary. The most suitable indicator of hot spots within the waste was found to be an increase of amine concentrations. A phthalocyanine sensor was able to detect that off odour sensitively. Because of the low vapour pressure the system had to be completed by a gas pump. The package was finished in May 1995 with a successful demonstration in RWE "Müllheizkraftwerk Essen-Karnap". A second system was qualified in parallel to detect early fires in bulky waste (furniture, etc) which was stored in a separate compartiment in Esssen-Karnap. In this case methanol formed in microbial processes on the surface of wood was the appropriate key vapour to detect a fire. At present, four of these sensor detectors, are in operation there.

On June, 4, 1995, there was a smouldering fire in the distributing station of Niederaußem, successfully detected in a very early state by the GSME. It originated from a jammed conveyor belt brake and it is described in detail in the contribution " A.Schwarz et al., Detection of glow spots and overheated break at a lignite conveyor system by a gas sensor array".

In 1994 one IAP prototype of the sensor unit was transfered to GTE GmbH in Viersen, to prepare a production of the sensor unit. This cooperation between RWE, IAP and GTE intensified and Mr. Kelleter moved after finishing his doctoral thesis to GTE in December 1996. December 1994 are 45 sensor units, made by GTE, installed at the conveyor belts in Niederaußem. April 1995 the experimental work in Niederaußem was finished.

During October 1995 the GTE manufactured sensor unit, called GSME 03, passes the CE test according to EN 50081-2 and 50082-2 at Siemens-Nixdorf in Paderborn and in December 1995 it passes the "Schutzart JP64" test at Deutsche Montantechnologie (DMT) in Dortmund.

On February, 2, 1996, RWE in cooperation with GTE and IAP started to develope a modem system for remote readout of date and remote parametrization. This system is now a valuable tool to control the correct operation of the units.

On July, 11, 1996 RWE Energie organized in its headquarters in Essen a public colloquium titled: Gassensorik, Innovation im Brandschutz (Gas sensor systems, innovation in fire protection).

Higher volumes of production of the gas sensor unit started 1997 and Siemens, Essen, became responsible for the distribution. A new design for the electonic system, more efficiently to manufacture, a new smaller housing and a lower power consumption of 2 Watts (L03, L02, fig. 6) were taken in production and distribution by GTE/Siemens in July 1997.

At present about 80 gas sensor units for fire detection are surveying the conveyor belts in the Niederaußem power plant. Systems of this type are also installed at the power plants of Schkopau, Weisweiler and Datteln, further insatallations are in preparation. Such gas sensor systems are also in the coke works of Duisburg, at the excavators of Rheinbraun in Bergheim and in some other fields.

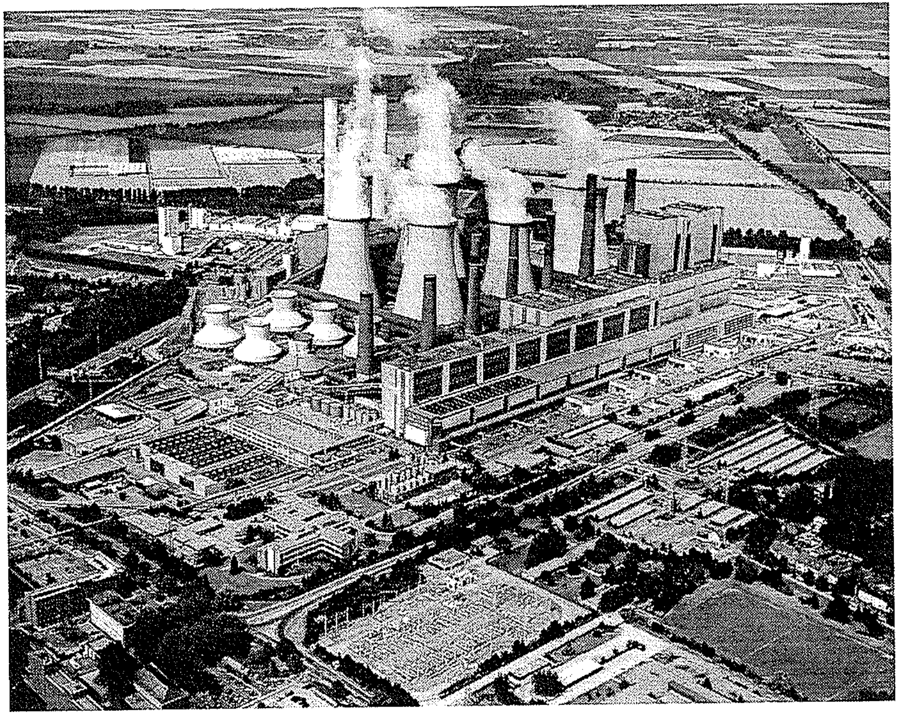

Figure 1:
Niederaußem power plant.

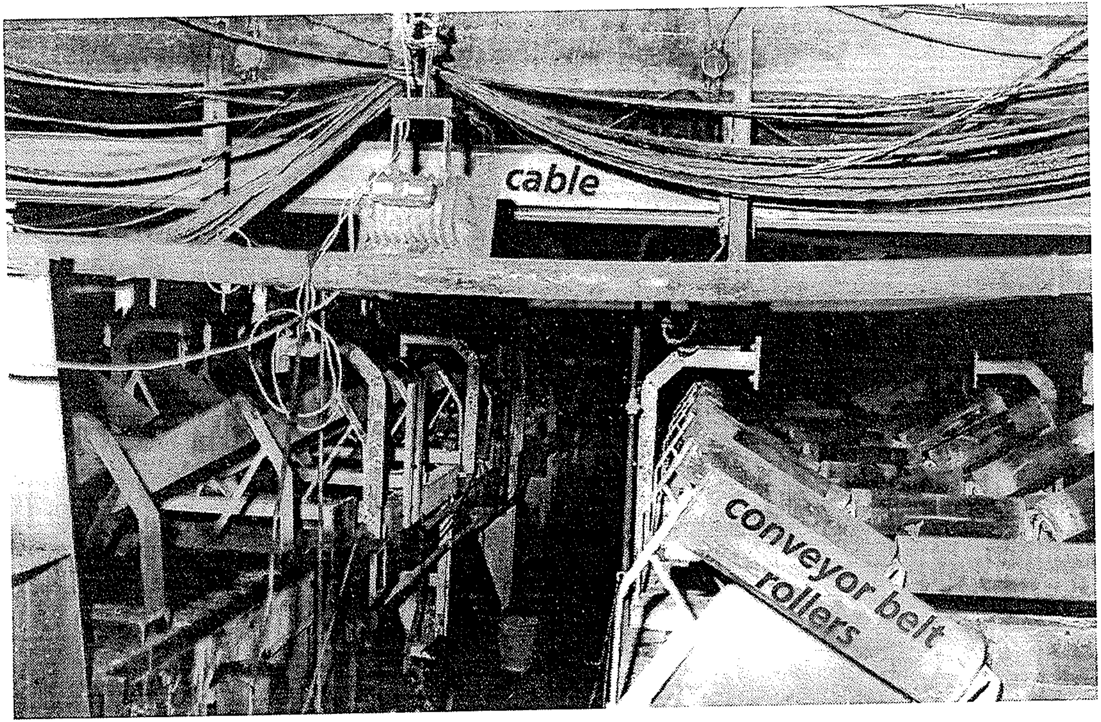

Figure 2:
Damaged conveyor belt, March, 23, 1991 (not March 3, as indicated)

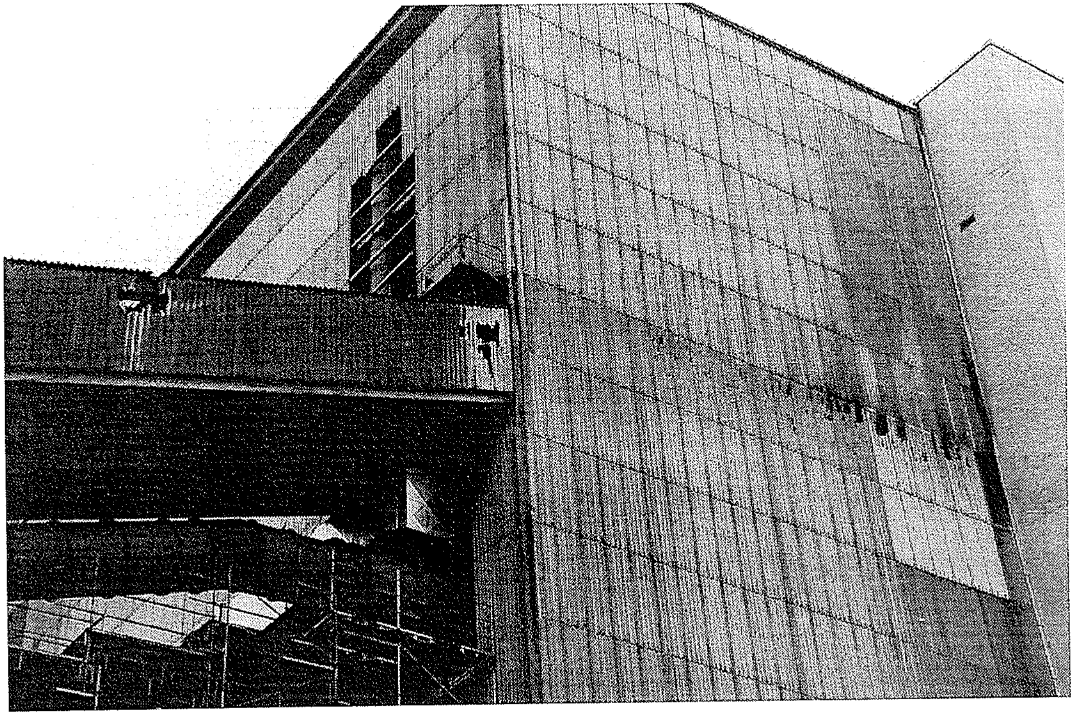

Figure 3:
Damaged eternite of the tilted conveyor bridge.

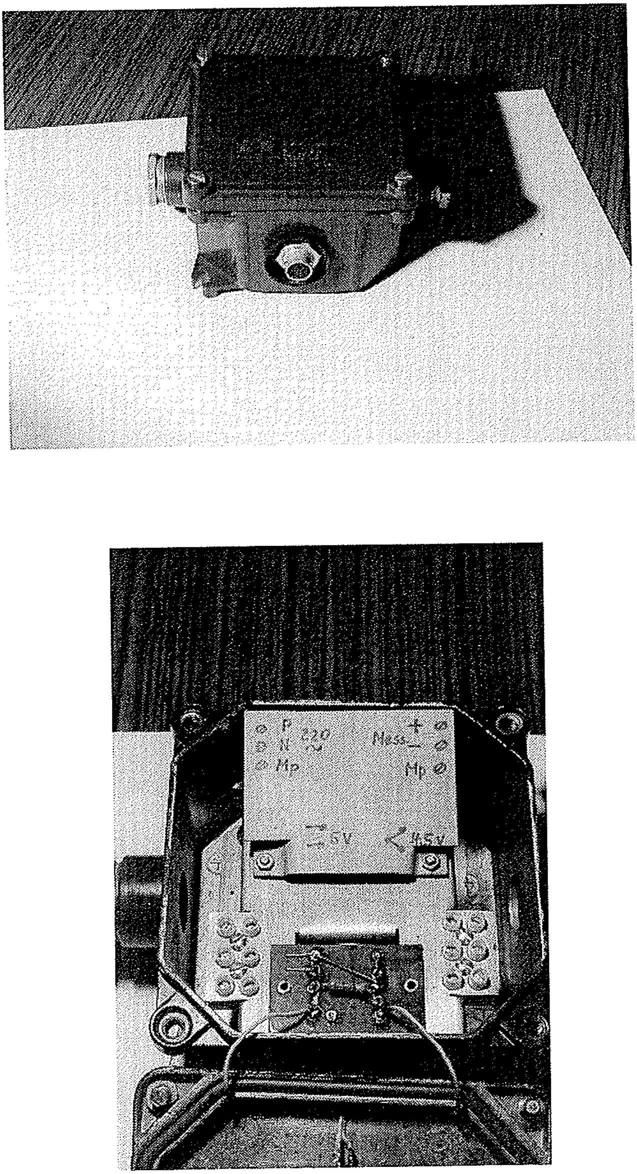

Figure 4:
Jänschwalde: single gas senor (visible in front of the box), simple circuit

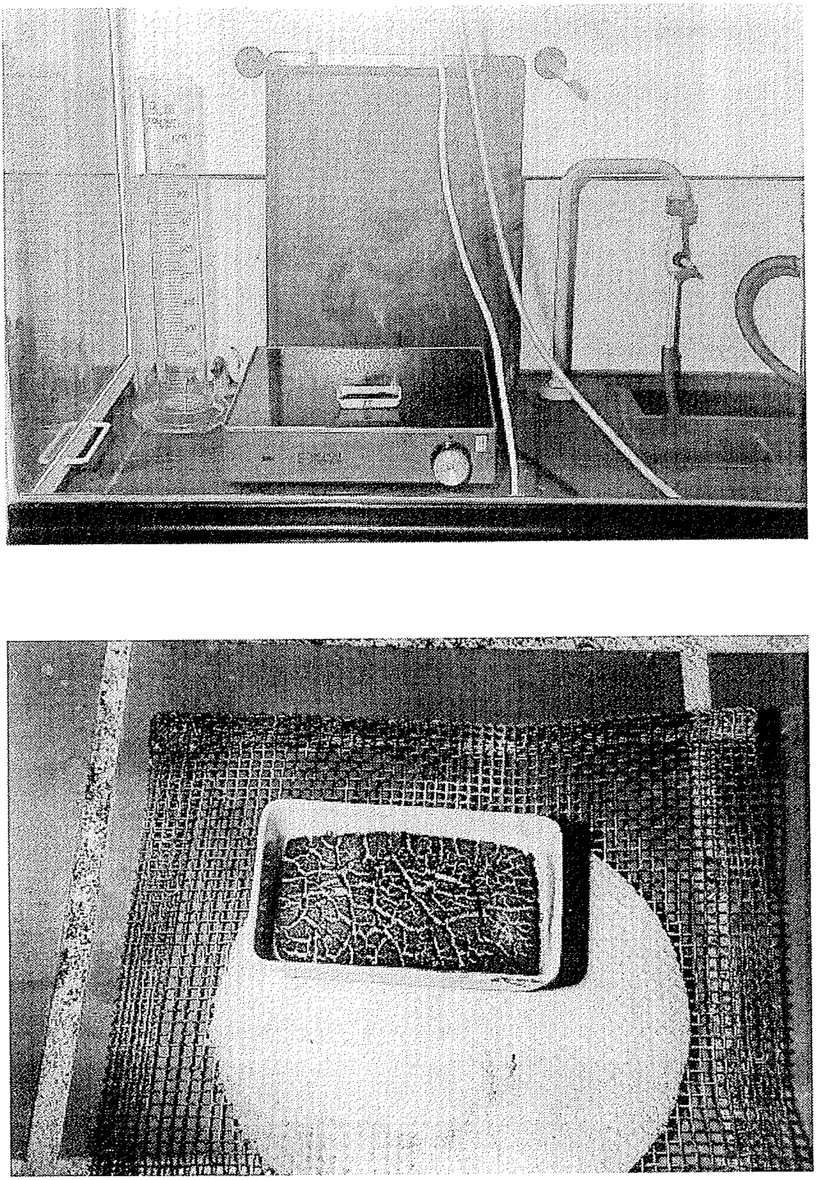

Figure 5:
Technical chemistry lab in Niederaußem, smouldering lignite

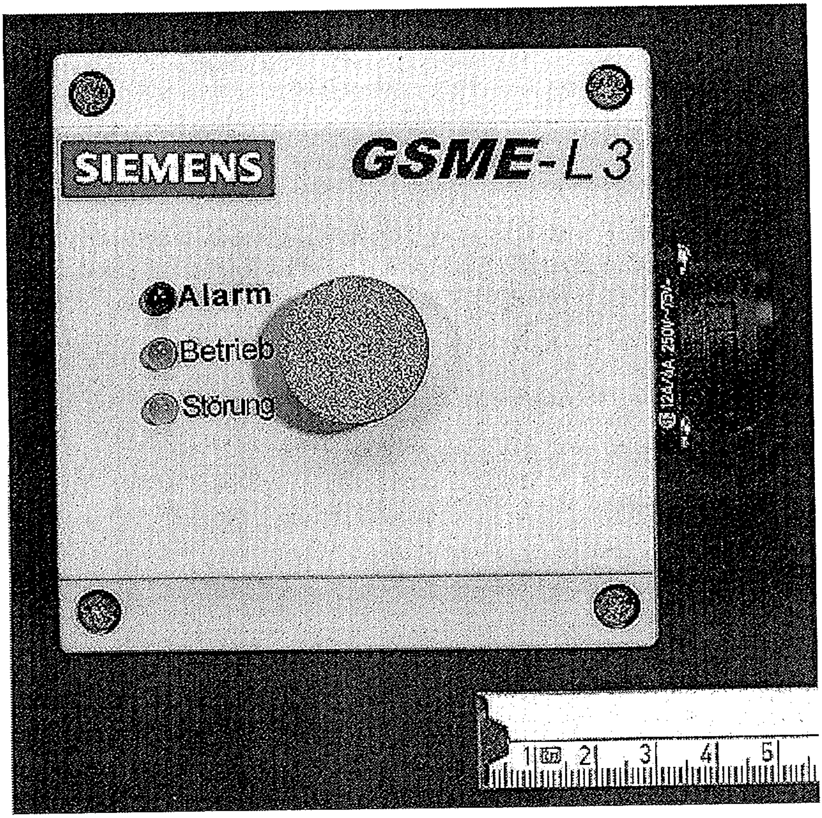

Figure 6:
Siemens L 03 detection unit, in production since 1997

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„Gefahrenzustands- und Brandmeldesystem mit in Meldelinien angeordnenten Meldeeinheiten"

[8]. **GM 93 09 640;** AT 30.06.93; BT 04.11.93
„Gefahrenzustands- und Brandmeldesystem mit an Meldeleitungen angeordneten Meldeeinheiten"

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Tests regarding the Suitability and Use of Ion Mobility Spectrometers for Early Detection of Chemical Degradation Products

Abstract

Extensive research has been devoted in the past few years to early discovery of fire via detection of gasses emitted in the phase of origin of a fire using suitable gas sensor technology. In the present research, the suitability and use of ion mobility spectrometers (IMS) for the early detection of thermal degradation products are investigated. It provides a review of the measurement method, their possible fields of application and performance ability.

The specific thermolysis products are identified on the basis of the signal patterns measured. Comparative measurements with other sensors for early fire detection concerning the response behaviour under different fire development scenarios demonstrate the possible implementation conditions for early detection of fires and hazard situations with the aid of the ion mobility spectrometer.

Introduction

The sources of a fire are often local, narrowly delimited overheating. Smouldering fires, which remain undetected or are detected too late in their initial phase, often cause major damage as a result. Under thermal stress, degradation products specific to the material involved are released in variable concentrations.

Since the overwhelming majority of potential inflammable materials involve organic substances, knowledge of the thermal behaviour of organic materials is of decisive importance.

Depending on the anticipated danger, a variety of early detection devices are in use.

For the early detection of thermal degradation products in the phase of origin of a fire gas detection systems based on different gas sensor technologies can be used [1-3]. In the present research, the suitability and use of ion mobility spectrometers (IMS) are investigated. In particular, this study focused on three main questions:

a) Which specific volatiles compounds develop from different materials under thermal stress.
b) Is it possible to detect these specific compounds with an Ion mobility spectrometer before a fire occurs.
c) Is an Ion mobility spectrometer a suitable detection unit in comparison to common fire detectors.

To answer the first question it is necessary to use powerful and expensive analytical methods to analyse the compounds. In this study infrared spectroscopy and gaschromatography/mass spectroscopy were used to analyse and to identify the compounds.

In order to study the thermal behaviour (i.e. to determine whether there are any characteristic exothermal or endothermal drifts during a defined heating rate) differential thermal analysis by simultaneous thermogravimetry (TG/DTA) was used.

The TG/DTA-system was then coupled to an ion mobility spectrometer to correlate the loss in weight and the exothermal or endothermal signals with the signal patterns of the Ion mobility spectrometer.

Basic principles of an Ion Mobility Spectrometer

Ion mobility spectrometry (IMS) is a technique used to identify traces of chemical vapours by measuring their mobility in the gas phase in an electric field.[4,5] In modern analytical IMS methods, ion mobilities are determined on the basis of ion velocities that are measured in a drift cell with supporting electronics.

The heart of the IMS technique is the IMS-cell. In Fig.1., a schematic overview of the IMS-cell and its functional principle with the resulting signals are shown.

The cell is composed of a reaction region and a drift region, both under an electric field gradient.

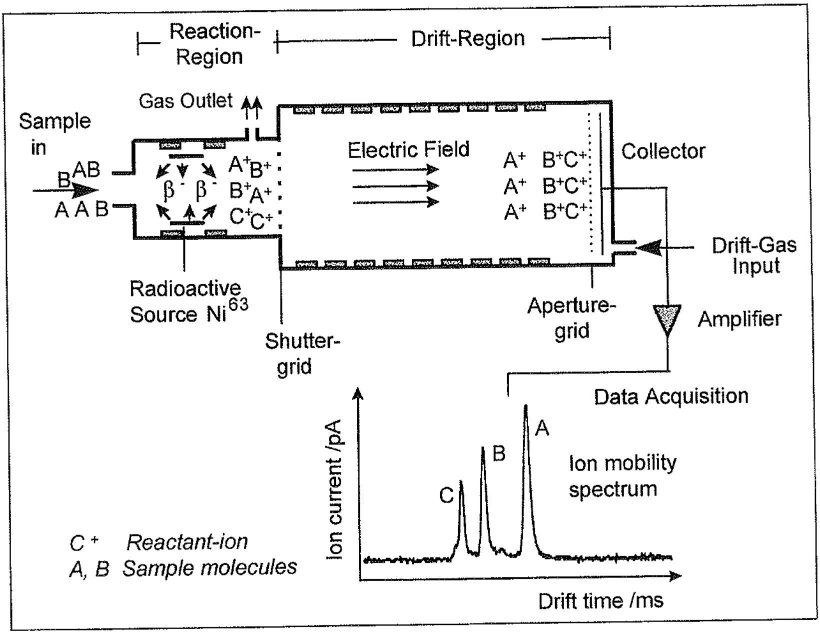

Fig. 1 Schematic diagram of the IMS-cell with resulting ion mobility spectrum

The first measurement stage involves the ionisation of the neutral molecules of a sample. These ion processes occur in the gas phase via chemical reactions between sample molecules (A,B) and a reservoir of reactive ions(C^+). The reservoir of reactive ions is formed by ionisation of the nitrogen in air using a radioactive source (e.g.Ni^{63}) and by a further series of ion-molecule reactions with trace amounts of H_2O, NH_3 and NO in the absence of a sample. The following reaction scheme shows the formation of stable reactant ions in the case of H_2O only [6-8].

Table 1. Formation of stable reactant ions.

N_2	+	e^-		$\longrightarrow$	N_2^+	$+ 2e^-$	*(1)*
N_2^+	+	$2N_2$		$\longrightarrow$	N_4^+	$+ N_2$	*(2)*
N_4^+	+	H_2O		$\longrightarrow$	H_2O^+	$+ 2N_2$	*(3)*
H_2O^+	+	H_2O		$\rightleftharpoons$	H_3O^+	$+ OH$	*(4)*
H_3O^+	+	H_2O	$+ N_2$	$\rightleftharpoons$	$H^+(H_2O)_2$	$+ N_2$	*(5)*
$H^+(H_2O)_2$	+	H_2O	$+ N_2$	$\rightleftharpoons$	$H^+(H_2O)_3$	$+ N_2$	*(6)*

stable reactant ions

The formation of $NH_4^+(H_2O)_n$ and $NO^+(H_2O)_n$ (not part of the sequence shown above) was also investigated and is due to trace impurities of NH_3 and NO in air [8]. The reservoir of reactant ions (C^+) is formed mainly of $H^+(H_2O)_n$ and also of $NH_4^+(H_2O)_n$ and $NO^+(H_2O)_n$. The index n depends on the relative humidity in the IMS-cell.

By means of air aspirated from the area to be monitored the neutral sample (A, B) is introduced into the reaction region and reactant ions undergo further ion-molecule reactions to produce analyte "product-ions" (A^+ and B^+). A pulsed electric shutter grid "opens" for a very short period of time (about 300µs) and among collisions with drift gas molecules a proportion of all ions is accelerated in the direction of the field.

The combination of acceleration by the electric field and collision with neutral gas molecules leads to an average ion velocity v_D that is directly related to the strength of the electric field (E).

$$\vec{v}_D = K \times \vec{E} \tag{7}$$

The constant of proportionality *K* is called the ion mobility, usually in units of $cm^2V^{-1}s^{-1}$

$$K = \vec{v}_D \, / \, \vec{E} = L^2 \, / \, Vt_D \tag{8}$$

where *L* is the ion drift distance in centimetres, *V* the voltage drop across *L*, and t_d is the drift time.

Ion mobilities are characteristics of substances and can be used for detecting and identifying vapours. Ion mobility spectrometry can measure specific ion currents below 10^{-12} A and it is therefore also highly sensitive as a detection technique.

Preparation for detecting specific degradation products with IMS

In order to develop an monitoring application for the IMS, some preparatory work has to be done. First of all, the thermal degradation of some plastic materials was studied. A simultaneous thermogravimetry-differential thermal analysis (TG/DTA) yielded information about the thermal stability and monitored the degradation with different programmed heating rates. To detect the specific volatiles released from the materials an IMS was connected to the TG/DTA-system as shown in Fig 2.

The results i.e. the detection and identification of the gaseous products were compared by using infrared spectroscopy and gas chromatography/mass spectrometry.

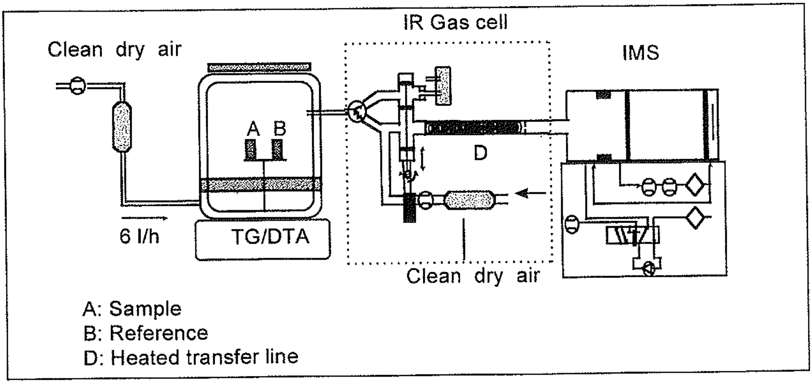

Fig. 2 Combination of TG/DTA with IMS

Figure 3 gives an example of monitoring of a flame-retarded polyurethane with the described combination. The flame retardant used was trichloro-ethyl-phosphat. The heating rate was 10°C/min. The IMS-scanning rate was about 5 seconds and the sample weight was 12 mg.

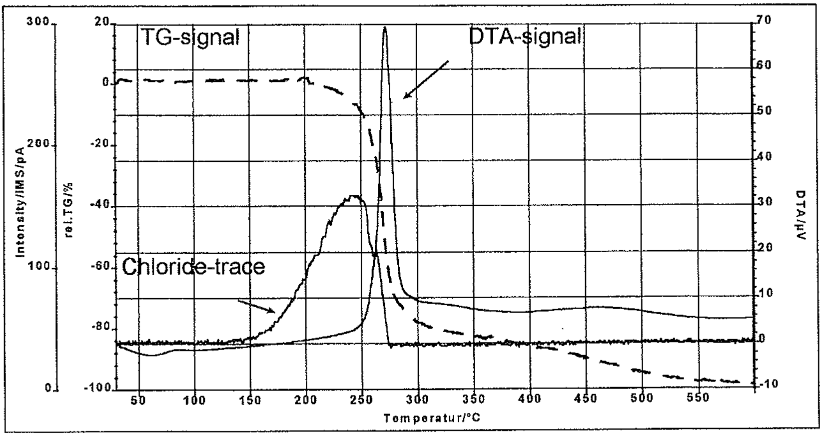

Fig.3 Thermogram and selected chlorine ion trace of a flame retarded polyurethane

The TG-signal shows the percentage weight loss of the sample. At nearly 200°C the decomposition stage occurs with a drastic loss in weight.

At this moment the DTA-signal shows a strong exothermal drift reaching a maximum at 270°C. Before this stage, at a temperature of about 160°C the selected mobility monitoring of the IMS detected some gases containing chlorine. The ion mobility constant is 2.58 $cm^2V^{-1}s^{-1}$. This trace has been shown by GC/MS to be due to the liberation of ethyl- and methylchlorine. The corresponding ion mobility spectrum is shown in figure 4.

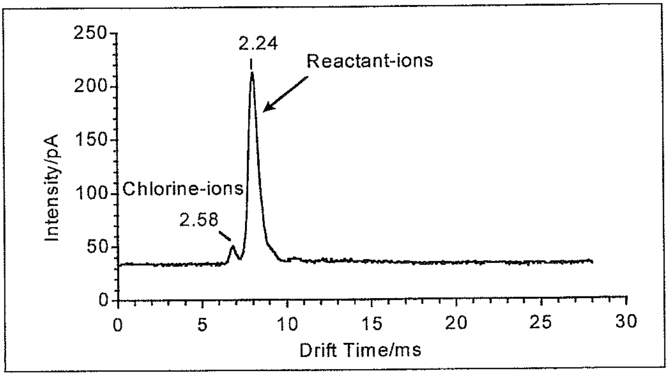

Fig.4 Ion mobility spectrum at 158°C

Another example is given in Figure 5. The thermogram shows the thermal degradation of a flame-retarded printed circuit board.

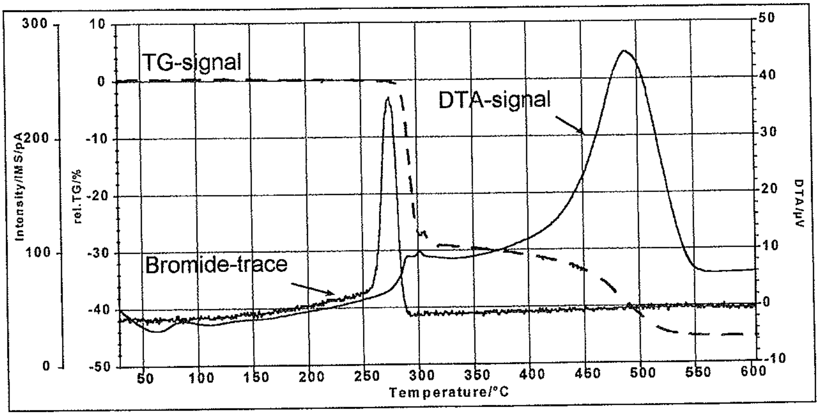

Fig.5 Thermogram and selected bromine ion trace of a flame-retarded printed circuit board

The flame retardant was tetrabrombisphenol A (TBBA). Before the first combustion step began at 285°C the IMS detected some gases containing bromine at 170°C. The ion mobility constant is 2.44 $cm^2V^{-1}s^{-1}$. The corresponding ion mobility spectrum recorded at 172°C is given in Figure 6.

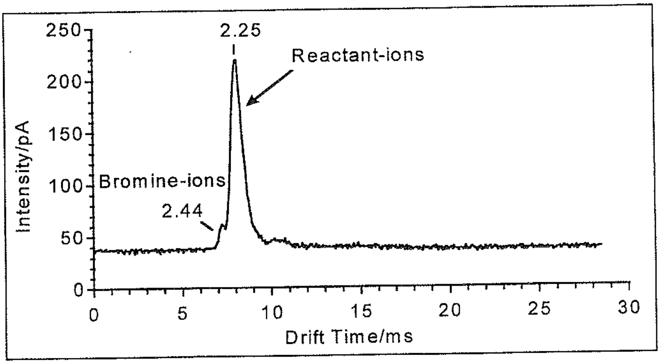

Fig.6 Ion mobility spectrum at 172°C.

Conclusions

Test measurements for the detection of thermal degradation products were carried out also under real conditions in a fire test room. Smouldering pyrolysis wood fire, glowing smouldering cotton fire and thermal degradation products of PVC, polyurethane and other organic materials were analysed using IMS, ionisation smoke detectors, gas detectors and highly sensitive smoke detectors. The comparison of the response values of the different detector types shows, that the significantly reduced intensity of the reactant-ions observed in the IMS-spectrum and the identification of specific degradation products can be used for a very early detection of fire for fire development scenarios in wihich the other systems yield no response or have a large delay time. The main advantages of the IMS are its high sensitivity, the excellent detection limits, the instrumental simplicity and robust configuration and the real-time capability.

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New fire detection concepts with fiber optics technology

1. Abstract

Fire incidents in tunnels and underground transport installations have shown that the consequences of a fire can often be devastating in terms of both injuries and cost. Difficult ambient conditions and restricted escape and access routes call for fire detection systems with high detection reliability. This stands for the highest probability of detecting any developing fire and - at the same time - providing highest immunity to false alarms. The application of fiber optics in the field of linear temperature measurements allows new fire protection concepts for tunnels and other restricted access installations.

In a typical tunnel environment there are numerous factors which make life difficult for a fire detection sensor. Smoke, dust, emissions, climatic conditions, condensation and electromagnetic interference can cause malfunction, actuate false alarms and result in increased maintenance work. But tunnels and underground traffic installations have become such important communications facilities that they must function without disruption around the clock. Interruptions, equipment malfunction or maintenance work cause immediate delays and subsequent losses to the economy.

2. Introduction

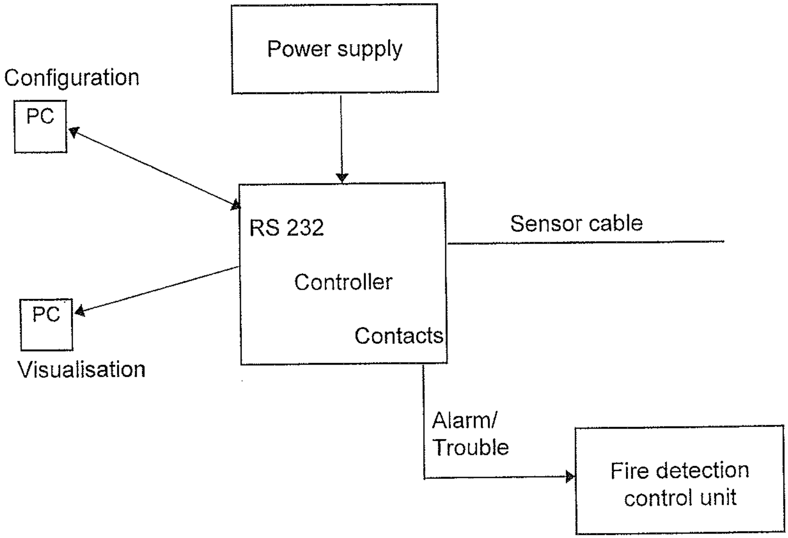
The FibroLaser II is a linear heat detector from the latest generation of fiber-optic sensors which, thanks to its measuring characteristics, makes it especially suitable for the trouble-free monitoring of road and rail tunnels and similar installations for fire.

Since the end of the 1980s, quartz glassfibers in stainless steel tubes have been integrated in overhead lines and power cables as light guides in order to be able to transmit information (network control) without interference from electrical and magnetic fields. Experience with such light guides confirmed the finding that these fiberoptic systems are not only suitable for the transmission of information, but also as locally distributed measuring sensors. Physical measured quantities such as temperature or pressure and tensile force can have an influence on the glass fibers and locally change the characteristics of the light guides in the fiber. As a result of the attenuation of the light in the quartz glass fibers through scattering, the location of an external physical influence can be determined so that the light guides can be used as a linear sensor.

The so-called Raman effect is particularly suitable for measuring temperature with light guides made of quartz glass. The light in the glass fibers is scattered on microscopically small variations in density, which are smaller than the wavelengths. With back-scatter, in addition to the elastic scattering component (Rayleigh Scatter) on the same wavelength as the radiated light we find additional components on other wavelengths which are coupled with the molecular vibrations and therefore with the local temperature (Raman Scatter).

With FibroLaser II, using a new operating principle with semiconductor laser diodes and an evaluation process designed for the purpose, we have been able to measure both scatter effects (Rayleigh and Raman scatter) in light guides up to 4 km in length. By optimizing the measuring interval and the local resolution it will be possible to indicate changes in temperature of a few degrees centigrade per minute reliably and without interference. For these reasons, FibroLaser II is particularly suitable for fire detection in tunnels in which the usual type of fire detector cannot operate satisfactorily due to the harsh ambient conditions.

3. Design of the linear heat detector

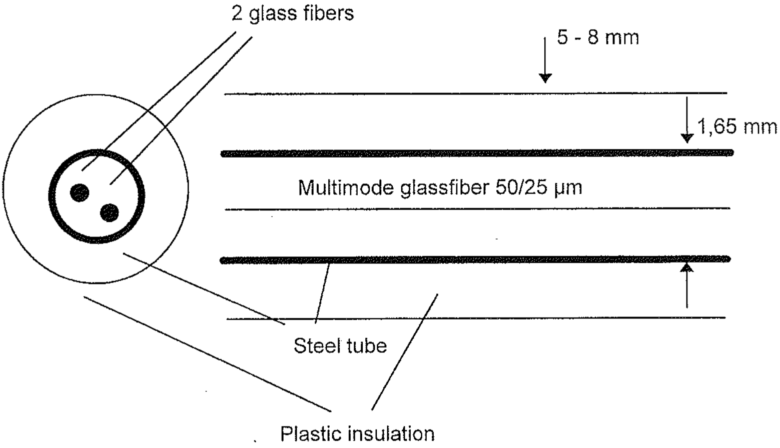


The linear heat detector FibroLaser II has the following system architecture:

- Sensor cable (up to 4 km)
- Controller with laser light generation, measured signal evaluation and software
- External power supply 24V DC / 100 Watt
- 10 volt-free, unidirectional alarm and trouble outputs for a fire detection system control unit (9 main zone alarms, 1 combined trouble signal)
- Connection for PC (RS 232) for setting the optimized operating parameters during commissioning.
  The PC with the commissioning program is decoupled during operation.
- Optionally, a PC can be connected to indicate sub-zones and/or the temperature profile along the cable. This has no retroactive effect on the controller.

4. Functional characteristics

4.1 Sensor cable



The sensor cable consists of a steel tube with an outer diameter of 1.65 mm. In the tube there are 2 independent quartz glass fibers, type Multimode 50/125 µm, each with an outer diameter of 250 µm, whereby the actual light guide in the core has a diameter of 50 µm. The remaining void in the tube is filled with an anhydrous substance.

The steel tube is encased in a plastic insulating sheath with a diameter of 8 mm. This plastic sheath enables easier handling during installation and improves both mechanical stability and sensitivity to purely radiated heat. Tests have shown that as a material, HDPE has optimum thermal and mechanical characteristics.

4.2 Controller

The controller is modular in design and has the following sub-modules:

- Frequency generator with laser source
- Switching power supply
- Optical module with filter and detectors
- CPU and communication

The controller must have an external 24V supply and 10 volt-free alarm and trouble signal outputs. A retroactive effect on the controller via the outputs caused by the series-connected fire detection system control unit is impossible. During commissioning the measured parameters are loaded into the controller software via a separately coupled PC with the commissioning software. During operation, this PC is decoupled.

If required, the measured data can be displayed during operation with a PC and special visualization software at the RS 232 interface. A retroactive effect on the controller is impossible.

4.3 Measuring principle

Raman scattering

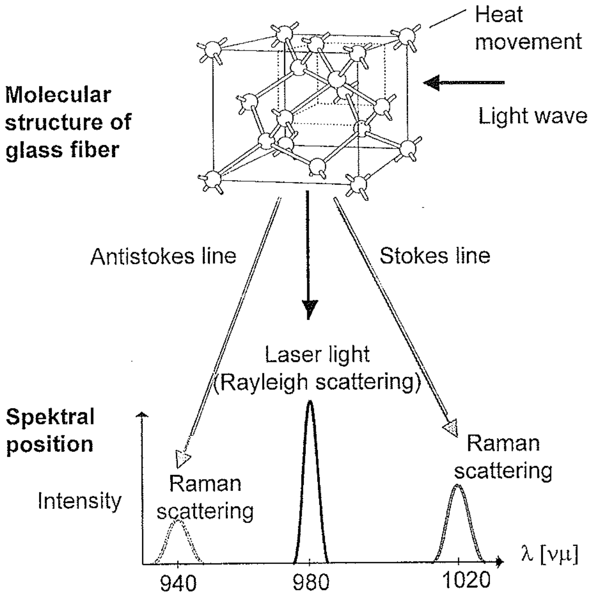
Doped quartz glass is used for the fiber optic. Quartz glass is characterized by SiO_2 molecular bonds. Lattice vibrations of the molecular bonds occur as a result of a temperature increase. When light impinges on the thermally excited molecular vibrations, an interaction between light particles (phonons) and electrons in the molecules occurs. This results in scattering of the light in the light guide which is termed Raman scattering. The frequency of the scattered light is shifted with respect to the frequency of the incoming light by an amount equal to the lattice vibration resonance frequency.

The light back-scattered from the light guide therefore contains three different spectral components:

- the Rayleigh scattering with the wavelength of the laser source used.
- the Stokes components with the higher wavelength with which the phonons are generated, as well as
- the Antistokes components with a lower wavelength than the Rayleigh scattering with which the phonons are destroyed.

The diagram shows the spectral position of the newly created Raman bands. The intensity of the so-called Antistokes band is temperature-dependent while the so-called Stokes band is almost independent of temperature. The local temperature of the light guide can then be determined from the ratio between the intensity of the Antistokes and Stokes light.

Fig. 1: Raman scattering



Measuring and evaluation methods

FibroLaser II employs the Optical Frequency Domain Reflectometry (OFDR) method.

In the case of OFDR, information about the local process is only obtained after the complete measurement period for the detection of the backscattering signal as a function of frequency (complex measurement: phase and amplitude) and the associated Fourier transformation is complete. The essential advantages of OFDR are the quasi-continuous wave operation of the laser and the narrow band detection of the optical backscattering signal, whereby a significantly higher signal-to-noise ratio can be achieved compared to the pulse technique.

This technical advantage allows the application of inexpensive semiconductor laser diodes and the use of inexpensive electronic modules for the signal averaging. On the other hand, this method requires a technically more difficult measurement of the Raman scattering (complex measurement of amplitude and phase) and signal processing using the FFT (FFT, Fast Fourier Transformation), which places high demands on linearity of the electronic modules.

OFDR was developed as a high resolution measurement procedure for the characterization of light guides having lengths of only a few millimeters. The application of this technique for Raman backscattering has therefore neither been publicized nor developed.

The following diagram (Fig.2) shows schematically the organization of the OFDR Raman temperature measurement system. The FibroLaser II temperature measurement system comprises an analysis unit (frequency generator, laser light source, optical module, HF mixer, receiver and microprocessor unit) and a quartz glass fiber as a linear temperature sensor.

The system is arranged in three channels comprising an additional reference channel together with the two measurement channels (Antistokes and Stokes). According to the OFDR method, the output of the laser is sinusoidally swept through the frequency domain from a start frequency (kH range) to an end frequency (100 MHz) within the measurement time period using the HF modulator. The resulting frequency deviation is a direct measure of the spatial resolution of the reflectometer. The frequency modulated laser light is coupled to the optical module in the sensor cable.

The continuously backscattered Raman light from the fiber is spectrally filtered in the optical module and converted into an electrical signal using photodetectors. Finally the signal is amplified and down-converted to the low frequency (LF) spectral range. The Fourier transformed averaged LF signal contains the two Raman backscattering curves (see Fig. 3). The amplitude of the backscattering curve is proportional to the intensity of the Raman scattering at the local point. The fiber temperature along the sensor cable is then found from the amplitude ratio of the two measurement channels.

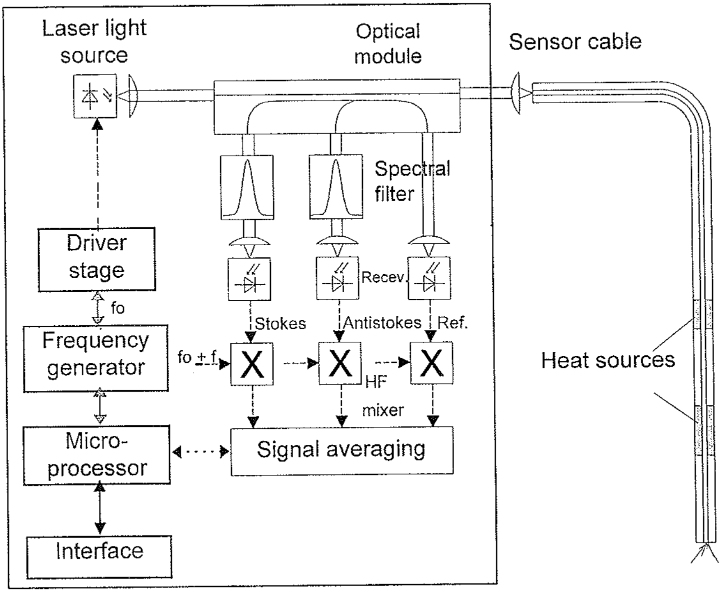


Fig. 2: Organization of the OFDR Raman temperature measurement system

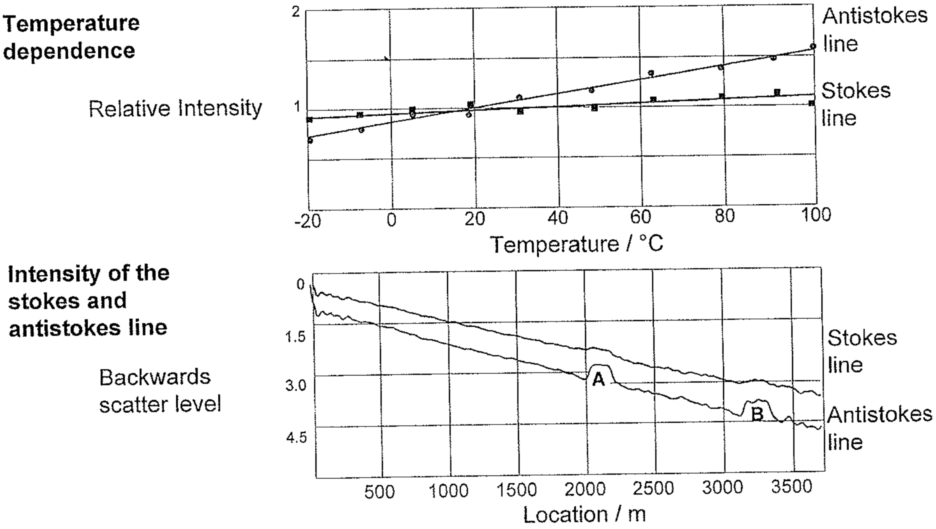


Fig. 3: Raman backscattering curves. A and B shows a temperature change in the FibroLaser II sensor cable.

4.4 Application as linear fire detector

The FibroLaser II measuring process enables a change in temperature to be measured locally. The spatial resolution of the continuous measurement can be selected.

The better the spatial resolution, the longer the evaluating electronics needs to poll the entire sensor cable.

For fire detection in a 4 km long sensor cable, the choice of the spatial resolution distance and the measuring interval can have a strong influence on the detection time. The tests and the theoretical analyses showed that measuring intervals of 60 sec. to 120 sec. and spatial resolution distances of 1.5m respectively 3 m give optimum detection times for tunnel fires. With FibroLaser II the relationship between measurement interval and resolution distance can be determined at commissioning.

As FibroLaser II indicates the momentary temperature per measuring interval at all resolution points, three different alarm data are made available upon fire detection.

- the current absolute temperature at the resolution point

- the change of temperature per unit of time at the resolution point (temperature gradient)

- the absolute change of temperature in a zone (temperature difference)

Realistic fire tests have shown that for fire detection the following alarm values must be simultaneously monitored:

- Maximum temperature alarm value: ~55°C
- Temperature gradient : ~ 6°C / Min.
- Temperature difference : ~ 20°C

During commissioning, the precise alarm values must be determined according to the application with a supplementary calculation procedure which simulates the tunnel fires to be expected.

All values can be determined individually per zone.

A fire alarm is activated as soon as one of the three alarm values is exceeded.

Note: The sensor cable can detect hot gases which flow around the cable (convective heat exchange) as well as purely radiated energy. In tunnels with powerful ventilation the fire alarm is mainly activated by the temperature gradients as a result of radiation.

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Anlagen zur automatischen Ortung und Sichtbarmachung von Glutnestern in Müllbunkern

Abstract

ARTUS LC is a full-automatical system for temperature control which allows to prevent glowing fires. The system also helps to fight fires in difficult optical situations, i. e. for instance smoky rooms. By means of a high-resolution infrared-camera, ARTUS LC controls areas or buildings and recognises dangerous changes of temperature. Glowing fires are found early, localised precisely and appropriate actions can be taken to prevent damages.

IMUS means „Infrarot-**M**üll-**U**eberwachungs-**S**ystem. It has been developed for preventive recognition of glowing fires and fire fighting in waste bunkers of waste incineration factories. IMUS allows by means of a thermal camera and different detection mechanisms to recognise glowing fires, to follow and to fight them.

ARTUS LC und IMUS ersetzen die visuelle Kontrolle auf Rauchentwicklung und Flammenbildung durch berührungslose Temperaturmessung mittels Infrarotkameras. Damit haben sie gegenüber den herkömmlichen Methoden den Vorteil, gefährliche Temperaturerhöhungen bereits frühzeitig zu erkennen. Visuelle Methoden sprechen erst im Brandfall an, denn Rauchentwicklung und Flammen sind Folgen des Brandes. Durch die Temperaturmessung, die jederzeit erfolgt, wird bereits bei Temperaturen unterhalb der Entzündungsschwelle die Aufmerksamkeit des Systems geweckt und ggf. ein Alarm ausgelöst. Darüber hinaus ist das System aufgrund seines Funktionsprinzipes in der Lage, bei ausgebrochenen Bränden durch den sich sofort entwickelnden Rauch hindurchzusehen und den Brandherd und seine Ausweitung zu beobachten. Damit wird erstmals eine *gezielte* Feuerbekämpfung möglich, da visuelle Methoden bei Rauch und Wasserdampf versagen. Insgesamt wird durch den Einsatz von ARTUS / IMUS die passive und aktive Sicherheit von Anlagen erhöht bzw. werden Risiken verringert, was durchaus auch versicherungstechnisch interessant sein kann.

ARTUS LC schützt Produktionshallen (z.B. Sondermaschinen-Überwachung), Rohstoff-, Zwischen- und Endproduktläger, Freiläger, Lösungsmittelläger (z.B. auch Faßläger), Fördersysteme, Recyclinghöfe, Reifenlager, Sekundärrohstofflager (Kunststoffe) in losen Schütten oder in Ballen und Dimenlagerung

Wirkungsweise

Das System basiert auf der Gesetzmäßigkeit der Abstrahlung elektromagnetischer Energie von der Oberfläche aller Körper, deren Temperatur oberhalb des absoluten Nullpunktes (0 K = -273,15°C) liegt. Diese Gesetzmäßigkeit macht Aussagen über den Betrag und die Verteilung der Energie im elektromagnetischen Spektrum.

Über den Umweg der Strahlungsmessung ist die Ermittlung der Objekttemperatur möglich, wobei gilt: höhere Temperatur führt zu höherer Strahlungsleistung. Diese Aussage gilt zunächst unabhängig vom Arbeitswellenlängenbereich des verwendeten Meßsystems.

Es gibt jedoch im Infraroten nur einen Bereich, in dem eine Messung durch die Atmosphäre einwandfrei möglich ist, den langwelligen Bereich von 8 bis 14 µm. Für diesen gelten folgende, auch für die Messung im Freilager wesentliche Anforderungen:

Der langwellige Bereich (LW) bietet eine bessere Empfindlichkeit für Messungen bei Umgebungstemperatur sowie ein besseres Temperaturauflösungsvermögen.

Wegen der besseren Empfindlichkeit ist im Langwelligen durch eine optimale Abstimmung der Optik/Detektor-Konfiguration eine bessere geometrische Auflösung, d.h. die Erkennung kleinerer Strukturen möglich.

Die physikalischen Strahlungsverhältnisse bedingen im LW einen etwa 600mal höheren „Störabstand“ zwischen heißen Quellen in der Umgebung und dem Objekt selbst, wodurch die Gefahr von Fehlmessungen infolge von Reflexionen drastisch verringert wird.

Die mittlere Transmission (Durchlässigkeit) der Atmosphäre (inklusive Kohlendioxid und Wasserdampf) beträgt im kurzwelligen Bereich ca. 73 % und im LW dagegen ca. 98 %. Darüber hinaus ist die Beeinflussung durch Atmosphärenveränderungen im Kurzwelligen deutlich stärker als im Langwelligen, was sich insbesondere durch Verschlechterung der Sicht beim Auftreten von Rauch und Wasserdampf bemerkbar macht.

Für Schüttgut kommt es vor allem auch darauf an, versteckte Glutnester aufzuspüren. Da es mit Hilfe der IR-Technik zunächst nicht möglich ist, in die Stoffe "hineinzumessen", sind eigentlich nur Temperaturerhöhungen erkennbar, die unmittelbar an der Oberfläche auftreten. Da aber das Schüttgut eine mehr oder minder inhomogene Ansammlung ist, bleiben stets Luftkanäle bestehen. Damit kann die von Glutnestern erzeugte Wärme durch Konvektion an die Oberfläche des Schüttgutes gelangen und diese dort lokal erwärmen. Eine Oberflächentemperaturveränderung wiederum ist durch die IR-Kamera räumlich und thermisch detektierbar, so daß die Stelle oberhalb des Brandherdes auf der Oberfläche bestimmt werden kann.

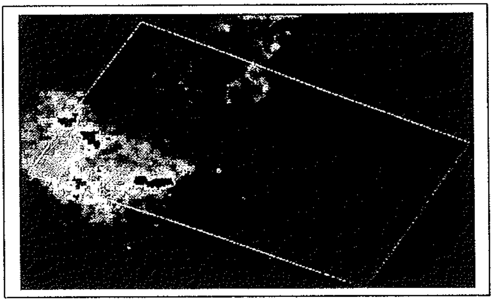


Abb. 1 - Kritische Temperaturerhöhung in einer Kunststoffschüttung

Das System besteht aus einem mikroprozessorgesteuertem Infrarot-Wärmebildsystem (8 – 12 µm), einem hochbelastbaren Schwenk/Neige-Kopf, einem Steuerrechner mit einer speziellen Software sowie weiteren Komponenten, die für die einwandfreie Wirkungsweise der Anlage im 24-Stunden-Betrieb und unter extremen Belastungen notwendig sind, z.B. eine Blasvorrichtung für die IR-Optik, eine USV-Einheit und geeignete Schutzgehäuse.

Das neue Microbolometer von Inframetrics

Die Inframetrics *ThermaCAM ULTRA* erweitert die Möglichkeiten der Rund-um-die-Uhr-Überwachung von Wärmequellen, insbesondere Glutnestern zur Brandfrüherkennung. Drei Jahre intensiver Forschungsarbeit wurden investiert, um auf Basis der im 3 - 5 µm Bereich arbeitenden *ThermaCAM* ein Microbolometer-Radiometer für den in der Brandbekämpfung entscheidenden 8 - 12 µm Bereich zu bauen.

Dank dieser „state-of-the-art“-FPA-Technologie besitzt die *ThermaCAM-ULTRA* sogar eine bessere Auflösung als die bisher im 8 - 12 µm Bereich eingesetzten radiometrischen IR-Kameras, die alle für ihren Betrieb ein Scannersystem und einen miniaturisierten Hochleistungskühler zwingend erforderten. Solche verschleißenden Baugruppen benötigt die *ThermaCAM-ULTRA* nicht mehr. Damit ist die *ThermaCAM-ULTRA* im Rund-um-die-Uhr-

Einsatz sowohl in der Anschaffung als auch im Dauerbetrieb kostengünstiger und hat keine bewegten Teile mehr für den Einsatz.
Bei der Konstruktion der *ThermaCAM-ULTRA* wurde sehr viel Wert auf die Meßfähigkeiten des Systems gelegt. Im Gegensatz zu den anderen am Markt erhältlichen Microbolometern wird hier der Detektor schon „on-Chip“ korrigiert, so daß eine ständige Nachkalibration des Meßsystems vermieden werden kann. In Verbindung mit der genauen Temperaturmessung der Detektorumgebung gibt die *ThermaCAM-ULTRA* Temperaturen insbesondere im Dauerbetrieb sehr stabil und genau wieder.
Durch die neue 14-Bit breite digitale Schnittstelle ist eine volldigitale und die volle Detektordynamik direkt ausnutzende PC-Bildverarbeitung nun möglich.

Das zukunftsweisende System bietet darüber hinaus vielfältige Optionen für den Betrieb, die Diagnose und die Feuerbekämpfung. Die Weiterentwicklung des Systems sowie seine Anpassung an neueste Erkenntnisse und gesetzliche Bestimmungen wird vom Systemhaus Hörotron ständig vorgenommen, ebenso wie die Sicherstellung einer hohen Verfügbarkeit der Anlage durch spezielle Wartungsvereinbarungen.

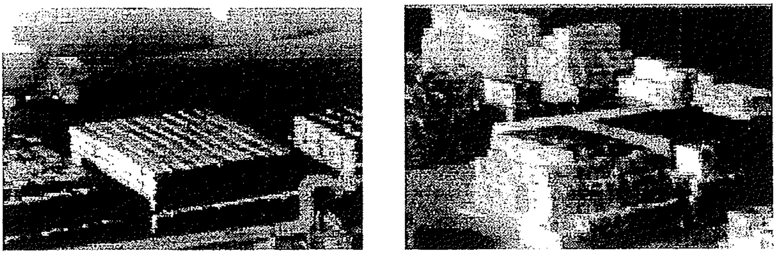
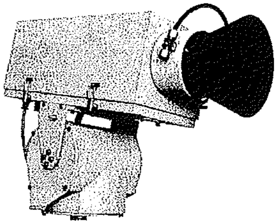
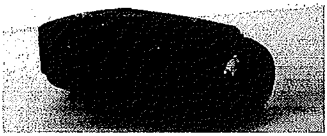


Abb. 2/3 - So sieht die Infrarotkamera einen Lagerplatz. Erwärmte Gebiete - hier hauptsächlich durch Sonneneinstrahlung verursacht - erscheinen hell im Bild. Wird der vorgegebene Temperaturschwellwert von z.B. 80 °C an einer Stelle überschritten, so löst die Software der Überwachungsstation Alarm aus.

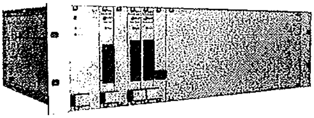
Linterslager von Buckeye, Glückstadt. Mit freundlicher Genehmigung.



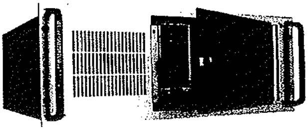
Thermografiekamera im Schutzgehäuse, Schwenk-/Neigekopf



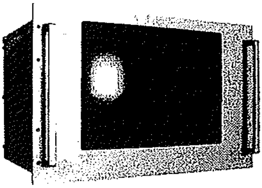
Inframetrics ThermaCAM ULTRA



Interfaceeinheit (Überwachung, Alarmierung)



Steuerrechner (Bildverarbeitung)



Kontrollmonitor

Zwecks Überwachung teilt man die Lagerfläche / Müllbunkerfläche in beispielsweise 16 unterschiedlich große, einander teilweise überlappende Zonen ein. Lage und Geometrie der Zonen sind flexibel definierbar. Die Zoneneinteilung wird auf dem Kontrollmonitor dargestellt. Die Thermografiekamera fährt nacheinander diese 16 Zonen an. Auf dem Kontrollmonitor läßt sich mitverfolgen, welche Zone augenblicklich überwacht wird; außerdem stellt dieser Monitor die eingestellten Kameraparameter und die in der Zone gemessenen Temperaturen dar. Ein zweiter Monitor zeigt das Wärmebild, so wie es die IR-Kamera sieht.

Während der jeweils einige Sekunden dauernden Meßvorgänge wertet der Rechner die Temperaturen in den zu überwachenden Zonen aus. Überschreitet das Temperaturverhalten einer Zone einen der vordefinierten Alarmzustände (Maximaltemperatur, Flächentemperatur, Nesttemperatur), so wird ein optisch/akustischer Alarm ausgelöst. Die Steuerung stellt sicher, daß anhand des Kontrollbildschirms die Zone und anhand des Thermobildes der genaue Ort der Temperaturerhöhung festgestellt werden kann. Da die Bezeichnung der Lagerzonen eindeutig ist, kann das Personal eine örtlich gezielte Brandbekämpfung einleiten.

Wegen der sehr guten Auflösung der IR-Kamera und der hohen Bildfrequenz ist dabei eine Orientierung über den Erfolg der Maßnahmen anhand des Thermobildes leicht möglich. Erst wenn der potentielle Brandherd erfolgreich beseitigt wurde, verschwinden das akustische Signal und die Alarmierung. Die Systeme ARTUS LC / IMUS setzen den normalen Überwachungsbetrieb mit der Überwachung der alarmauslösenden Zone fort. Die Anlage arbeitet vollautomatisch und erfordert keinerlei Bedienung.

Alle Parameter können am System entsprechend den örtlichen Gegebenheiten eingestellt werden, insbesondere die Anzahl der zu überwachenden Zonen, die Koordinaten der Zonen, die Überwachungszeit, die Alarmparameter, die Ansprechschwellen usw. Da in den Lagern Fahrzeugverkehr zur Beschickung und Entnahme herrscht, muß eine Fahrzeugerkennung durchgeführt werden. Mit Hilfe eines Klassifikators können im Infrarotbild befindliche Fahrzeuge, deren Temperaturen oberhalb der Alarmgrenze liegen und einen Alarm auslösen würden, von der Software erkannt und ausgeblendet werden. Dadurch ist die Flexibilität des Systems garantiert sowie die Reaktion auf die örtlichen Gegebenheiten möglich.

Störungen an der Anlage (Ausfall der Stromversorgung oder von Systemkomponenten, z.B. Zuleitungen) führen zu einer akustisch/optischen Meldung. Die Art der Störung wird systemintern dokumentiert und kann bei Bedarf abgerufen werden.

Softwarefunktionalität

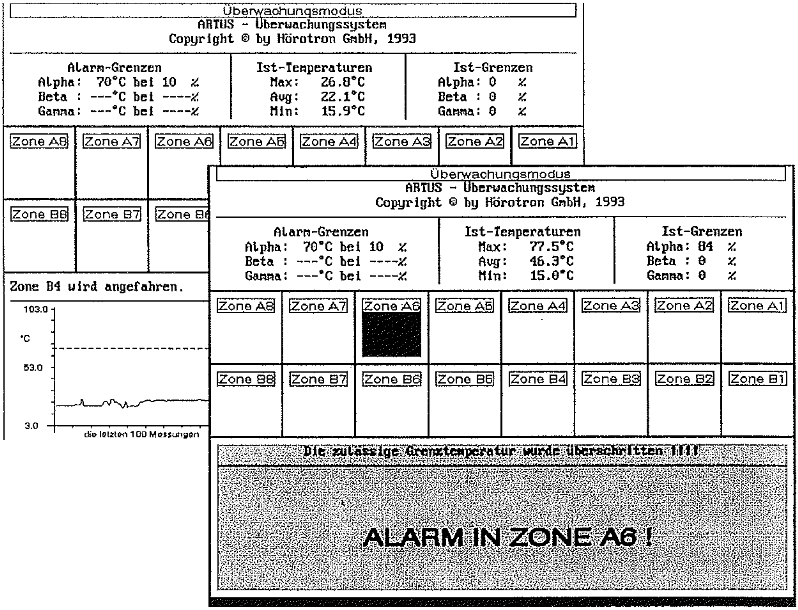
Die folgende Aufstellung gibt eine kurzen Überblick über den Aufbau und die Leistungsfähigkeit der Software ARTUS für die Steuerung des Gesamtsystems.

Regelungsfunktionen

- Steuerung einer Inframetrics Thermokamera ThermaCAM ULTRA über serielle Schnittstelle und Videobild, d.h. Einstellung von Temperaturbereich, Mittentemperatur, Zoom und Fokus (optional) sowie von Emissionsgrad und Hintergrundtemperatur
- Steuerung eines Schwenk-/Neigers zur Positionierung der Kamera
- Konfigurierbarkeit von bis zu 16 Überwachungszonen (optional mehr) und deren grafische Darstellung
- selbständige Funktionsprüfung aller Komponenten
- Ausgabe von Zustands-, Fehler- und Alarmmeldungen auf Kontrollmonitor und Interfaceeinheit
- Fahrzeugerkennung

Temperatur-Überwachungsfunktionen

- On-Line Auswertung des Wärmebildes über eine hochauflösende Bildverarbeitungskarte
- Darstellung des Thermobildes und der aktuellen Temperaturmeßwerte
- Temperaturverlaufs-Aufzeichnung für die einzelnen Zonen
- Abspeicherung der aktuellen Temperaturmeßwerte für spezielle Auswertungen
- über Grenzwerte steuerbares Alarmfall-Verhalten



```
Überwachungsmodus
ARTUS - Überwachungssystem
Copyright © by Hörotron GmbH, 1993

    Alarm-Grenzen            Ist-Temperaturen        Ist-Grenzen
Alpha:  70°C bei 10  %      Max:   26.8°C          Alpha: 0   %
Beta : ---°C bei ----%      Avg:   22.1°C          Beta : 0   %
Gamma: ---°C bei ----%      Min:   15.9°C          Gamma: 0   %

Zone B4 wird angefahren.
```

```
Überwachungsmodus
ARTUS - Überwachungssystem
Copyright © by Hörotron GmbH, 1993

    Alarm-Grenzen            Ist-Temperaturen        Ist-Grenzen
Alpha:  70°C bei 10  %      Max:   77.5°C          Alpha: 84  %
Beta : ---°C bei ----%      Avg:   46.3°C          Beta : 0   %
Gamma: ---°C bei ----%      Min:   15.0°C          Gamma: 0   %

Die zulässige Grenztemperatur wurde überschritten !!!!

ALARM IN ZONE A6 !
```

Abb. 4 - Anzeige der aktuellen Parameter auf dem Kontrollmonitor

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Fire Parameter Detection Arithmetic and it's Application Researches

Abstract

In order to distinguish the practical fire, signal measuring and processing methods of threshold comparing, forecast analyzing, tendency and slope computing, interrelation analyzing, auto-suitable filtering, artificial neural net and so on can be taken as fire parameter detection arithmetic. It can obtain the ideal detection intelligence for primary fire that adopt the different fixed arithmetic in accordance with fire signal fixed value and a special integrated circuit (ASIC) in detectors of distribution intelligence systems.

Introduction

The kernel of fire monitoring and controlling systems is to realize the effectively collecting and processing of fire information. It is the normal way for fire parameters on fire spot that we adopt methods of compound detecting and integrated data processing and realize the function such as automatic data collecting and processing, detection sensitivity adjusting in time, data analyzing and judging in many discriminations and so on. The key of above-mentioned procedure is to determine the method of effective fire parameter processing and design the circuit of collecting and processing fire information. So this paper analyses and discusses the detection arithmetic of fire parameters and it's application based on fire signal properties in system developments.

The detection arithmetic requirement of fire parameters

Based on the energy and substance transform in material combustion, fire parameters mainly have smoke or smoke-aerosol, temperature, flame and combustible gas. It can bring about methods of air ionization detection, photo-electric detection, heat or temperature detection, flame detection, combustible gas detection and so on, and constitute different fire detectors. It is very important for obtainable fire parameters in detectors how to effectively process fire detecting signals in time and judge practical fire. Ideal processing methods of fire signals should be suitable to circumstance state change, automatically adjust the fire parameter model, rapidly distinguish fire, reliably judge fire and realize very low false alarming. So in practice the requirement of data processing is of the feature of automatic compatibility, study capability, fault-tolerant and parallel processing ability.

The detection arithmetic of fire parameters

When the output-signal variable $x(t)$ of fire parameter sensors expresses some fire special properties, the $x(t)$ can be taken as a non-stable stochastic process and described as follows:

$$x(t)=\begin{cases} x_h(t) & fire \\ x_n(t) & not\quad fire \end{cases} \tag{1}$$

In the formula, $x_h(t)$—the fire feature parameter signal;

$x_n(t)$—the noise or not fire signals caused by other factors.

It is evident that the non-stable stochastic property of the $x(t)$ decides to adopt some methods of signal measuring and processing as follows in order to effectively measure the fire signal $x_h(t)$.

Threshold comparing

This arithmetic is applied to output signals of alone fire sensor or detector and compares the effective signal value $y(t)$ of fire parameters with the pre-supposed signal threshold S_0. When the $y(t)$ surpasses the pre-given threshold S_0, it outputs fire alarming. The arithmetic can be shown as follows:

$$y(t)=P[x(t)] \qquad C[y(t)]=\begin{cases} 1 & y(t)>S_0 \\ 0 & y(t)\le S_0 \end{cases} \tag{2}$$

In the formula, P[.]—the effective information in fire spot;

C[.]=1—expressing practical fire;

C[.]=0—expressing not fire.

Signal integrating and differential

Signal integrating is the improvement of the threshold comparing. The signal *x(t)* in time *(t-t_0)* is integrated by signal averaging and delay processing to restrain the disturbance of electric-pulse and industry frequency and raise the reliability and anti-disturbance capability. The arithmetic is shown as follows:

$$\overline{X}(t)=\frac{1}{t-t_0}\int_0^t x(t)\cdot dt \qquad y(t)=P[\overline{X}(t)] \qquad C[y(t)]=\begin{cases}1 & y(t)>S_0\\ 0 & y(t)\leq S_0\end{cases} \tag{3}$$

Signal differential is suitable to detect temperature parameters in practical fire. This arithmetic applies the value difference of the *x(t)* to compute signal vary-rates and judge practical fire. It can be shown as follows:

$$y(t)=\frac{dx(t)}{dt}\approx x(t)-x(t_0) \qquad C[y(t)]=\begin{cases}1 & y(t)>S_0\\ 0 & y(t)\leq S_0\end{cases} \tag{4}$$

It should be pointed out that the reliability and anti-disturbance ability in fire detection are raised by using signal averaging and delay processing in the signal differential method.

Signal filtering

Signal filtering has quite kinds of methods and mainly adopts digital average filtering in fire detection. The arithmetic can get rid of the pulse disturbance in the signal and realize the signal smooth processing. Its technological process includes removing the maximum and minimum of some continuous signal data and taking the average of remaining data as a valid value.

Tendency computing

The arithmetic applies intact mathematical expression to describe the signal feature and processing course. The simple tendency arithmetic can be shown as follows:

$$y(n)=\sum_{i=0}^{N-1}\sum_{j=i}^{N-1}u(x(n-i)-x(n-j)) \tag{5}$$

In the formula, n—the dispersed time variable;

N—the length of observed data;

u(.)—the unit step function.

Based on the formula (5), we can further constitute signal compound computing and special tendency computing. Then we can rapidly follow the signal tendency change, smooth the noise influence and effectively reduce false alarming.

Slope computing

Slope computing is the improvement of tendency computing. It can retain the sensitivity of the signal variable and compensate the insufficient of the not-defining signal variable value in the tendency computing. If the stable value of the signal *x(n)* is X, depended on the signal analyzing theory, the interrelated difference function *d(n)*, the accumulative function *a(n)* and the slope function *g(n)* of the *x(n)* can be shown as follows:

$$d(n) = \frac{X - x(n)}{X} \tag{6}$$

$$a(n) = \begin{cases} [a(n-1)+1] \cdot u(d(n-1) - S_0) & S_0 > 0 \\ [a(n-1)+1] \cdot u(S_0 - d(n-1)) & S_0 < 0 \end{cases} \tag{7}$$

$$g(n) = d(n) \cdot \delta(a(n) - N) \tag{8}$$

In the formula, u(.)—the unit step function;

S_0—the pre-fixed threshold;

N—the range length of computing slope;

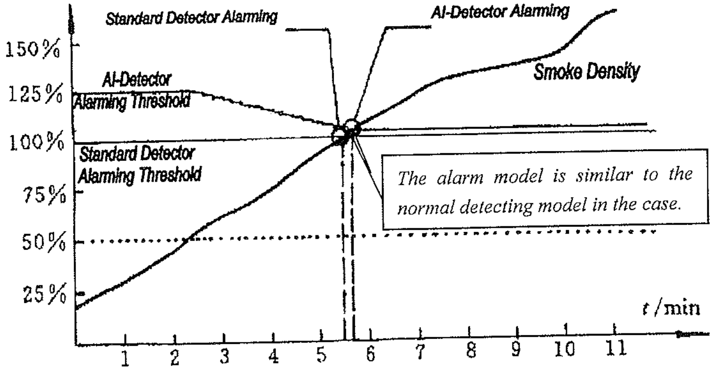
δ(.)—the unit pulse function.

Adopting the slope function *g(n)* can overcome the noise disturbance and ensure that the slope is computed and the specific range of signal changes is understood when the signal has the large range change. The fire should be finally judged by comparing the signal slope and the pre-fixed alarming threshold. Combining the slope computing with the tendency computing can further raise the reliability of the fire detection.

It should be pointed out that all of the fire detection arithmetic above-mentioned is directed against the special value of signal vary-range, tendency and duration. Because detection signals in practical fire are non-stable stochastic process, the ideal method of fire detections is the statistical processing and man-made neural net. Fire detection methods of the statistical processing and artificial neural net can further raise the reliability and the speed and deduce the false alarming in fire detection. The related content refers to document [1]~[4].

Application for detection arithmetic of fire parameters

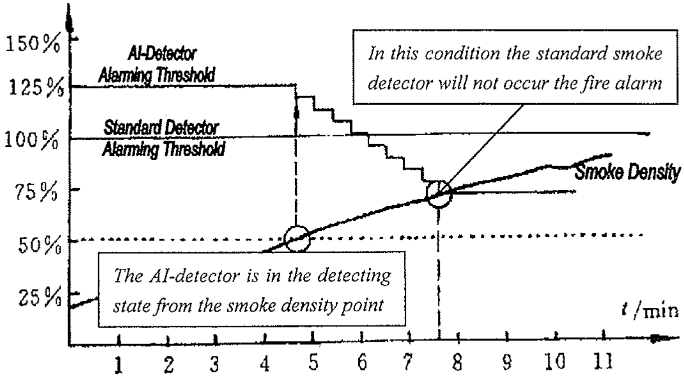
In the design of fire detection systems, the realization of the fire detection arithmetic has two patterns. One of them, which can form the model of distribution intelligence fire detection systems, applies a special integrated circuit (ASIC) in detectors to realize parts of arithmetic and automatic adjustment and finishes the rest of detection arithmetic and fire judgement in fire alarming controllers. The other, which can form the model of concentrating intelligence systems, realizes all detection arithmetic in controllers and only accomplishes data collecting and transmission in detectors.



The alarm model is similar to the normal detecting model in the case.

Fig.1 Alarming model of the smoke density normal-vary in AI-detectors

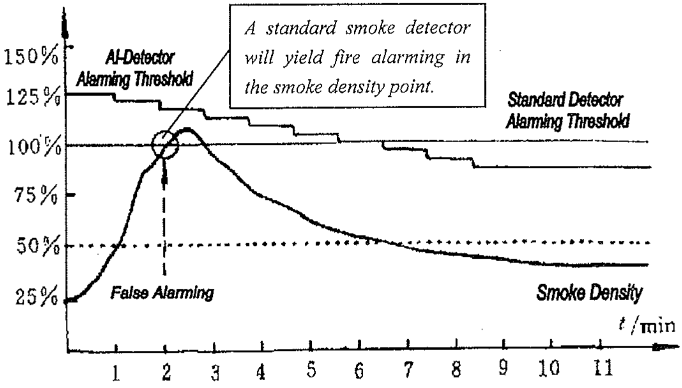
In practice, the selection of fire parameter detection arithmetic should synthetically concern many-sided factors such as the entirely design of fire detection alarming systems, the technical level of the computer development, the price orientation of fire systems in market and so on. When we develop the intelligent system of fire detecting



In this condition the standard smoke detector will not occur the fire alarm

The AI-detector is in the detecting state from the smoke density point

Fig.2 Alarming model of the smoke density slow-vary in AI-detectors



A standard smoke detector will yield fire alarming in the smoke density point.

Fig.3 Alarming model of the smoke density rapid-vary in detectors (e.g. Smoking will bring about this result)

and alarming, methods of tendency slope computing, signal compound computing, digital filtering, simple neural net analyzing and so on are adopted in model JTY-LZ-AI ion smoke detectors (i.e. AI-detectors). Cooperating the main engine of fire alarming systems, the AI-detector can complete the automatic compensation of its environments, the rapid analysis of variable rates, the automatic adjustment of its sensitivities, the manifold alarming of output states and so on. It can be seen from fig.1 to fig.3 that the AI-detector can reliably distinguish different fire vary tendency and rapidly judge practical fire. The AI-detector can also realize effective data acquirement and processing and obtain the ideal primary detection intelligence in the system.

Conclusion

Synthesizing the above-mentioned detection arithmetic of fire parameters, the fixed arithmetic which take properties of fire signal fixed value as the treatment object can't satisfy the ideal requirement of the fire detection. Methods of statistical processing and man-made neural net now are being in the development step and have very more investments in practice. So the diversified mature arithmetic and the distribution intelligence are adopted in our system's developments. Then we obtain the primary detector intelligence and ideal product performance-price rates.

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Ein LOW-COST Flammenmelder mit guten Alarm- und Falschalarmeigenschaften

Abstract

The department of communication engineering presents a prototype LOW-COST-Version of an infrared (IR)-Flame-Detector with good detection capabilities **and** excellent false alarm resistivity.

No false alarms in case of high power intensity modulated IR-broadband radiation **and** fast detection ($\approx$ 0.3 Sec.) of flames from carbon hydrogen burning material even on the noise background of high power intensity modulated IR-broadband radiation sources are the remarkable features of this device.

The main intention for this development was to show that the required signal processing methods can be implemented using LOW-COST-microprocessors.

Einführung

Flammenmelder als automatische Brandentdeckungssysteme haben einen sehr geringen Marktanteil ($\ll$ 1%) und sind im Vergleich zu den klassischen Brandmeldern (Rauch- und Wärmemeldern bzw. einer Kombination aus beiden) extrem teuer.

Die Gründe dafür sind auf einige spezielle Eigenschaften der Flammenmelder zurückzuführen.

Neben der für einige Einsatzbereiche unverzichtbaren **guten Eigenschaft**:

- extrem schnelle Entdeckung offener Flammen (innerhalb von Sekunden oder gar Sekundenbruchteilen),

gibt es einige **schlechte Eigenschaften**, die im folgenden aufgeführt sind:

1. Schwelbrände - als eine wichtige und häufig auftretende Klasse der zu entdeckenden Brände - werden nicht entdeckt.
2. Gefahr des Verpassens von Alarmen bei nicht direkter "Sichtverbindung" zwischen Flamme und Melder.
3. Täuschungsalarmanfälligkeit in Anwesenheit starker Störstrahler.
4. Gefahr des Verpassens von Alarmen in Anwesenheit starker Störstrahler durch Blendung.

5. Im Vergleich zu Rauch- und/oder Wärmemeldern → hoher Versorgungsenergiebedarf.

Wegen dieser Eigenschaften ist der Einsatzbereich von Flammenmeldern und damit die Produktionsstückzahl begrenzt auf Gebiete, in denen spezielle Risiken auftreten (wie z.B. die mögliche explosionsartige Enwicklung von Flammen in Produktionslinien, Lagern bzw. Produktionsstätten von brennbaren Gasen/Flüssigkeiten, besonderen Reinigungsanlagen etc.).
Die Notwendigkeit der Verwendung vergleichweise teurer optischer Komponenten (wie z.B. optische Schmalbandfilter, Gehäusefenster mit besonderen Transmissionseigenschaften, die Verwendung optischer Mehrfachsensorik zur Verbesserung der Entdeckungs- und/oder Täuschungsalarmeigenschaften) einerseits und die simple, auch hier gültige Relation "geringe Stückzahl ⇔ hoher Preis" führt zu der eingangs genannten Situation.

Weil zumindest die unter den Ziffern 1 und 2 genannten schlechten Eigenschaften prinzipiell nicht behebbar sind, ist auch nicht zu erwarten, daß LOW-COST-Flammenmelder mit guten Eigenschaften deren Marktanteil drastisch erhöhen.
Gelingt es aber die unter den Ziffern 3..5 aufgeführten schlechten Eigenschaften auch noch zu möglichst geringeren Herstellungskosten zu verbessern, so ist zumindest ein verbesserter Schutz bei besonderen Risiken zu geringeren Kosten erzielbar. Dabei ist zu berücksichtigen, daß gerade bei sich explosionsartig entwickelnden Bränden eine Kopplung der Flammenmeldung mit automatischen Löschmaßnahmen wünschenswert oder notwendig ist, was wegen der Täuschungsalarmanfälligkeit i.d.R. die UND-Verknüpfung mehrerer - auf denselben Schutzbereich aus verschiedenen Positionen ausgerichteter - Flammenmelder erfordert, um Schäden durch ungewolltes Löschen zu vermeiden.

Maßnahmen zur Unterdrückung von Falschalarmen durch Störstrahler.

Die von offenen Flammen emittierte elektromagnetische Strahlung überstreicht einen weiten Wellenlängenbereich vom ultravioletten (UV) über den sichtbaren bis hin zum fernen IR-Bereich (Wärmestrahlung). Eine Vielzahl nützlicher oder unvermeidlicher Quellen (wie z.B. heiße Körper, Lampen, Sonnenstrahlung etc.) emittieren - ebenfalls breitbandig - Strahlung in den gleichen Wellenlängenbereichen und sind somit potentielle Falschalarmquellen.
Die noch immer mit gutem Erfolg verwendeten Methoden zur Eliminierung von Falschalarmen durch Störstrahler sind:

1. Die Unterdrückung der von den optischen Sensoren erzeugten elektrischen Signalanteile, deren Spektralkomponenten - hervorgerufen durch Intensitätsmodulation der optischen Strahlung - nicht in dem für Flammen typischen Flackerfrequenzbereich $0 < f \ll 20Hz$ liegen (vergl. z.B. [1], [2]). Damit können Störstrahler mit konstanter Strahlungsintensität (z.B. unbewegte heiße Körper, konstante Sonneneinstrahlung, netzbetriebene Glühlampen mit den Spektralkomponenten 0 Hz und 100 Hz etc.) eliminiert werden, sofern nicht durch andere Ursachen Spektralkomponenten im Bereich $0 < f \ll 20Hz$ erzeugt werden (z.B. durch bewegte Quellen bzw. teilweise Abschattungen der Quelle durch bewegte Gegenstände).

2. Schmalbandige Messung(en) unter Verwendung optischer Filter mit einem oder mehreren optischen Sensoren in ausgewählten Wellenlängenbereichen.
   Als Flammenindikatoren werden hier die Emissionsspektrallinien, insbesondere die des CO_2 bei $\approx 4.3\ \mu m$ genutzt, in denen bei allen Flammen kohlenwasserstoffhaltiger Brennmaterialien schmalbandig hohe Strahlungsleistungen emittiert werden und darüberhinaus unter Normalbedingungen durch die geringfügig zu kürzeren Wellenlängen hin verschobenen Absorptionslinien über genügend weite Luftstrecken Störstrahlung gedämpft wird (vergl. z.B. [1], [3]). Mithilfe zweier oder mehrerer, geschickt im Wellenlängenbereich gewählter schmalbandig messender optischer Sensoren läßt sich (z.B. durch schlichte Messung der eingekoppelten Wechselsignalleistungen (vergl. Ziffer 1)) ein recht gut unterscheidbares Signaturmuster für verschiedene Flammen- und Störsituationen auswerten. Das gilt allerdings nur dann, wenn entweder die Flammenstrahlung oder aber die Störstrahlung dominierend ist.
   Im gemischten Fall, d.h. Flammen- und Störstrahlung mit ähnlicher Intensität gleichzeitig vorhanden, versagt diese Signaturmethode. Dieser häufig vorkommende gemischte Fall wird später noch näher bertrachtet.

3. Der Einsatz aufwendigerer Signalverarbeitungsmethoden mit dem Ziel aus den Charakteristika der gemessenen, i.A. stochastischen Signale der Sensoren Rückschlüsse auf Flammen- oder Störsignale zu ziehen (vergl. z.B. [4]).
   Solche Methoden erfordern einen hohen Rechenaufwand und sind erst seit kurzer Zeit mit billigen und doch leistungsfähigen Mikroprozessoren anwendbar. Auch hier gilt wie unter Ziffer 2, daß diese Methoden dann weitgehend unwirksam werden, wenn Flammen- und Störstrahlung ähnlich intensiv gleichzeitig vorliegen.

Der unter den Ziffern 2 und 3 erwähnte "gemischte Fall" ist somit von besonderer Bedeutung in Bezug auf die Detektivität. Bei gleichzeitig vorhandener, ähnlich intensiver Flammen- und Störstrahlung werden typische Merkmale der reinen Flammen- wie auch der reinen Störstrahlung sowohl in den Leistungs- als auch in den Signalsignaturen verwischt.

Eine Methode zur Verbesserung der Detektivität bei ähnlich intensiver, gleichzeitig vorhandener Flammen- und Störstrahlung.

Im Rahmen eines BMFT-Projektes [4] wurde im Fachgebiet Nachrichtentechnik der Gerhard-Mercaror Universität von *Ch. Kranz* ein Verfahren entwickelt, mit dem die Entdeckung von Flammen vor dem Hintergrund starker, intensitätsmodulierter Störstrahler bei einem "zweiäugigen" IR-Flammenmelder deutlich verbessert werden kann. Es basiert auf der Auswertung der Korrelationseigenschaften der elektrischen Signale zweier im IR-Bereich schmalbandig messender Sensoren bei 4.3 μm und 5.5 μm.
Ohne hier auf die Einzelheiten einzugehen kann gezeigt werden, daß mit dieser Methode bei dieser Sensorkombination die Entdeckungsfähigkeit von Flammen im "gemischten Fall" bis zu einem um den Faktor 28 schlechteren Flammensignal-/Störsignal Leistungsverhältnis im Vergleich zu einem reinen Leistungssignatur-Detektor erhöht werden kann. Anhand eines Labormusters, ausgestattet mit einem leistungsfähigen Signalprozessor und einem 1-Bit-Sigma/Delta-A/D Wandler mit einer effektiven Auflösung von 14-Bit, konnte die Wirksamkeit des genannten Verfahrens auch praktisch demonstriert werden.

Obwohl auch extrem leistungsfähige Signalprozessoren in wenigen Jahren billig verfügbar sein werden, scheinen zur Zeit die Kosten dafür noch zu hoch zu sein, um einen solchen verbesserten Flammenmelder mit der verwendeten Ausstattung zu vermarkten. Aus diesem Grunde wurde vom Author dieses Berichtes eine LOW-COST-Version mit marktüblichen Sensoren entwickelt, bei der besonderer Wert darauf gelegt wurde, mit einem möglichst billigen Mikroprozessor und reduziertem Schaltungsaufwand ähnlich gute Eigenschaften zu erzielen.
Diese Entwicklung ist vorläufig abgeschlossen und ein funktionstüchtiger Prototyp steht seit Anfang 1997 zur Verfügung. Es wurde ein 8-Bit Mikroprozessor vom Typ ST6220 der Firma SGS-Thomson zum Einzelstückpreis von $\approx$ 12.- DM eingesetzt. Die gesamte Elektronik inclusive Mikroprozessor aber ohne die beiden Sensoren kostet in Kleinstmengenpreisen gerechnet etwa 30.- DM.
Die verwendeten marktüblichen pyroelektrischen Infrarotsensoren der Firma HEIMANN sind mit einem Einzelstückpreis von etwa 120.-DM vergleichsweise teuer. Bei Abnahme größerer Mengen dürfte der Stückpreis aber drastisch reduziert werden können.

Der wesentliche Teil der Arbeit bestand darin, die Signalverarbeitungsalgorithmen ohne Verwendung einer Multiplikationsoperation mit einer 8-Bit Integer-Arithmetik abzuarbeiten. Die dazu gefundenen Methoden sind signaltheoretisch wohl begründet und wirksam. Durch die Verwendung des im Mikroprozessor vorhandenen 8-Bit-A/D-Wandlers ist allerdings die Empfindlichkeit insgesamt etwas geringer als bei dem wesentlich teureren Prototypen.

Vorläufige technische Daten		
Spannungsversorgung:	9V-Blockbatterie oder extern	6..9V
Stromaufnahme:		6.0 mA
Versorgungsleistung:		36..50 mW
Meldung:	Störstrahlung/Flammenstrahlung	grün/rot/LED
Gehäuse:	Plastik	10cm*6cm*2.5cm
Arbeitstemperaturbereich:		noch nicht erprobt
Kommunikation:	serielle Rechnerschnittstelle bzw. manuelle Abfrage der registrierten Alarme über Taster und LED	
Empfindlichkeit im ungestörten Fall:		
Beispiel:	Spiritusfeuer Schale 10 cm^2	d=4m: $t_E < 0.3s$
Beispiel:	Spiritusfeuer Schale 10 cm^2	d=10m: $t_E < 0.4s$
Empfindlichkeit bei intensitätsmodulierter Störstrahlung:		Flammen-/Störleistungsabhängig
Beispiel:	Sichere Entdeckung der Flamme eines 600W Campinggasbrenners vor dem Störhintergrund eines 2kW-Heizstrahlers mit Reflektor und mechanischem chopper - beide Quellen im Abstand 1.5m	$t_E \approx 0.3s$

Da mit diesem Labormuster zunächst lediglich demonstriert werden soll, daß die notwendige Signalverarbeitung mit billigsten Mikroprozessoren abgearbeitet werden kann, wurden bislang keine weiteren möglichen Maßnahmen z.B. zur Reduzierung der Versorgungsleistung, der Verwendung eines professionellen Gehäuses usw. ergriffen.

Die Signalverarbeitung in dem vorliegenden Modell ist speziell ausgelegt für die möglichst schnelle Meldung ($\leq 0.5s$) explosionsartiger Flammenentwicklungen vor starkem Störstrahlungshintergrund.

Für diese extrem kurze Entscheidungszeit, die während der Dauer einer oder weniger Perioden der wesentlichen Spektralkomponenten (unterhalb von 6 Hz) des Flammenflackerns erfolgt, ist die Täuschungsalarmrate bemerkenswert gut. Keine Fehlalarme durch starke stochastisch oder periodisch intensitätsmodulierte, breitbandige Störstrahler (Schwarzkörperstrahlung, heiße Körper, Lampen); keine Fehlalarme durch indirekte Sonneneinstrahlung.

Selbst bei Ausrichtung der Sensoren durch eine normale Fensterscheibe direkt auf die Sonne, wobei die Sonneneinstrahlung durch vom Wind bewegtes Blattwerk und Wolken intensitätsmoduliert wurde, traten über eine Testzeitdauer von einem Jahr nur vereinzelt Fehlalarme auf. Fehlalarme in einer solchen Situation sind aber bei "zweiäugigen" Flammenmeldern im Prinzip deshalb unvermeidlich, weil wegen der hohen Intensität und Parallelität der Sonneneinstrahlung, z.B. durch bewegtes Blattwerk so scharfe Schlagschatten geworfen werden können, daß die Sensoren unterschiedlich abgeschattet werden.

Generell gilt auch hier, daß bei Erhöhung der Mindestentscheidungszeit selbst solche schwierigen Situationen noch zuverlässiger entschieden werden können.

Zusammenfassung

Der für geringstmöglichen Hardware-Aufwand konzipierte LOW-COST Flammenmelder besitzt bemerkenswert gute Detektionseigenschaften selbst in der schwierigen Situation, in der eine Flamme vor dem Hintergrund starker, intensitätsmodulierter Störstrahler entdeckt werden soll. Diese guten Eigenschaften werden durch eine besondere Form der Signalverarbeitung erzielt.

Das Labormuster kann während der Postersession auf der AUBE'99 besichtigt und experimentell erobt werden.

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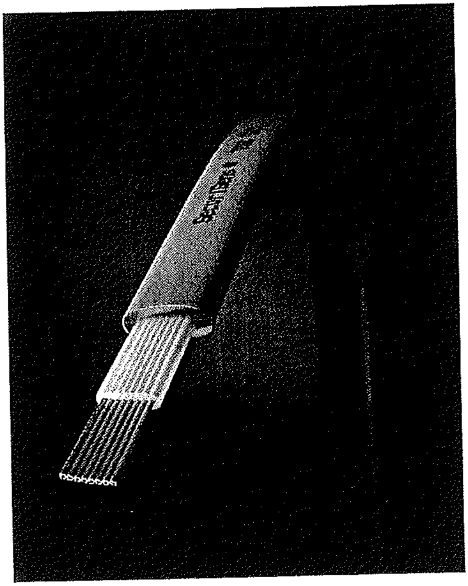
Temperature Sensor Cable SecuriSens® TSC 511

SecuriSens® TSC 511 is a thermo application of the sensor cable LiSA (Linear Sensor Array). LiSA uses proprietary technologies of MetaPhysics S.A.

Abstract

In this paper, we present an innovative approach for early fire detection. We use an integrated sensor cable based on innovative techniques for sensor addressing and data transmission. The Linear Sensor Array (LiSA for short) is manufactured using automatic assembly equipment. The system comprises sensors, a connecting cable, a Cable Terminal Processor (CTP) and a collection of software tools. We present system performance data and software functionality.



System Aspects of Sensors in the Fire Protection Domain

During the last few years, a tendency emerged to use more and more intelligence for fire detectors. The availability of cheap computing power and the application of algorithms derived from the pattern recognition domain, resulted in sensors that are able to detect flame, fire, smoke and related or derived physical properties with very high reliability. When the last generation of fire detectors is considered, there are no unresolved issues concerning sensor performance and detection reliability.

The quest for new approaches in the fire protection domain is not motivated by insufficient sensor performance, but rather by the inadequate system architecture of conventional sensor systems. This inadequate architecture is most evident when complex applications are considered. The complexity of fire detection and the difficulties encountered in the generation of an adequate reaction does not come from the recognition of the event, but rather from the consideration of contextual information. Useful contextual information comprise information, which is not directly related to fire, smoke and flame, but which is relevant in order to generate an adequate system reaction and to keep the rate of false alarms low.

Examples of useful contextual information are: Date/time, workday or holiday, indoor-outdoor temperature, ephemera, season, building occupancy. The use of contextual information in the analysis step of the sensor data requires sensor bus systems for data collection and centralized data analysis. Thus, a system reaction may be issued which relies on the analysis of the signals from the entire sensor system and which considers the available contextual information.

Thus, it is central to the new approach to dispose of a high performance sensor bus system and of performant software for analysis. The data from the sensors have to be centralized. Analysis is performed at the lowest possible hierarchical level of the system, and it has to consider a maximum of contextual information.

The computing power which is available today is sufficient to execute complex algorithms. Using standardized PC hardware, algorithms of the pattern recognition type or neural networks may be executed in a matter of several seconds. The most important obstacle in the way of computer application in the building control- and sensing domain comes from the difficulty to collect data and to transmit them to the central computer.

Of course, costs of sensor networks are relevant to their application. Costs comprise the sensor costs, the costs associated to their networking environment, cabling and associated circuitry, the costs for software, of the planning and documentation of the system. Very often spread out sensor systems develop themselves during the time of use and eventually huge sensor systems may become difficult to handle.

It is costly to maintain and document huge sensor systems. Proper documentation and maintainance are necessary for a sensor system to be reliable. Leading companies in the building sensor market spend 25% of their turnover for the maintainance of sensor systems. It is the aim of the LiSA approach to address the above problems.

The LiSA Approach

The principal components of a LiSA system are:

- Addressable sensors inside the sensor cable
- Cable Terminal Processor (CTP)
- System software.

In the process of the development of LiSA it was the principle of reasoning that things become more reliable, cost efficient and repeatable when performed in an industrial environement, in the factory. The higher reliability and system quality is especially important, when the system is compared with systems that are assembled in situation (i.e. cabling of discrete sensors in the building).

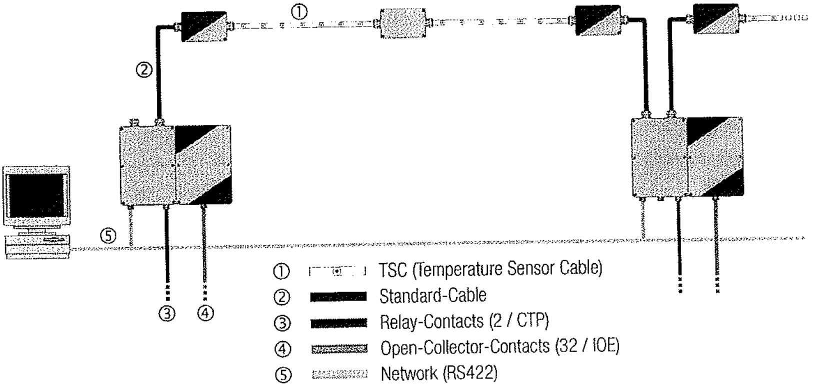
It was the idea behind the LiSA system development to produce turn-key systems with well defined system properties, high quality standards, which are easy to deploy and that need virtually no service.

LiSA is an integrated sensor system comprising a sensor cable and a Cable Terminal Processor (CTP). The sensors are integrated in the cable and all information related to them is centralized in the CTP. It performs data reduction and alarm generation locally, and is able to interface smoothly with other systems using standardized communication techniques.

The CTP's are designed to be cascadable, and multiple CTP's may be put together to process the input from thousands of sensors. A bridge to a more conventional computing network is accomplished using a host computer connected to multiple CTP's.

The cable terminal processor is considered to be the simplest networking unit of the system hierarchy, which is able to issue well adapted reactions on oncoming events.

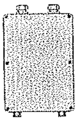
This system architecture is ideally adapted for complex fire protection problems where contextual information has to be considered.



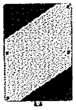
The main elements of the LiSA system:

Sensor
Temperature sensor executed as a small addressable electronic circuit integrated directly into the cable.

Temperature Sensor Cable (TSC)
Cable with integrated temperature sensors.

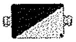


Cable Terminator Processor (CTP)
Electronic unit for evaluating measured data, complete with hardware outputs. Intelligent interface for communication and networking.

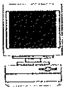


Input Output Extension (IOE)
Extension that adds 32 open collector outputs.

Cable Separator Module (CSM)/Cable Terminator Module (CTM)
This module insulates the various cable sections from each other in the event of a short circuit and is used as the terminating module at the end of the cable.



Cable Filter Box (CFB)
Connection box between two TSC or a standard cable and a TSC.



Software application for Microsoft® Windows®
PC-SW for visualizing the data and setting the system parameters, possibly in conjunction with a fire alarm control panel.

LiSA Sensors

Sensors are located at specific sites on the cable, called nodes. Every node comprises all electronic circuitry necessary for the addressing and transmission of sensor signals. Nodes are attached to the cable at sites that depend on the application. They may be attached at regular or irregular intervals to the sensor cable. The location where the sensor is attached to the cable is designated externally by the serial number of the sensor. In addition to the temperature of the environment, the sensor will also detect parts of its infrared emission. The result is that the sensor provides a quick reaction when open flames are in its optically sensible path.

The addressing and data transmission circuitry

The addressing and data transmission tasks are performed by the LiSA node chip. Sensors are addressed sequentially using a proprietary addressing scheme based on the impedance of the connecting cable[1]. Using this addressing scheme, no data have to be transmitted to address LiSA nodes. The addressing principle is based on a basic physical property of the bus cable that cannot fail. This is the reason for the high reliability and robustness of the node addressing scheme. Addressing and data transmission rely on doubly redundant balanced lines that are immune to induced electromagnetic noise. During the transmission of the analog signal from the sensor, a signal quality detector continually measures the transmission quality of the lines. This is done using balanced differential current signals, detecting induced common mode signals from an external source[2].

The result is, that all digital electronic circuits are situated in the cable terminal processor. Thus, costs and current consumption are reduced. The resulting data transmission precision is better than an equivalent of 12 bits of resolution.

Distance D	Sensors N	Cable Length L
D [m]	N [1]	L [m]
15	380	5'710
10	466	4'660
5	658	3'292
2	1'038	2'076
1	1'462	1'462
0.5	2'058	1'028
0.3	2'642	792
0.1	4'494	450
0.05	6'224	312

The number of nodes that can be assembled to form a sensor cable depends on the distance between sensors D, the number of sensors N and the cable length L. The table shows the respective figures. It is assumed that the cable power supply is regenerated at the cable termination. If this is not the case, only half of the number of sensors N and cable length L can be accounted for.
The figures contained in the table are indicative and subject to change; especially when application specific sensors, or non-regular sensor distances are used.

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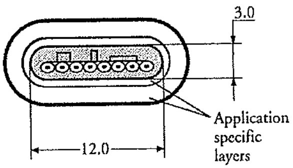
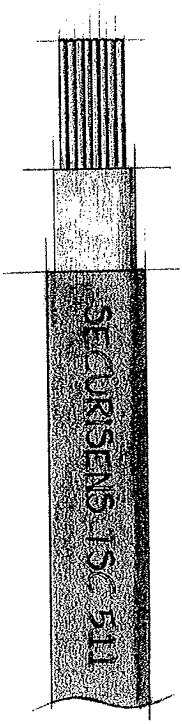
[1] *This technique and the corresponding circuits are patented.*

[2] *This technique and the corresponding circuits are patented.*

The sensor cable

A section of the sensor cable is drawn in the next figure. The hatched area represents the raw cable and the outer layers are extruded in order to protect it against external influences and to provide mechanical stiffness and chemical resistance.





Normally the cable needs no electric shielding. The innovative addressing- and data transmission scheme provides a noise margin which is sufficient to conform to the EMC prescriptions.

In its standard form, the sensor cable supports a temperature range between -40 and 80 °C (cable not moving). The admissible temperature range during cable layout is somewhat lower. This temperature range is limited by the plastic layers of the cable shields; the temperature range of the node electronics extends from -55 to 125 °C.

The precision of the temperature sensor is approximately ± 2 °C, and its sensibility is 0.1 °C. In order to obtain the high precision, all sensors have to be calibrated during fabrication. Thus, the cable is delivered together with a file containing the sensor calibration data.

Externally a number is printed onto the cable sheath designating the sensor location. Every sensor has its individual serial number which is used to assign its calibration data.

The Cable Terminal Processor (CTP)

The CTP of a **LiSA** system comprises a PC - compatible CPU board which is able to drive up to three **LiSA** cables. Every **LiSA** interface board may be calibrated. This is necessary when the system requires a high precision of sensor readings. The calibration coefficients are stored in a permanent storage memory on the interface board. Their function is to compensate for the tolerance of the analog board electronics.

The CTP with all options and its **LiSA** interface needs only 3 Watts of power. It is completely isolated from the supply voltage. Its temperature range extends from -20 to 70 °C.

Other resources accessible to the software are:

- the addressing circuitry for an unlimited number of **LiSA** - nodes.
- a Silicon Serial Number (SSN): Every **LiSA** - Interface has its own, unalterable serial number.
- a temperature sensor
- a green LED indicator for the supply voltage and two programmable LED's.
- 2 programmable relays 150VDC/125VAC, 1A
- a 8-pole DIP switch for parameter input
- a real time clock
- the **LiSA** - power supply for up to 3 sensor cables with up to 400 nodes each (less cables mean correspondingly more nodes)

There are no switches to set-up on the CPU board; all addressing and parameter setting is performed automatically by the software at boot time.

The Software

The software is based on an interpreter program of an instruction list where the conditions are defined that yield an alarm. Standard and extended algortihms for fire detection systems, like „two detector dependence“ etc., are included. Thus the software is very flexible and will adapt easily to changing applications.

A special program running under the Microsoft® Windows® operating system is provided for configuration and data visualization on a remote PC. These opearations are very easy to perform and the entire system may be configured and tested by a couple of mouse-clicks.

A special TRACE - mode permits to test the correct functioning of the programmed algorithms where every step of the algorithm and its intermediate results show on the console or on the printer.

Using a test- and diagnostics mode, all functions of the CTP are remotely tested by an attached laptop computer.

Special events are written into a LOG file which may be queried by a remote computer. The scope of the system of LOG files covers a time of two years. When an alarm is issued its history will be dumped into the LOG file.

Outlook

Actually the LiSA system is in the process of market introduction. The next steps will comprise diverse new sensors, facilities for user input, enhanced connectivity and interoperability of the system software and redundant system architectures.

Complementary Information

On request a copy of the proceedings of the 1997 Nürnberg Sensor fair is available, which contains a detailed technical system description.

The special fire detector SecuriSens® TSC 511 is a sensor cable used as a linear heat detector. This highly reliable product is very simple in terms of planning, installation and assembly and offers a diverse range of software evaluation features. It is utilized primarily in tunnels, cable and supply ducts and for other long measuring distances as well as in special industrial applications.

Function

The sensors are constantly scanned for the latest measured values. An evaluation logic circuit then analyses these values to determine whether a fault or an alarm has to be reported.

Several sensors can be joined together to form groups. The ability to configure multiple sensor dependency and other evaluation criteria is achieved through a software interface along with other settings.

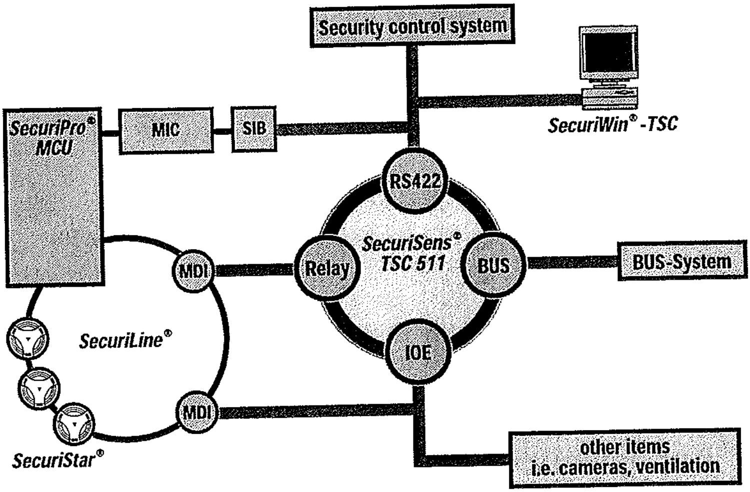
Applications

To maintain redundancy a second evaluation unit can be installed at the end of the cable in the next configuration stage. In this way, there will be separator modules integrated into the cable at regular intervals. If a short circuit occurs, the defective part of the cable can be insulated and the rest can continue to be scanned from either side.

Areas of use

- Road tunnels
- Train tunnels
- Underground and city railway
- Parking garages
- Cold storage warehouses
- Conveyors
- Industrial property protection
- Assembly lines
- Incinerators
- Raffineries
- Gas and district heat lines
- Waste disposal systems
- Saw mills
- Farming operations
- Offshore applications
- Marine applications
- Transporting plant

Interfaces / Context



Summary / Highlights

- SecuriSens® TSC 511 is a sensor cable used as a linear heat detector
- SecuriSens® TSC 511 is highly reliable
- SecuriSens® TSC 511 cable length up to 3.5 km (D = 7.2 m)
- SecuriSens® TSC 511 is maintenance free
- SecuriSens® TSC 511 is extremely fail safe
- SecuriSens® TSC 511 application are easily planned
- SecuriSens® TSC 511 is easily installed
- SecuriSens® TSC 511 fully configurable by software
- SecuriSens® TSC 511 fits in nearly all IT-context (busses, interfaces)
- SecuriSens® TSC 511 has a large growth potential (Cable Separator Module, loop-application, Manual Call Point, applications in hazardous zones (Zone 1))

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Biased Filter Algorithm of Multiple Sensor Signals for Automatic Fire Detection

Abstract

In fire case signals of fire sensors tend to exceed a predetermined threshold for a considerable duration. In this paper, biased filter algorithms of single and multiple sensor signals for automatic fire detection are proposed. The algorithms can compute not only signal magnitude but also signal duration of exceeding the threshold. By combining signals from different type fire sensors, the algorithms can improve the detectivity of fire detection system. A single or few sparse values that may be erroneous and of high magnitude do not influence the final output. Test results show that detectors using these algorithms are very reliable. The algorithms have been applied to fire detector production.

Introduction

Along with the rapid development in computer and integrated circuit technology, signal processing algorithm plays more and more important part in the field of fire detection. Signals of sensors in automatic fire detection system have their own characteristics. These are: (1) The signals consists of slowly changed components (with lower frequencies) and stochastically changed components (with higher frequencies); (2) The signals have reasonable steady value in normal condition; (3) The signals demonstrate distinct increasing (positive) or decreasing(negative) trend in fire case; and (4) the trend is likely sustained for a considerable duration in fire case. Most fire detectors available in the market make fire decision by magnitude exceeding a given threshold value. This magnitude decision making method is likely to produce false alarm by interferences of environmental factor.

Today, optical smoke detectors are replacing ionization smoke detectors, which were widely used for several decades, for the outstanding detection against smouldering fire and for the free of radioactive pollution. However, optical smoke detectors are not ideal for detecting black smoke with smaller particles, which limits their application scope. In fact, the air temperature rises in most of the fires with smaller particle black smoke. The temperature signal can thus be used to compensate smoke signal. This is an effective way to detect black smoke fires by using optical based smoke detectors.

Biased filter algorithms proposed in this paper is constructed on these two principles: (a) Signal magnitude is increasing and is tending to exceed a predetermined threshold value in a developing fire, (b) The signal duration exceeding the threshold value will be considerable long if a fire is really developing.

The feature of the biased filter algorithms are : (a) Fire decision making is not effected by short period interferences, (b) Relative threshold can be used for detection, which makes detection sensitivity stable in the process of electronic component ageing and dust accumulation, and (c) The computational program is simple to be realized.

The algorithm can be applied to multiple sensor, in which the combination of magnitude and duration feature of two or more fire signals can be adopted to increase the sensitivity and reduce the rate of false alarm. Practical application of optical and heat combined fire detector shows that they can effectively detect open fires with black smoke.

Biased filter algorithm of single sensor

To pick up the duration feature, we usually set a predetermined threshold and observe the duration exceeding the threshold. Biased filter with finite impulse response (FIR) is employed in our practice. Firstly, let us study a typical digital filter with FIR. From the theory on digital signal processing, we know that the unit impulse response h(n) of a digital system with FIR can be expressed as a finite sequence, and the output y(n) from a FIR filter can be expressed with a discrete convolution:

$$y(n) = \sum_{i=0}^{N-1} h(i)x(n-i)) \qquad (1)$$

where N is the length of the finite sequence and x(n) is the input signal.

From formula (1), we know that filter output y(n) can be in fact considered as the sum of N products of x(n) and weights h(n).

In our case, we are only interested in the part exceeding the predetermined threshold value. Introducing threshold and unit step function u(.) into formula(1), we then get

$$y(n) = Cu[x(n) - s_t]\sum_{i=0}^{N-1} w(n,i)[x(n-i) - s_t] \qquad (2)$$

where C-constant, w(n, i)—weight function equivalent to unit impulse response h(n) in formula (1) and s_t—predetermined threshold.

Formula (2) represents the biased filter algorithm. The unit step function u(.) ensures that accumulated part is only the part above the threshold. The output y(n), in this way, corresponds the signal that exceeds threshold and the duration in which the signal exceeds threshold. “Fire amount” detector made by Siemens adopted this algorithm, in fact. The recursive formula of Siemens algorithm was expressed as:

$$y(n) = [y(n-1) + C(x(n) - s_t)]u[x(n) - s_t] \qquad (3)$$

where w(n, i)=1.

From formula(3), we know that y(n) is only accumulated when $x(n)>s_t$, otherwise y(n)=0. As a result, high magnitude of short duration can not trigger a false alarm. The algorithm is easy to be realizes as the algorithm is actually used to accumulate the area above the threshold. A graphic expression for calculating the area is shown in Fig. 1, where $x_R(n)$—steady value in normal condition and the area calculated is the part where x(n)- x_R(n)>s_t.

Feeding the output y(n) obtained through biased filter algorithm into decision making circuit, then we get

$$D(y(n)) = \begin{cases} 1 & y(n) > S \\ 0 & y(n) \leq S \end{cases} \tag{4}$$

where D(.)=1 denotes fire, D(.)=0 denotes no fire, and S—threshold for fire decision.

The threshold value is an essential factor for decision making. In biased filter algorithm, predetermined threshold s_t is set as a relative difference above the steady value, that is to decide whether x(n)- x_R(n) is greater than s_t or not in Fig. 1. In this case, electronic circuit aging and dust accumulation only effect steady value x_R(n), and the relative change x(n)- x_R(n) does not change with the change of x_R(n). It's clear that detection sensitivity does not change with the steady value change.

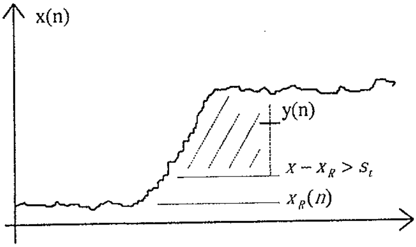

Fig.1 Graph for calculating "fire amount"

Biased filter algorithm of multiple sensor

Following the development of multiple sensor (or multisensor detector) in fire detection, algorithms for multiple variable input has been applied to fire detection. Biased filter algorithms were expanded from single sensor input condition to multiple sensor input condition. Biased filter algorithm of multiple sensor provide higher detectivity and reliability for fire detection by combining two or more fire characteristics, for instance, the combination of optical and ionization, of optical and heat, and of optical, ionization and heat.

The combining approaches may include the addition (including weighted addition) and multiplication. Suppose we have two input signals x_1(n) and x_2(n), and weight function w(n,i), then biased filter using multiplication can be expressed as follows

$$y(n) = Cu[x_1(n) - s_1]u[x_2(n) - s_2]\sum_{i=0}^{N-1} w(n,i)[x_1(n-i) - s_1][x_2(n-i) - s_2] \tag{5}$$

where s_1-- predetermined threshold of signal x_1(n), s_2-- predetermined threshold of signal x_2(n), C -- correction coefficient for adjusting the steady value, and u(.)-- unit step function.

In the condition of w(n,i)=1, biased filter of multiple sensor has following recursive expression

$$y(n) = [y(n-1) + C(x_1(n) - s_1)(x_2(n) - s_2)]u(x_1(n) - s_1)u(x_2(n) - s_2) \qquad (6)$$

We see from formula (6) that accumulating the products of the two signals above the predetermined threshold can only be carried out when these two signals exceed their own threshold at the same moment, otherwise the filter output remains zero. With the multiplication employed, signal $x_1(n)$ is enlarged by $x_2(n)$ times and, in the other hand, signal $x_2(n)$ is enlarged by $x_1(n)$ times. This is equal to increasing the detector sensitivity. The approach of multiplication does not increase the risk of false alarm. The operating condition of this approach is the two signals exceeding the predetermined threshold at the same moment, which is very rare event in normal or non fire case. Therefore biased filter with multiplication operation is a practical and simple algorithm.

Experimental result

Optical smoke detectors are less sensitive to black smoke with smaller particles, as the light scattered by the particles is weak by its nature. Most optical smoke detector can not effectively detect standard test fires SH3/GB4715-1993 (polyurethane, equal to TF4/EN54-9) and SH4/GB4715-1993 (n-heptane, equal to TF5/EN54-9). Fortunately, these two fires produce heat leading to notable temperature rising. By combining optical sensor and heat sensor in single detector, these two open fires can be detected.

The responses of the optical and heat combined smoke fire detector, designed by us, against SH1/GB4715-1993 (smouldering fire of wood, equal to TF2/EN54-9) are demonstrated in Fig 2, where real line denotes temperature signal, dotted line denotes smoke signal, and the vertical coordinate denotes smoke magnitude. The smouldering wood produces very weak heat and large amount of gray smoke particles. Smoke signal here is very strong.

The response signals of these two sensors combined fire detector against SH3/GB4715-1993 (TF4/EN54-9) are plotted in Fig 3, The black smoke makes considerably reduced output of optical smoke sensor (the maximum smoke output is only about 40% of SH1 case) but, at the same time, produces considerable heat. The product (see Fig 4) is calculated with $(x_2(n)-s_1)(x_2(n)-s_2)$, where $x_1(n)$ corresponds smoke signal, $x_2(n)$ corresponds temperature signal, thresholds $s_1=25$ and $s_2=8$. From Fig 4, we see that combined equivalent signal is fairly enlarged.

The response curves of the detector against SH4/GB4715-1993 (TF5/EN54-9) is plotted in Fig 5. SH4 is black smoke too, which produces smoke signal similar to SH3. But this fire produces a lot of heat making a distinct temperature rising. The product of smoke and heat is shown in Fig 6,from which more sensitivity increasing can be seen .We also know that , from Fig 4 and Fig 6,the combined equivalent signals only appear at the moment when both of smoke and heat signals exceed their own thresholds (510s for Fig 4 and 350s for Fig 6), otherwise the equivalent signals remain zero. It is obvious that this algorithm has very strong ability against interferences.

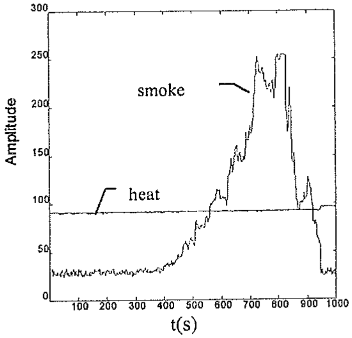

Fig 2: Optical smoke and heat signals against SH1/TF2.

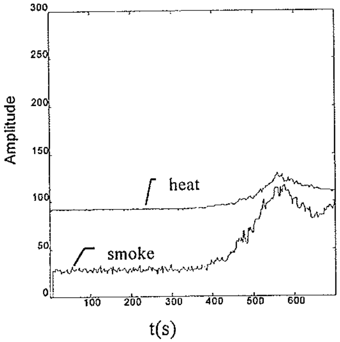

Fig 3: Optical smoke and heat signals against SH3/TF4.

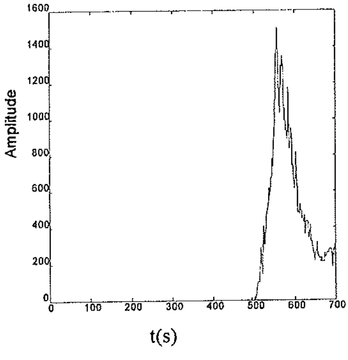

Fig 4: Product of smoke and heat (in case SH3/TF4).

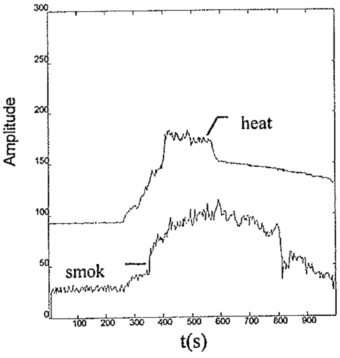

Fig 5: Optical smoke and heat signals against SH4/TF5.

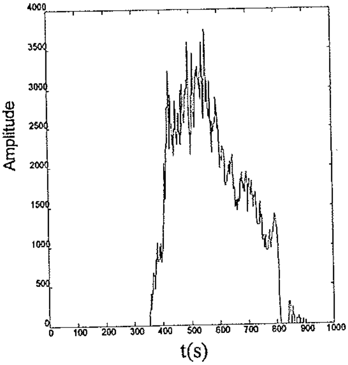

Fig 6: Product of smoke and heat(in case SH4/TF5)

Conclusion

In fire case the sensor signals demonstrate increasing trend for a considerable long duration. Not only the magnitude feature but also the duration feature of the signals can be applied to fire detection. Today, scattered optical smoke fire detector has been widely used, but relative weak detecting behavior against smaller particle black smokes limits its application scope. In most cases, along with the developing of smaller particle black smokes, there is notable temperature rising. By combining optical smoke sensor and electronic heat sensor into a single detector, with the heat signal compensation for smoke signal, the detecting sensitivity of optical smoke sensor against black smokes can equivalently be improved.

The essence of biased filter algorithms of single and multiple inputs is that the algorithms utilize the signal feature of magnitude and duration for detecting fires with improved detectivity, and combine two or more inputs to increase the equivalent detecting sensitivity with much lower false alarm rate. Other advantages of the algorithms are immune from interferences, stable detecting sensitivity against component ageing and dust accumulation, and easy to be realized. The algorithms have been applied to mass production of optical smoke detector and optical and heat combined smoke detector. Test results demonstrate that the optical and heat combined smoke detector can effectively detect black open fires. The application scope of optical smoke detector can be expanded by this way.

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Reliability Analysis Techniques to Improve Discrimination Between Fires and False Alarms

Abstract

A mathematical model that relates the reliability of an Automatic Fire Detection (AFD) system in detecting genuine fires to the reliability of an AFD system in suppressing false alarms. This model is developed with particular application to AFD systems installed in large UK National Health Service (NHS) hospitals, where it is necessary to minimise the disruption to patients staff and visitors during a fire alarm situation, and also to minimise the number of instances of attendance to a hospital by a fire brigade.

Introduction

An Automatic Fire Detection (AFD) system installed in a large occupancy is often complex in its configuration. This level of complexity is required in order to ensure that communication of a fire incident to all relevant parties is successful, from all parts of the occupancy. There are a number of different principal system components that carry out the main detection and communication process: detectors, control panels. There are also secondary components that are necessary for the provision of electrical control, for instance termination resistors, interface panels wiring. Within components, there are sub-components such as microprocessor circuits, power supply circuits and detector sub-assemblies. Each of these components and sub-components has an inherent reliability and has been tested according to quality standards. In addition these components are validated with a particular Mean Time Before Failure or failure rate. However, when connected together, the reliability of the system may fall short of a desired level because of the additional effects introduced as a result of connecting the components together, and thus the system may not fulfil its objectives.

The system objectives of AFD system are to:

- Be available to Detect fires on demand;
- Be available to Suppress false alarms on demand.

These two objectives could be in conflict. Reliability in one sense could affect reliability in the other sense. An optimum level of overall reliability can be achieved by balancing the system objectives.

The optimisation criteria depend on a number of non-technical issues, such as:

- The fire risk to the lives and property in the occupancy where fire detection is implemented;
- The number of times the fire brigade attends the occupancy, whether for a genuine fire or a false alarm, and thus the resource used by the fire brigade;
- The impact of a false alarm on the services provided by the occupancies, relative to the impact of a genuine fire on these services.

A non-technical, economic set of criteria could be used as a methodology to set a desired ratio of false alarms to fires. This methodology is beyond the scope of this paper. This paper does however propose an AFD system design methodology that will allow an optimisation of the ratio of the number of false alarms to the number of genuine fires detected. There are many different underlying causes for both non-detection of fires and false alarms. To demonstrate the application of the model described later, this paper focuses on those cases of system failure (both non-detection and false alarms) whose underlying causes are system electrical faults.

Application to AFD Systems Installed in Hospitals

The paper takes its set of examples as AFD system installed in a large NHS hospital, with at least 1000 smoke and heat detector heads. This is a particularly illustrative example because such a hospital would contain different locations of varying fire and false alarm risk; for example wards, clinics, kitchens and boiler houses. The fire and mobilisation risks to patients, visitors and staff are of importance, as is the risk to loss of healthcare services due to a fire or disruption due to a false alarm. AFD systems in hospitals should be designed such that it contributes to the minimisation of these risks, both in the detection of real fires and suppression of false alarms. The mobilisation of patients under any circumstances (false or otherwise) can introduce in itself the risk of injury, and these risks are of concern to make the suppression of false alarms in hospitals an issue to be addressed. Design on this basis will produce benefits to life safety.

An accepted UK Home Office figure for the ratio of fires to false alarms attended by fire brigades is on average 1 to 10 at occupancies in the United Kingdom, and the figure for attendance by fire brigades at healthcare premises is approximately the same. The attendance rate of healthcare staff to false alarms is however much higher, a figure of 50 to 1 is not unreasonable if all good intent unwanted alarms, including smoking are included (discrimination of deliberate and good intent fires are beyond the scope of this paper). Any reduction in the overall number of false alarms can reduce the wasted resource of fire brigades and healthcare staff.

The underlying causes of system faults that are of particular concern in a large hospital include: power supply variation (mains supply or generators), data corruption and thermal effects on electrical component parameters. The nature and classification of each of these faults is beyond the scope of this paper.

There are many technical ways in which AFD system reliability in hospitals, according to the two primary system objectives, can be optimised. Components and sub-components could be chosen that are more reliable, and usually more costly. For complex systems, an alternative and possibly cost effective way could be to alter the configuration of the system, i.e. the interconnection of components. This paper considers the principle components only, and how the components can be configured in such a way as to achieve an optimum balance.

In order to economically justify such an approach to design, the costs of any design implementation should be minimised. Furthermore, it should be possible to upgrade AFD systems already installed, for whichever manufacturer or manufacturers provide the system, so that the number of false alarms is reduced. These economic factors are of particular concern in NHS hospitals because of the level of public accountability required for the operation and maintenance of hospital systems.

In UK National Health Service healthcare premises, fire detection systems should observe the code of practice advocated by British Standard (BS) 5839: Fire detection and alarm systems for buildings[1]. The NHS document FIRECODE Health Technical Memorandum (HTM) 82: Alarm and detection systems[2] provides guidance for the design and installation of AFD systems in healthcare premises, and is intended to supplement BS 5839. The appropriate type and spacing of detectors is recommended in order to reach a particular level of detection performance. Detector siting is a separate consideration to detector reliability, and it beyond the scope of this paper. The reliability of a fire detector is determined by the initial electrical parameters to which a detector is manufactured, and the hospital environment acts to reduce the reliability of the detector once it has been installed. The primary causes for this degradation in reliability are electrical effects, thermal effects, dust and insects. In purchasing more expensive detectors, the reliability can only be slightly increased. For Control Panels, the reliability depends on the embedded software reliability and the hardware reliability of the microprocessor circuitry. Environmental degradation of the reliability of control panels may be due to long term stress as a result of electrical supply variations. Again, more expensive Control Panels could lead to a slight increase in reliability. By increasing the reliability of the individual detectors and/or control panels, there could be an overall increase in AFD system reliability in detecting genuine fires but there could also be a decrease in the AFD system reliability in suppressing false alarms. These changes in system reliability depend on the configuration of the components in the AFD system. The costs of high reliability detectors and control panels may be prohibitive, and such purchases may put constraints on the expandability and flexibility of the system. This paper proposes an alternative method of improving AFD system reliability, involving additional connections between detectors and control panels. These additional connections provide alternative paths for communication between detectors and the main control panel. In many cases, such additional connections can be practically implemented in existing cable ducts in hospitals, thus providing some cost savings over more expensive modifications to the AFD system components.

Technical Focus of the Analysis

An AFD system in a hospital typically consists of a hierarchy of control panels, with a main panel and a number of secondary or tertiary level panels connected to it. Detectors are connected to the secondary or tertiary level panels. A cost effective and flexible way of increasing AFD System reliability is to connect together control panels on the same hierarchy level, that were previously unconnected. Such an arrangement could, if carried out according to design methodology, increase both the reliability of detection of genuine fires and reliability of suppression of false alarms.

The main function of a control panel is to pass detector signals from the detector heads to a main panel, from which the fire brigade may be contacted in an emergency. This function has an inherent reliability, and the more intermediary panels between the detector heads and the main panel, the less reliable the system is at detecting and alerting to genuine fires.

Many control panels for analogue addressable AFD systems have software that can perform some level of discrimination between genuine fires and false alarms. The panels perform this function by for instance, comparing the detector signal to ambient thresholds, assessing the rate of rise of detector signals and comparing the detector signals with the fire signatures of different ignition materials. The overall false alarm suppression function has an inherent reliability. The more intermediary panels between detector heads and the main panel, the more reliable the system will be at suppressing false alarms.

It follows that there must be an optimum number of intermediary panels between detector heads and the main panel, which as a single measure could reduce the ratio of false alarms to fires a minimum value. This paper introduces details of a mathematical model that is being developed as part of a more detailed research programme by the author of this paper. The model aims to determine the optimum number of intermediary panels (m) to minimise the fire to false alarm ratio. It is recognised by the author that there are a large number of other factors necessary to establish the ratio. The further stage of research will be to establish whether the technical solution to the value of 'm' is unique and how the solution relates to the calculation of 'm' by other means such as economic considerations.

The Model

The model uses Reliability Block Diagrams (RBDs), each one in terms of the principal components of an AFD system and their interconnectivity. Each component, as mentioned before has an inherent reliability. The model considers reliability in terms of the ability of the system to function as desired when subjected to conditions that could cause electrical faults in the system. The source of faults that could cause genuine fire non-detection and false alarm generation is, in this development of the model, the same and therefore it is assumed that the failure rates of the principle components in terms of fire detection and false alarm suppression are equal. Data collected from large NHS hospitals seems to suggest that this is the case. This is a large simplification of the operation conditions, but such an assumption at this stage aids more coherent development of the model. In order to convert the failure rates of all components into reliabilities, further assumptions are made to the effect that the components are operational during their 'useful life' period and that the impact of electrically generated faults on the system is the result of random activity. The implication of this assumption is that the failure rates of individual components is constant, and the reliabilites of the components are exponentially related to time.

In order to focus on the most important features of the AFD system in terms of the determination of the fire to false alarm ratio, two (part-model) generic arrangements of components are considered: one to model the detection of genuine fires and one to model the suppression of false alarms. Each part-model shows interconnection of the principle components of an AFD system in series and parallel with each other. In order to appreciate formulae (1) and (2) for each of the part-models respectively (presented later in this paper), some basic concepts are first stated:

- Reliability of a series system of components is the product of the reliabilities of the individual components;
- Unreliability of a parallel system of components is the product of the unreliabilities of the individual components;
- The sum of the reliability and unreliability of an individual component is one.

Although formulae (1) and (2) are not presented in terms of unreliabilities, the above facts can be used to understand the complexities of the formulae.

Definitions of Parameters

In the following analysis details:

'd' is the number of detectors connected to a particular panel;
'm' (as discussed before) is the number of panels between a particular detector and the system output beyond the main panel;
R(p) is the reliability of an individual panel
R(d) is the reliability of an individual detector

Reliability in Genuine Fire Detection

The AFD system objective is to detect genuine fires, and therefore the reliability part-model for the detection of genuine fires most resembles the electrical configuration in terms of a generic arrangement of components.

The part-model is shown in fig.1

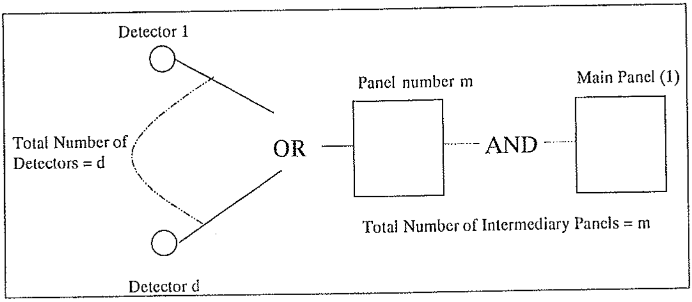

Fig. 1 AFD System Reliability Part-Model for Detecting Genuine Fires in Hospitals

The model indicates that for detectors installed in a particular area of a hospital, one *or* more of them can detect the presence of a genuine fire given enough time. However, in order communicate this information to the Main Panel, panel ‘m’ *and* all the intermediary panels need to function correctly.

The mathematical formula to calculate the AFD system reliability in detecting genuine fires (R_i) is as follows:

$$R_i = R(p)^m * \{1-(1- R(d)^n\} \qquad (1)$$

Reliability in False Alarm Suppression

The reliability part-model for the suppression of false alarms is the converse of the fire detection part-model, in that components that appeared in series now appear in parallel and vice versa.

Then RBD for this part model is shown in fig.2.

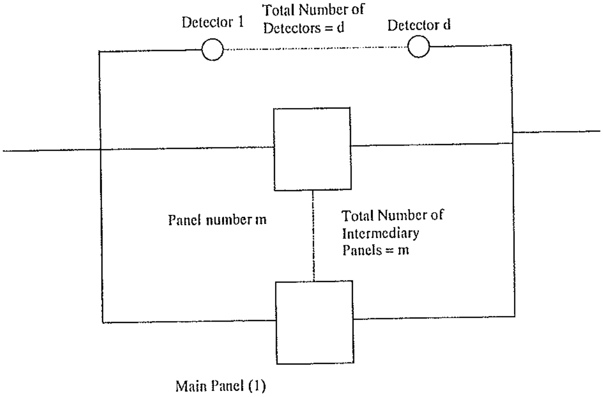

Fig. 2 AFD System Reliability Part-Model for Suppressing False Alarms in Hospitals

The model indicates that for detectors installed in a particular area of a hospital, the first detector *and* all the others up to detector d must suppress a triggering due to a non-fire effect. However, in order suppress communication of false alarm information at the output of the Main Panel, panel 'm' *or* all the intermediary panels need to function correctly.

The mathematical formula to calculate the AFD system reliability in detecting genuine fires (R_a) is as follows:

$$R_a = 1 - (1 - R(d)^n) * (1 - R(p))^m \qquad (2)$$

Progress in Development of the Model

Considerable progress has been made in combining formulae (1) and (2) algebraically and determining a resultant mathematical function that relates the reliability of genuine fire detection to the reliability of false alarm suppression. The ratio of fires detected to false alarms suppressed can then calculated according to the assumptions already stated.

The fire/false alarm function derived by the above means is in terms of the number of detectors 'd' connected to a particular panel, and the number of intermediary panels 'm' between this particular panel and the main panel. ('m' includes the main panel). It is not possible to release specific details in this paper of the nature of this function.

To take a specific installation case, that of a 6-bedded hospital ward, a value of 'd' was chosen as 30, and this somewhat simplified the functional expression. Further simplification of the expression was conducted and then a numerical analysis in order to determine an optimum number for 'm'. At this stage of the research, it is not possible to fully identify a value of 'm' that can be validated using fire detection and false alarm data already collected.

Conclusion

It is concluded at this point in the research study that there is a need for evaluating the trade-off between the detection of a genuine fire and suppression of false alarms in AFD systems, particularly those installed in hospitals. The reliability of AFD systems in hospitals is considered as the most appropriate concept of carrying out this evaluation.

A significant proportion of the failures of the principal components of AFD systems are due to electrical/technical system faults occurring randomly. The failure rate of components is therefore the same for this particular underlying fault mode, and thus the reliabilities of the principal components for both fire detection and false alarm suppression is the same.

The AFD system reliability has been considered in two parts: reliability in detecting genuine fires and reliability in suppressing false alarms. Using Reliability Block Diagrams, formulae have been developed to represent AFD system reliability in its two constituent parts.

The two system reliability formulae were combined and manipulated in order to determine a value for 'm' , the number of intermediary panels, for a given ratio between the reliability of fire detection to false alarm suppression. The expression was simplified using a practical value for 'd', the number of detectors connected to a panel.

Algebraic and numerical analysis has yet to reveal a meaningful value of 'm', and it is yet to be validated by data collected from hospital site surveys and manufacturers data.

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Volumetric measurement methods of fire phenomena

Abstract

An overview on existing methods for point, line and volumetric fire detection methods is given, which includes also known methods on two-dimensional and volumetric approaches for the measurements of fire phenomena. New concepts for the volumetric imaging of fire phenomena (concerning extinction and scattering effects) are then presented which allow for a significant reduction of components and costs of suitable measurement systems compared to earlier solutions.

Introduction - some aspects of volumetric fire detection

Most fire detectors installed operate as a point alarm devices. The physical fire phenomenon is measured only at the location of the sensor. For more specialised applications line detectors may be chosen, which measure the extinction along a certain path or which measure the temperature along fibre-optic or other cables equipped with heat-sensitive elements. UV and IR flame detectors (including systems using infrared imaging for the determination of hot spots or open flames) represent truly volumetric detection techniques.

Fire detection using point devices is a proven and very cost effective technique, although drawbacks exist. Point devices may run into trouble when the plumes of a smouldering fires cool down and do not reach the detectors location at the ceiling. These problems are well known and to a certain degree workarounds exist in the form of applying special detection techniques like aspiration systems e.g. /1/ in addition to careful planning and design of the installation.

Nevertheless, even a very simplified kind of volumetric imaging of the smoke density in the vicinity of the detector (or if possible in the whole volume to be monitored) would certainly ease the task of distinguishing between real fires and quite a lot of situations normally leading to false alarms. Volumetric detection devices could easily distinguish between a couple of small clouds produced by a group of smokers underneath the detector and clouds being produced by a fire in the initial stage.

But up to now volumetric smoke detectors do not play any important role in fire detection. Few exceptions of fire detectors relying on volumetric measurement methods have been reported. A number of very interesting techniques which are based on principles like the reflection of IR radiation on the walls of the room to be monitored have been reported in /2/. Other methods have been described which process video images in aircraft hangars or those having a view on an area with large woods in order to detect fires.

Techniques for two-dimensional and volumetric measurement systems

While being not attractive for fire detectors due to the lack of cost-effective techniques, two-dimensional or volumetric measurement methods for fire phenomena with the ability to determine the distribution of smoke parameters in a plane or in a volume do have their application areas in fire research. Such systems are valuable in order to study the propagation of fire phenomena in the initial stage and aid in verifying computational fluid dynamics (CFD) models.

A first version of such a method was described in /3/ and relies on the determination of smoke density in a plane by means of multiple extinction measurements. The measurements are gained by means of a number of IR sources and detectors located around the border of the area of interest. A computer-tomographical algorithm in the form of a modified Algebraic Reconstruction Technique (ART) applied to these measurement data determines a smooth image of the smoke density distribution in the plane.

An extension to this volumetric measurement method can only be achieved by carrying out a series of measurements at certain elevation levels of the plane or by covering the walls of the room to be monitored with additional emitters and sensors. The first possibility lacks of consistent measurement data due to repeatability limitations of fire tests and the second approach describes a more theoretical method. Even measurements in one plane at a modestly low resolution require at least a set of 16 emitters and 16 sensors, which all have to be connected to one control unit leading to a correspondingly high amount of components, cabling and costs.

Other attempts have been made to determine the scalar temperature distribution and air velocity flow fields in a plane by measuring the deviations in the time-of-flight of ultrasonic impulses along certain paths using a VART-method (vector algebraic reconstruction method), see /4/. Also in this case the amount of hardware components in terms of US transducers for instance is significant. For minimum local resolution of flow field and temperature images 44 transducers had to be foreseen in the prototype of this system.

New two-dimensional and volumetric measurement methods

A Two-dimensional gas concentration measurement method

In the last years the measurements of the gas phase of aerosols become more and more attractive, fire detectors based on gas measurements were introduced to the market. One well known technique (not with regard to fire detection applications, but mainly concerning reference measurements), is the NDIR principle which relies on measuring the extinction of IR radiation in a narrow wavelength range, being specific for the corresponding gas component.

If future technologies will permit the use of cost-effective components for emitting and receiving IR radiation also the determination of gas components in a plane might be realised by applying the opto-computer-tomographical method described in /3/. Instead of measuring the extinction around 0.9 µm wavelength or lower (for the determination of smoke densities), the distribution of the CO or CO^2 gas concentration e.g. would follow exactly the same method when measuring and processing multiple extinction data at a wavelength of 4.7 µm or 4.3 µm respectively.

Modified two-dimensional and volumetric extinction measurement methods

One of the major drawbacks of methods described above is of course the use of a large amount of 16 sensor and 16 emitter units, which have to be located around the area of interest and have to be interconnected to a central control and signal processing unit.

A significant reduction of at least the amount of emitter units can be achieved by using a set of mirrors in order to produce additional virtual radiation sources. This method requires the use of a deflection unit being able to direct one collimated beam of a suitable visible or near IR source to each mirror, thereby changing the origin of the radiation, see the following figure 1.

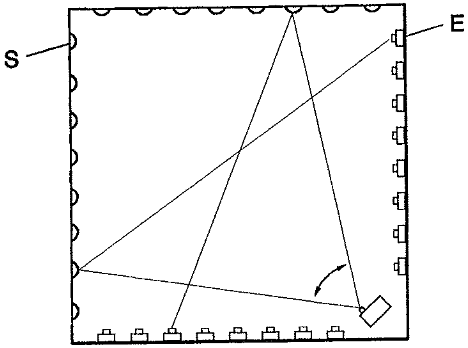

Figure 1: Arrangement for performing multiple extinction measurements

This methods saves 16 emitters at the cost of 16 mirrors. The evaluation of measurement data of this approach requires a modified ART-algorithm since extinction data sets are taken along two different paths (from the radiation source to a mirror and from there to one of the sensors). But high demands concerning the positioning of mirror elements and on the accuracy and repeatability of the deflection unit have to be put, as the reflected beams exactly must hit the locations of all sensors. The requirement is, that only a few millimetres deviation of each beam at the end of a path of around 20 m have to be kept.

A two-dimensional scattered light measurement method

A new method is based on the measurement of scattered light by means of a collimated and deflected beam, a camera and a set of cylindrical mirrors. No additional sensors (apart from calibration devices for the light source) will be needed. Thereby any kind of cabling is reduced to a minimum. In a similar way as described in the preceding paragraph, virtual sources at different locations are realised by using cylindrical mirrors, see the following figure 2.

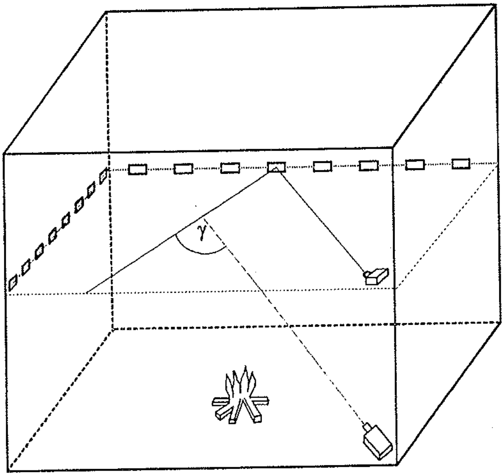

Figure 2 Arrangement for performing multiple scattering measurements

In order not to spread the beams, faceted mirrors are used. Multiple reflections are avoided by directing the reflected beams to points on the opposite walls in between the mirrors. Pointing at different horizontal locations of the surface of these mirrors deflects the beams to different locations on the wall.

The camera is positioned on the floor of a darkened fire test rooms and looks upwards, thereby monitoring the radiation scattered by the aerosol particles of the buoyant plumes being crossed by the beams.

In the next figure 3 all beam paths in the horizontal plane of a square room (with normalised dimensions) are shown, resulting from a set of 16 cylindrical mirrors and 27 points on the walls to which the beams are pointing.

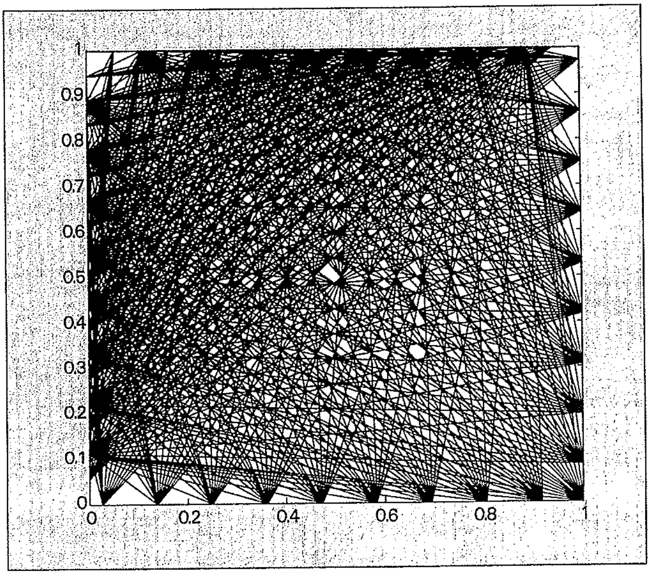

Figure 3 Beam paths in the measurement plane

If for an example a local resolution of about 3% of the dimensions of a square room is envisaged, corresponding to 33 times 33 surface elements in the plane, it can be seen from figure 3, that nearly all surface elements are crossed by various beams (from 5 to 27 beams per surface element). Still a few "white" regions remain, but these may be also covered after additional optimisation of the location of mirrors e.g. .

The scattering angle is dependant on the location of the beam and on the location of the scattering centre. Under the assumption of a not too inhomogeneous smoke density (at least on the average), for each surface element measurement data with different scattering angles can be provided, thus enabling a certain degree of local characterisation of smoke. The quality of this characterisation of course varies, as the set of available scattering angles obtained for each surface element changes.

If the location of the camera on the floor is modified, also the distribution of scattering angles can be influenced. A position in the centre of the floor will lead to scattering angles of 90° above the camera and to angles ranging from 45° to 135° near the walls for an elevation of the measurement plane of 50% of the room dimensions.

An extension to a volumetric scattered light measurement method

The method described above can easily be extended to a volumetric acquisition of the smoke density distribution. This can be realised by using spherical mirrors which have to be located at a certain number of positions spread across the walls. In this way the whole volume of the fire test room to be monitored can be criss-crossed by beams.

This allows for obtaining measurement data for any volumetric region of the test room. But also measurements in a plain can be improved in this way as additional scattering angle values can be obtained.

Outlook

Some aspects of the methods described above need additional consideration. A sufficiently high resolution of smoke density measurements will require a high-energy laser source and a camera optimised for low noise detection. Also a suitable algorithm has to be developed which converts measurement data into images of smoke density and which to a certain degree is capable of compensating losses in radiation intensity along the beam paths.

Compared to earlier solutions the method provides the possibility of obtaining significantly more data for the local characterisation of smoke at a reduced number of components which even might be utilised to set up a comparatively well transportable measurement system.

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False fire alarms

A partnership approach for resolving problems

Abstract

During the last 20 years there have been a number of projects to overcome the UK false alarm problems associated with automatic fire detection systems. To date none of these have been very successful and each year the number of false alarms has risen. A new initiative has now been started in the UK using a focused approach to the problem and which involves all those organisations who have a role to play. Early results from pilot projects are extremely encouraging.

The initiative has now been extended to cover most of the UK and a means of keeping all interested parties aware of the results has been established. Real reductions in false alarms are predicted.

Introduction

In the United Kingdom, there is a significant problem associated with false alarms from fire detection systems. These problems are mainly associated with automatic smoke detection systems.

Over the last 20 years there have been a number of attempts to reduce the scale of the problem but with very little real effect. The latest initiative shows definite signs of being much more successful and is worth consideration in other countries where there are false alarm problems.

History

It has long been recognised that there are three fundamental types of false alarms that cause the fire brigade to be called out. These are:

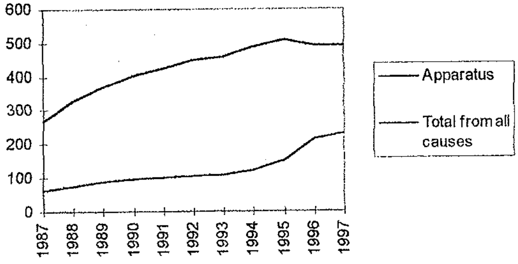
- Malicious Calls - where a person knowingly makes a call to the fire brigade or in some way causes a fire alarm to be operated when there is no evidence of a fire.

- False Calls with Good Intent - where someone thinks there is a fire and calls the fire brigade who subsequently confirm there is no fire.
- Calls Due to Apparatus - where an automatic or a manual fire detection system operates when there is no real fire.

It is this last cause of false alarms which is of greatest concern to the fire protection industry as it is the one they are able to influence.

In the UK, the level of calls due to apparatus has been rising year on year and Figure 1 shows the trend over the last decade. While there is some evidence that recent changes in data classification have caused the level of false alarms to be overstated, it is recognised that the present situation is totally unacceptable.

Figure 1 False alarms due to apparatus



In the early 1980's there was a major study in one area of the UK [1] that came up with evidence that there were three main causes of false alarms in the "due to apparatus" category, these are:

- Equipment failures e.g. dirty smoke detectors, electronic component failures
- Processes undertaken in the protected area e.g. steam generation or cooking food
- Human errors e.g. a service engineer forgetting to isolate equipment

There was also evidence that less than 10% of systems accounted for about 80% of the total false alarms due to apparatus.

As a result of this research, a number of initiatives both technical and process based were implemented to address the problems however the level of false alarms continued to rise.

What still remains unclear however, is the relationship between the number of installed detectors and the number of false alarms. To this day we do not know whether the ratio of false alarms to installed detectors is getting better or worse as we do not yet know the number of installed detectors.

In the early 1990s, the legality of fire brigades making a charge for attending a false alarm was challenged and the law courts ruled it to be illegal. Charging therefore ceased but the rate of false calls did not change significantly. It could therefore be assumed that charging is not an incentive for minimising false alarms.

In 1993 the government, with the support of the fire brigades and the fire protection industry, established an enquiry into the continually rising level of false alarms [2] . This lead to 16 recommendations of which 9 were considered to be particularly important. These included the following proposals:

- Third Party Certification of system designers and installers
- The wider use of analogue systems
- Preventing fire brigades from resetting alarm systems
- Improved guidance to the owners of systems causing high levels of false alarms.
- Greater focus on remedial measures to reduce false alarms.

After considerable discussion and trials of means of tackling the problem, an initiative evolved in 1997 which, while still in its early phases, is showing greater improvements and commitment than any other initiative.

The new approach

After analysing the causes of failure of previous initiatives, the following key issues were identified and were addressed by the latest initiative:

- Earlier initiatives have attempted to reduce the general level of false alarms without any real focus. This has lead to an ineffective scatter shooting approach.
- The problem has been seen as one involving only the local fire brigade and the occupier of the protected premises

- Fire Brigades have had many important priorities and false alarm reduction has not always been one of their highest priorities.
- There was no monitoring of the effectiveness of false alarm reduction therefore motivation was never very high

The latest initiative addresses all these issues and the key points are as follows

1. The fire brigades are facilitating the reduction of false alarms by co-ordinating the activities of those who can really influence the situation. They are not expected to be the experts in all aspects of false alarm reduction.
2. Each fire brigades is identifying 20 of the worst premises in their area and concentrating on their improvement. Only when these premises are well on the way to resolving their problems will the brigade focus on some more sites.
3. Fire brigades will initially talk to the occupier of the premises to ascertain the likely cause of their problem. They will then give them some advice on how to reduce the problem e.g. move some process equipment, re-site detectors, call in the installer, undertake system maintenance. The occupier would then be expected to make contact with the appropriate organisation to assist with the work. If there is no evidence of an improvement, the occupier will receive more focused attention from the brigade.
4. After assessing the 20 sites, each fire brigade is setting a target for the reduction in the level of false alarms when compared to the previous years results.
5. Contact points in fire detection system product manufacturing and servicing companies have been established so that fire brigades and occupiers can easily seek their advice when necessary.
6. A help desk has been established within The British Fire Protection Systems Association to provide expert, unbiased advice to fire brigades and the occupiers of premises and any others that may be having a problem understanding how to improve the false alarm performance of a system.
7. Progress towards achieving the target reductions are monitored centrally by government, the fire brigades and the industry.

8. The results of the initiative are fed back to brigades and other interested organisations. This allows local brigades to relate their results with those of other brigades.
9. Examples of successes in reducing false alarms are being publicised to assist others experiencing similar problems.
10. A central co-ordination group made up of representatives of government, the fire brigades and the fire protection industry are co-ordinating the initiative and ensuring its profile remains high and results are publicised. This group has at least one meeting a year with the relevant British Government minister to advise him of progress and future plans.

Results to date

The initiative was launched to all brigades in 1997 but was intentionally only operated by a few selected brigades so that lessons could be learnt from their experiences. After approximately 15 months since the initial launch, the results are as follows:

- Virtually all fire brigades have now started to implement the initiative
- The sites which were initially targeted for false alarm reduction have reduced their levels by up to 30% in the first year and most are planning further significant reductions
- Brigades are setting quite stretching targets for 1999 which they believe are achievable with a focused effort.
- Probably the worst group of false alarm generating premises are health care establishments including hospitals and nursing homes. This is often because their systems are complex. Funds are not always made available for their effective maintenance and upkeep and staff are often more interested in patient care than the prevention of false alarms. Health care premises also have one of the largest populations of installed fire detectors in the UK.
- Organisations involved with particular types of premises are volunteering to become involved with the initiative, these include an Association involved with sheltered accommodation for aged persons and the National Trust which owns many historic buildings in the UK.

- The government is assisting with research into the installed base of fire detectors in order to allow measurement of the real ratio of installed detectors to false alarms.
- The government's fire service inspectorate are considering the inclusion of the false alarm reduction initiative in their thematic inspection of fire brigades.
- The government minister responsible for the fire service has publicly endorsed the initiative and continues to take a personal interest.

The future

While we can already measure the success of the initiative on selected sites, it is too early to see any effect on the national false alarm statistics and indeed it may be a number of years before we see a significant reduction. It should not be unreasonable to expect a reduction of between 5 and 10% of the total false alarms due to apparatus within 2 years of the official launch of the initiative.

As the performance of the initially targeted problem systems improves and attention moves to other systems, so the decrease in false alarms should become more evident. As time goes by however the opportunities for improving existing systems will become more difficult to identify.

The initiative will continue for many years however there are real opportunities for issues relating to false alarms to be considered much more seriously when systems are being installed. This will include more careful analysis of processes within premises and the greater acceptance of system "tuning" which is now available from some suppliers. In the longer term emphasis on preventing the installation of systems with inherent tendencies to generate false alarms will produce the greatest opportunities for overcoming the problems.

Conclusions

After many years of seeing the continued rise in the level of false alarms, there is now evidence that a successful means of overcoming the problem has been identified and implemented.

Without doubt no individual group will be able to resolve the problem but by the continued co-operation of all the groups involved there is evidence that we will succeed.

The UK is not alone in recognising the problems of false alarms associated with automatic fire detection systems but it is probably ahead of most countries in its attempts to resolve the problem. It is only too pleased to share the methodology and results with other countries.

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Performance of an Optical and an Ionisation Smoke Detector Compared to a Wide Range Aerosol Spectrometer

Abstract

The parameters of newly developed fire detectors are often verified by comparing them to the standardized sensors MIREX and MIC using test fires according to EN 54/9. But a precise characterization of the sensitivity of the new detectors is only possible if detailed informations about the comparison sensors MIREX and MIC are present. For the analysis of the sensitivity of these sensors to smoke particles of different sizes, measurements of the smoke origin from standard test fires were executed. Apart from the measurement of the sensors reactions also the particle size distributions of the smoke aerosol as function of time are determined using the Electrical Aerosol Spectrometer (EAS) of the University of Tartu, Estonia. On the basis of the measured particle size distributions the sensor reactions are compared with the calculated different total concentrations of smoke aerosol as the number-, the surface- and the volume-concentration.

The paper briefly describes the measurement set-up and discusses the correlation between the smoke sensor readings and the different aerosol total concentrations.

Introduction

The development of a reliable fire detector requires mathematical modelling of the information transform process from the fire to the reaction of the detector. Despite a number of efforts are made so far still a gap exists in the knowledge of the smoke parameters which effects a reaction of the detector.

With the development of an electrical aerosol spectrometry it became possible to follow the fast evolution of aerosol particle size distribution in the particle diameter range from

3nm to 10μm with time resolution of a few seconds. That enables to follow the variations of the smoke aerosol from a fire in details in real time side by side with the detectors and in this way to gain new data for the modelling of the sensor characteristics.

Instrumentation

A) The smoke density measurement devices MIREX and MIC

Two standard smoke density measurement devices are used in parallel. The MIREX-device (Caupaul 1989) bases on the light extinction principle and uses an infrared LED source. The IR-transmitter and the receiver are mounted in the same case so that the effective light path in free air is 2 m with an optical mirror in the middle. The other device is the Measurement Ionization Chamber (MIC, Scheidweiler 1976) which measures the current reduction owing to the deposition of free air-ions on the surfaces of the smoke particles.

B) The Electrical Aerosol Spectrometer

An Electrical Aerosol Spectrometer of Tartu University, Estonia (EAS) (Mirme et al. 1984, Mirme 1994, Kikas et al. 1996) was used to measure the smoke aerosol size distribution. The last version of EAS has an enlarged particle size range from 3nm to 10 μm of particle diameter. EAS uses two different electrical charging methods followed by a parallel mobility classification for the particle measurement in full size range. A sophisticated mathematical data inversion algorithm transforms the mobility distribution to particle size distribution. The concurrent collection and measurement of particles in all size fractions in parallel avoids the dynamic errors in the data (Mirme and Tamm 1991). A fast data processing enables to continuously record aerosol particle size distribution with a time resolution of 4 seconds. EAS has continuous on-line verification of all principal operation parameters. It needs short periods every 15 - 20 minutes only (time is not critical) for testing electrometric circuitry and not any other maintenance.

Measurement setup and data acquisition.

The study was carried out in the Fire Detection Laboratory of the Department of Communication Engineering, Duisburg University. The fire test room of the laboratory has a base of 10 X 10 square meters and a movable ceiling according to the requirements of the European Standard EN 54 part 9. The 4 m standard ceiling height was used in this study.

The MIREX and MIC are installed on the ceiling at the 3 m radius around the fire location (see EN 54/9). EAS is installed in similar way. The smoke is introduced to the instrument via short pipes from the fire room. The sensors and the EAS were remotely operated from another room, outside the fire test room.

Temperatures below the ceiling at the centre right above the fires and at 3 meter distance (as the sensors) were also monitored.

EAS was operated in a way that a short instrument test was made just before fire ignition. The fire aerosol data were collected in the memory of a computer and were stored to a disk after the fire and next test. The distribution measurement period was 4 seconds. The aerosol was diluted and introduced to EAS with an injection type diluter driven by compressed clean air. The dilution factor ranged from 1.4 to 150 depending on the fire material used.

In this study the size distribution is represented in the most practical form of fraction number concentrations. Fourteen fraction concentrations were estimated, logarithmically uniformly covering the full size range from 3.2 nm to 10 µm with geometric mean diameters d_i = 4.22, 7.50, 13.3, 23.7, 42.2, 75.0, 133, 237, 422, 750, 133, 2370, 4220 and 7500 nm.

The following smoke aerosol distribution parameters were estimated:

TN - (Particle) Total Number Concentration, Particles per cm^3,

TD- Total Diameter Concentration, Sum of Particle Diameters in $\mu m/cm^3$,

TS - Total Surface Concentration, Sum of Particle Surface in mm^2/m^3,

TV - Total Volume Concentration, Sum of Particle Volume, in $\mu m^3/cm^3$.

The parameters are derived from fraction number concentration distribution using geometric mean diameters, d_i as basis for transforms:

$TD=Sum(N_i*d_i)$, etc.

Index i counts for the fractions.

EAS classifies particles electrically, the measured size is close to a Stokes' size that does not depend on mass density or optical properties of a particle. That differes from optical particle size (determined by scattering of the light, effected by light absorption e.g. by soot) or aerodynamic size (effected by the mass density). Therefore comparison with the optical detector MIREX may give valuable information on smoke particle properties.

Aerosol total concentrations TD, TS and TV are estimated as those for spherical particles.

It was tested that the error of calculating the distribution parameters from fraction number concentrations instead of integrating the distribution density function, does not exceed 10 %, that is small enough compared to the natural variations of fires.

The MIREX and MIC measured in every second, their data were also transformed to four second average format. In order to organise the ranges of the numerical values, the data by MIREX and MIC were rescaled multiplying them by a factor of 10^4.

The study was performed by monitoring different types of fires with the instruments and by comparative analysis of the results. The fires were made in accordance with the European Standard EN54 part 9. There were seven different test fires in total (Table 1).

Fire Type	Material
TF1	Open wood
TF2	Smouldering wood
TF3	Smouldering cotton
TF4	Polyurethan
TF5	n-Heptane
TF6	Ethanol (Alcohol)
'TF7'	Decalin

Table 1: List of test fires

Monitoring covered the full burning time starting at the ignition up to some period after the fire except a smouldering cotton fire, TF3 due to the long smouldering time.

Results and discussion

More than 80 fires and nonfire situations have been measured in total. Because of possible variations in burning rates that changes the time scale of fires, an averaging of the data was considered not to be quite correct. Therefore from all fires of a given type only one, the most typical fire is selected for the analysis. Selected in this way fire data form a database consisting of seven test fires, TF1 to TF7 that is considered as representative for standard fires. The further analysis is made using that database.

A) Time variations of the aerosol distribution produced by fires

Smoke aerosol from a fire has typically rapid increase of the concentration, with some development of the size as smaller size fractions increase first.

The increase stops with ceasing the fire. However the distribution continues to develop with decreasing the concentration. The decrease was faster in smaller size fractions and slower at large sizes (results presented in this Proceedings AUBE '99 by E. Tamm et al.: 'Aerosol particle concentration and size distribution measurements of test-fires as a background for fire detector modelling').

B) Time variations of the sensors MIC and MIREX data versus particle concentration

Since the sensors are responding to smoke by integrating signal over wide particle size range the data can be compared with integral parameters of fire aerosols. Basic integral parameters could be statistical moments of aerosol size distribution, which in aerosol physics are commonly used in form of different total concentrations of aerosol particles. In general the sensors provide data with similar time variations (Figure 1). All the parameters increase almost in parallel in time until the end of fire.

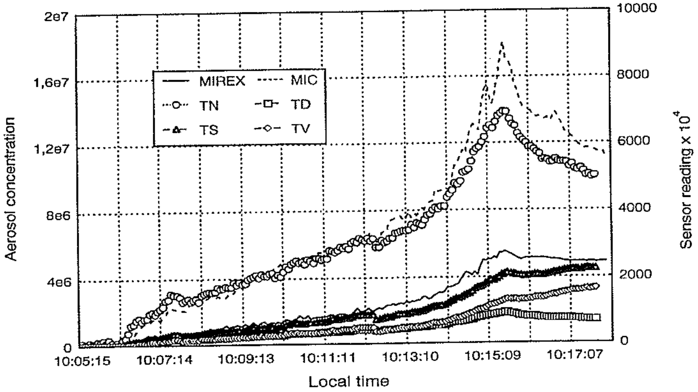

Fig. 1: Time variation of fire sensor readings and aerosol total concentrations of a fire TF7.

After the end, number and diameter concentrations and also the sensor readings decrease. The surface concentration almost does not change but aerosol volume concentration (TV) continues to grow. Some trend can be noticed from fire to fire. Volume concentration of wooden fires did increase not very significantly after the end and for some fires no increase of mass was observed. (TF4, Figure 2).

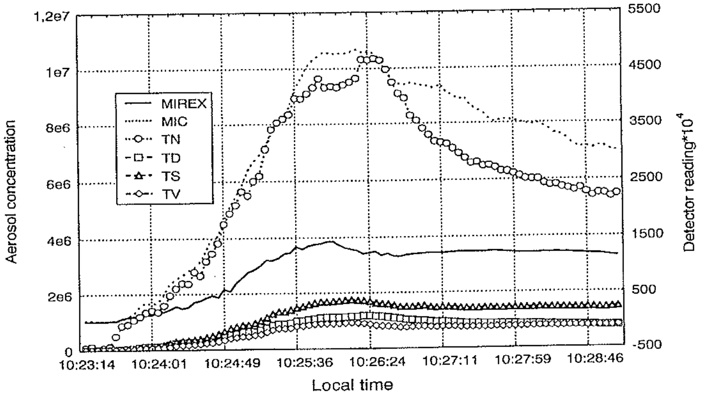

Fig. 2: Time variation of fire sensor readings and aerosol total concentrations of a plastic fire TF4.

The particle generation by alcohol fires is exceptional. Optical sensor readings were comparatively elevated and a specific burst of very fine particles always happened at the cease of the fire.

C) Correlation of the sensor readings with size fraction concentrations

Since the aerosol is varying greatly during a fire, the statistical averaging may have no meaning and the estimates are not fully applicable. However the statistical methods are well elaborated and easy to use. Thus for overall characterisation of the sensors a statistical analysis of the test fire database was made.

A correlation coefficient that measures a relative covariance of two statistical parameters for given conditions however can be treated here as a measure of connection between the smoke parameters. Nonparametric Spearman rank order correlation coefficients are calculated as giving more reliable estimates when the statistical properties of variations are not known as it is the case here. Correlation of all four particle total concentrations as well as the fire detectors readings with fraction number concentrations is estimated by these coefficients (Fig. 3). The results presented here can be treated as a kind of mean characteristics of fires since the database used presents all test fire types.

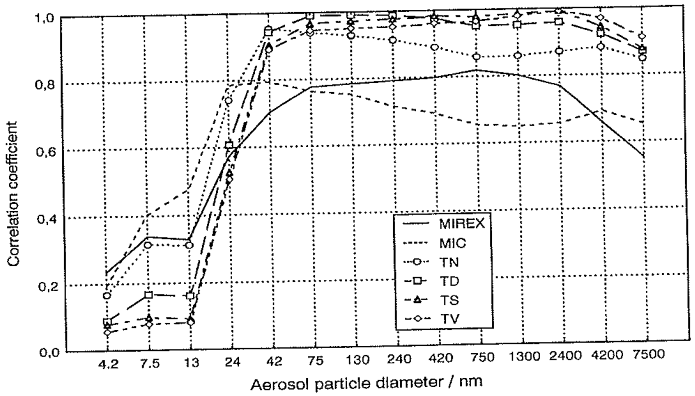

Fig. 3: Correlation of fire sensor readings and of aerosol total concentrations with smoke aerosol fraction number concentrations.

Data of both sensors drop at the sizes below 20 nm (Figure 3), however the ionisation detector MIC senses more small particles while the optical sensor is sensing better submicrometer and micrometer sizes. But the sensitivity of the optical sensor is dropping at the sizes above 3 micrometer while that for the ionisation detector stays almost constant.

The correlation of MIC is reduced by alcohol (TF6) fire mainly. The correlation of MIC was close to correlation of total concentrations if the data of TF6 were not included.

However the correlation does not show a direct causal link with the aerosol particle sizes. Concentration of the particles of different sizes are varying very much synchronously since the aerosol is originated from the same source and there is strong connection between aerosol concentrations of different particle sizes. Therefore the total concentrations also correlate strongly with almost all fraction concentrations although the large particles almost do not contribute in total number etc. Also for total concentrations the particles below 20 nm have low correlation. The particles of that size range have short life time and are collected by long living accumulation range particles (0.1 μm and larger). It can be noticed that the sensors data correlate with the particle fraction concentrations similarly to total number, diameter, surface and volume concentrations, with some differences at large and small sizes. The tight connection between aerosol fractions also makes it not possible to follow the reduced sensitivity of the optical sensor to small particles that could be expected because of operation principle.

D) Correlation of the sensors data with the aerosol total concentrations

The comparison of the reaction of sensors to the smoke aerosol total concentrations enables to conclude which aerosol integral parameter is actually sensed.

According to their working principle, the optical sensor MIREX can be expected to sense and integrate aerosol surface, while the ionisation sensor should sense proportionally to total diameter. Thus the sensors should show the highest correlation with the respective total concentrations. The actual correlation (Table 2) do not coincide with said above exactly. The sensors seem to sense the smaller particles better (TN counts for smaller particles than TD, and TD counts for smaller than TS). This effect may be caused by some side effect like increased particle loss or increase of random variations at large particle sizes.

	MIREX	**MIC**	**TN**	**TD**	**TS**	**TV**
TN	.755	.813	1	.952	.901	.879
TD	.789	.747	.952	1	.981	.959
TS	.778	.687	.901	.981	1	.989
TV	.737	.658	.879	.959	.989	1

Table 2: Spearman correlation of fire sensors with different aerosol concentrations

E) Differentiation of fires using aerosol data

An attempt was made to differentiate the fires by comparing the reactions of fire sensors to different aerosol parameters. Although the parameters of fires varied greatly in course of the fire (Figure 1 and 2), the variations of the parameters have been well correlated (Table 2). That enables to reduce the effect of uncertainty of absolute values, which may depend on many unknown factors, by normalizing smoke detector reaction. The data were normalized by using the ratios of a sensor reading to aerosol total concentrations. That can be treated as the sensitivity or the reaction of a sensor to respective aerosol concentration.

Most of burning period the ratios are quite stable. There were some fluctuations at the beginning of the fires. Some development of the ratios is observed in case of open wood TF1 and alcohol fires TF6. The not large variations of the ratios enable to compare the fires by studying the mean ratios. An additional improvement of estimates was made by using the medians instead of mean values as more stable to outlayers.

An optical sensor MIREX seems to be most sensitive to open wood fire TF1 and least sensitive to alcohol fire, TF6 compared to ionisation detector MIC (Figure 4). The smouldering wood (TF2) has smaller reaction compared to open wood if to consider MIC while that has the strongest effect compared to aerosol concentrations measured by EAS. The sensitivities of both detectors are the lowest for TF5 compared to the aerosol concentrations.

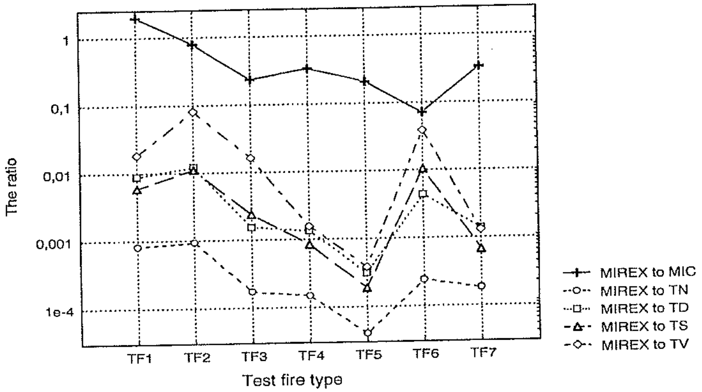

Figure 4: Normalized reaction of an optical fire sensor MIREX to aerosol total concentrations of different fires.

F) General discussion

The reaction of an optical detector to aerosol may be explained by different blackness of smoke particles. The content of soot in particles is low in wood and alcohol fires, therefore much light is scattered. The smoke from TF5 seems to be of most black. The reaction of ionisation detector is more difficult to explain. A possible explanation may depend on the details of operation principle of the detector. One reason may be that ion mobility depends on the concentration of vapours, in particular alcohol vapours. If the operation principle of MIC is sensitive to ion mobility that may give the observed reaction.

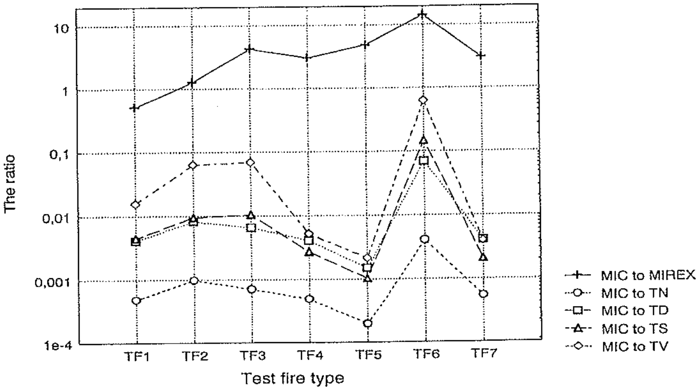

Fig. 5: Normalized reaction of an ionization sensor MIC to the aerosol parameters of different fires.

The ratios in figures 4 and 5 together form a certain pattern for each fire that may be used to differentiate the fires. A grouping of TF3, 4, 5 and 6 may make difficult to differentiate these fires basing on MIC and MIREX data only (Figure 4 and 5). Using MIC and aerosol it may be difficult to differentiate TF2 and TF3. But combining the patterns on the two graphs together the essential differences can be found for each fire. The only two fires are TF4 and TF7, which may have patterns too close for differentiation.

The variation of smoke aerosol size distribution is in agreement with basic aerosol theory. The particles in the air tend to grow because of coagulation and condensation.

An active aerosol source (fire is burning) usually starts to produce high concentration of very small particles. The particles crow because of Bownian motion. That leads to increase of all aerosol concentrations, smaller fractions first, large size fractions following. At high concentrations of large particles the small ones may coagulate directly to them. That results in short life time for small particles and not high, fluctuating concentrations in the small size fractions. When the particle source stops, the small size fractions drop fast, the large ones still grow. The particle total mass should stop growing because there is no income of particles. In these experiments the mass concentration continued to grow although with reduced speed. That should indicate on a condensational growth of the particles. The reason may be the decrease of the temperature in the room. The process seems to preserve the surface concentration of the aerosol. The dependence of postfire behaviour of aerosol mass on fire type may provide information on substances emitted by a fire in gas (vapour) phase.

The observed correlation of the sensors with aerosol total concentrations (Table 2) may be an effect of combining the fires. However the total number and diameter also total diameter and surface correlate very high so that the results can not be considered as contradicting to the operation principles of the detectors.

The reduced correlation with very large particle concentration (Figure 3) may indicate that the detector does not get the large particles into the sensor effectively, in particular when the rate of air mixing in the room is reduced.

Conclusions

The study took advantage of outstanding features of EAS that is able to measure extremely fast changing aerosol simultaneously in a very broad particle size range.

The smoke aerosol from the fires seems to have a number of specific features that may be used in fire detection. The behaviour of the optical sensor is in agreement with the operational principle. The ionisation chamber seems to be more complex and may involve some fine effects of interaction of air ions with the vapours in the air.

The differences may make it possible to differentiate different fires. However the ranges of random variations of fire differences were not yet estimated and need more studies.

Acknowledgements

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Application Specific Sensitivity: A Simple Engineering Model to Predict Response of Installed Smoke Detectors

Abstract

A simple engineering model has been developed to predict response of smoke detector applications. The model predict what detector specific (nominal) sensitivity is needed in order to detect a required maximum mass of smoke fully diluted in a given volume. Calculated results allow the optimum type of detector and sensitivity to be selected for each room prior to purchase and installation. Results ensure that an approximate equal mass of incipient smoke release will be detected in each room independent of room volume or smoke detection principle, i.e. equal application specific (effective) sensitivity. The approximation is best at worst case scenarios. Effective sensitivity is set according to use, type of room, quiescent smoke level, fire damage sensitivity potential; alternatively to recorded mass of smoke release in test at the time when response to an incipient fire size is deemed appropriate by the fire engineer or property owner.

Initial submodels suit point, beam and aspirating detectors including fixed threshold and intelligent types. Typical nominal sensitivity range is 0.001-35 %/m obscuration or even broader to cope with fires in small closets, or small fires in large rooms and other area of high dilution. The model may verify effective sensitivity in unusual applications to conform objectives of international standards. The model complements engineering software that allow manual input of detector response time and correlate to optical density.

Background

Current standards for approval testing of point smoke detector sensitivity in Europe and in the US /4,12/ presume test specimens is designed to trigger at a fixed threshold only. The tests determine nominal sensitivity values. The nominal sensitivity of a smoke detector is the homogeneous smoke density level subjected to the sensing chamber which is just sufficient to trigger the alarm. The standards were made at a time when most smoke detector designs had fixed threshold - like EN 54 /4/ and UL 268 /12/ - but even the latest available drafts and guidelines for designs of beam and aspirating detectors does not seem to fully recognize the possibilities and benefits of threshold adjustments.

It is argued that inapt nominal sensitivity is the most prominent cause of unwanted alarms as well as the cause of delayed or unsuccessful detection. The apparent reason being fixed threshold detectors being applied to most type of rooms in disregard of specific volume, smoke damage potential, dilution and quiescent smoke level.

This was inevitable when fixed only detectors were available. Standardization bodies barely address this theorem which is generally unrecognized elsewhere in the business.

As adjustable detector sensitivity recently became available neither manufacturers nor system designers have been provided with tools to predict and set nominal values. Instead, an increase of the problem is observed as sensitivity settings frequently become even more out of place, especially on the part of beam and aspirating systems. The parametrization of marketed detectors is basically a provision for broad sensitivity adjustments /14/. The range figures are unknown, except one manufacturer imply /14/ a range of approximately 1.5-35 %/m obscuration by declaring to match class C of EN 54 /4/. Parametrization guidelines does not adhere to volume but to quiescent smoke level only.

Several new detector designs offer broad sensitivity ranges including beam, point and aspirating detectors. So, now the opportunity for correct setting exists - except no guideline to determine suitable values. The model G-Jet was conceived to meet these challenges. Initial submodels suit point, beam and aspirating detectors including fixed threshold and intelligent types.

Definitions

Nominal Sensitivity S_n: The minimum smoke density OD_n at a sensing point (smoke chamber, suction hole, beam etc) of a detector to trigger detection. By definition in G-Jet version 1 the nominal sensitivity equals the *effective sensitivity* (see definition) in a reference room volume of 250 m^3, with homogeneously dispersed smoke. The reference volume is by convenience equal to test chamber of EN 54 Part 9 /4/. S_n is detector specific, i.e. independent of application. $S_n = OD_n$ (%/m).

Effective Sensitivity S_e: The minimum amount of smoke material homogeneously dispersed in the detection volume sufficient to trigger detection. Also referred to as "application specific", "applied" or "installed" sensitivity. "Effective smoke density" is the smoke density corresponding to the mass of smoke particles evenly dispersed. Effective sensitivity correspond to OD_e. Dimensions are either gram (g), obscuration (%/m) or optical density (dimensionless). $S_e=OD_e$.

Required Effective Sensitivity S_{req}: The amount of material (g) as smoke homogeneously dispersed in the detection volume deemed appropriate to trigger detection in a given room. Normally, a dirty environment require moderate or low effective sensitivity and clean environment high sensitivity. Required effective sensitivity may be designated OD_{req}, and measured in units as S_e.

Required Time of Response t_{req}: The time at which S_{req} occur.

Optical Density OD: $OD_x=\log_{10}(I_0/I_x)$. I_0 is luminance at source, I_x is luminance at distance x. Unless otherwise stated values refer to 1 m measuring distance.

Smoke Obscuration S_x: $S_x=100(1-I_0/I_x)$. I_0 is luminance at source, I_x is luminance at distance x. Unless otherwise stated values refer to 1 m measuring distance.

Total Smoke Obscuration, given distance and smoke density:

$OD_x = 2 - \log_{10}(100 - S_x)$ and $OD_x = (x/y)\, OD_y$

These two formulas are used to calculate sensitivity of beam smoke detectors dependent on beam length and related G-Jet calculations. x and y are different measuring distances.

Smoke Yield: Correlations of material mass, specific smoke yields and smoke density are given in /5/. For most applications smoke density requirement is given input, but smoke yield data are needed to calibrate G-Jet to empirical fire test results of EN 54 Part 9 or in special applications.

Quiescent Smoke Level: Normal level of non-fire smoke density in a room.

Model Objectives

It was proposed that functional requirements to smoke detection systems should specify the level of smoke mass released in the detection volume just sufficient to raise the alarm, i.e. required effective sensitivity. This requirement should take into account the type of room in terms of quiescent smoke level, volume and sensitivity to smoke damage. The challenge was to model most type of smoke detectors so that effective sensitivity could be predicted from input data on type, nominal sensitivity, room geometry and installation layout - and compared to the requirement.

The objective was to design detector applications in confidence that the optimum solution regarding sensitivity to real fire, sensitivity to nuisance sources and cost was chosen. One should be confident that if ten paper sheets slowly burned would just raise an alarm in a printer closet, the same paper sheets should also just raise an alarm if slowly burned in an open plan office of volume 100 times or more. At the same time, the number of smoking cigars necessary to trigger a nuisance alarm would be the same in both rooms.

The aim was then to determine effective sensitivity to real fire uniformly throughout a building, and to determine effective sensitivity to nuisance alarm. The probability of unsuccessful detection of a predefined incipient fire size, and probability of false alarms, should then be designed equal for all rooms or specific to each room as appropriate.

It should not be required to do commissioning smoke tests in situ to adjust sensitivity and print-out reports should act as validation in respect of performance based regulation.

Adhering to Performance Codes

In many countries performance based codes call for performance data of most safety systems. Available fire engineering tools does not adequately model smoke detector response: simple default smoke detection is often set equal to an increase in temperature, like fixed temperature 13 °C at RTI value of 0.5 $m^{1/2}s^{1/2}$ or 20 °C /15,17,18,19/, thereby anticipating flaming fires. Most models do not address the pre-flaming stage of fires at all /19/. BSI in /17/ suggest evaluation of optical smoke density at the sensor points as a reasonable simple approximation, and is adopted for G-Jet. ISO draft /18/ acknowledge problems associated with advanced modeling and imply the same. CFD models are still critical to inputs, demanding considerable skill and heavy computing resources /15,18/.

Effective smoke detector sensitivity is a required input in life safety calculations at a number of scenarios such as smouldering fires in bedrooms or when evaluating smoke conditions in escape routes against survivability limits. Or, to evaluate the fire risk at damage sensitive premises like computer centres it may be necessary to consider the pre-flaming stage primarily. G-Jet were designed to this need and will combine with engineering model software that allow manual input of detector response time.

Model Concept

The model is based on calculating the nominal sensitivity corresponding to a required effective sensitivity given type of smoke detector, layout of sensing points, room geometry/volume and smoke mass subjected to the detection volume.

The required effective sensitivity of any application is chosen so that slowly developing fires are detected at a comfortable early stage. Contrary to popular belief, this translate to a level in the majority of cases well above that of nuisance smoke levels. This is explained in model context by large room volumes requiring high nominal sensitivity and vice versa by small rooms.

Smoke mass yield from a given mass of specific material may be calculated from empirical data and correlated with smoke density by way of Drysdale /5:356-362/. Alternatively, loss of mass may be recorded in situ test at the time/density subjectively deemed appropriate for detection.

G-Jet is deliberately simple. It is realized that reliable smoke spread prediction is still not practically achievable while substantial improvement is possible by simple means.

Postulations

The assumption is made that no smoke detector types are prone to unsuccessful or unacceptable delay in detecting flaming fires provided their locations and sensitivity settings comply to rules.

An assumption is made that the most difficult fires to detect are slow or smouldering which thereupon are modeled as smoke mass evenly dispersed in the detection volume.
It is recognized that most detection problems are associated with low smoke production, and that correct nominal sensitivity have a large potential to prevent nuisance alarms, increase life safety and safety of property.

Conventional fixed threshold detectors have to be supplied at a very high sensitivity in order to cope with the most demanding applications. Thus, they are much too sensitive for most applications and causing nuisance alarms. This argument is also made by manufacturers of new intelligent and adjustable smoke detectors /1, 2, 14/.

EN 54-9 /4/ nominal sensitivities may be set within a range of approximately 1-35 %/m obscuration provided fire test results to class A, B and C requirements are adhered to. A typical point smoke detector with 1.5%/m fixed threshold will suit a 250 m^3 open plan office. But equal sensitivity in 2.5m^3 printer closets require detectors of nominal threshold 78%/m. The full range of sensitivity allowed by standards offer a unique potential for more reliable fire detection. Reference /7/ report of a comprehensive test: By reducing sensitivity of point smoke detectors from 3,3 to 6,6 %/m only, the total number including non-sensitivity related alarms were reduced by 50%.

The engineer is expected to perform professional guesstimate when deciding size of the uniform smoke cloud in percent of total room volume at the time of t_{req}.

Effective Sensitivity to Flaming Fire

A flaming fire is characterized by the buildup of a smoke layer which lends itself easy to detect. The plume will override forced air ventilation. Loss of smoke from the layer is virtually nil. Smoke density at detector points increase fast and usually exceed alarm thresholds within an acceptable time limit. Typically, variations in nominal smoke detector sensitivity will only make response times differ by seconds /19/. Hence, problems in detecting flaming fires are rarely reported.

Slow flaming fires, though, especially in large room volumes, are detected much later by low sensitivity smoke detectors. Such "weak stratification fires" challenge the detectors more like smouldering fires does. Hence, smouldering fires are considered 'worst case' and used in G-Jet. Detection emphasis is put on pre-flaming stage of fires rather than the first seconds of flaming fire. It is recognized that deadly fires and fires doing most damage typically have a substantial undetected incipient stage (derived from Norwegian statistics /8/) while flame-ignited fires are typically intimate with awake people and connected to their activities. Hence, detection in order to alert is less important.

Effective Sensitivity to Smouldering Fire

Smouldering fires are easy to detect in small rooms by most detectors. That is because the smoke concentration build-up rate compare to smoke layers at ceilings in flaming fires, even if smoke mass release is much reduced. However, this makes detectors sensitive to nuisance alarm conditions also which is the major problem in small rooms.

Smouldering fires are very difficult to detect in large room volumes by fixed sensitivity point smoke detectors. This is due to the dilution effect distributing the smoke into a large smoke cloud within the room or often almost uniformly throughout the volume /6/. In the model smoke mass released is assumed to be evenly dispersed, not only as it is relevant to real life scenarios but also as a worst case for conservative assumption.
Alarm statistics and general experience indicate that unharmful smoke become 'difficult to detect' in large rooms by detectors of low nominal sensitivity due to dilution effect.

Model Calculations

The engineering objective is either to determine the resulting effective sensitivity of a given detector application or, more often, to select appropriate nominal sensitivity and type of detector that will meet a required effective sensitivity. See figure 1.

Design example: Detection is deemed appropriate when a mass of smoke equivalent to 10 sheets of paper is evenly diluted independent of room size. This occur at time t_{req}. For a room volume of 250 m^3 (equal to G-Jet reference volume) one must apply a nominal sensitivity equal to the required sensitivity. In the smaller room the same 'fire' (i.e. mass of smoke) will develop a higher smoke density. This density is calculated and a corresponding lower nominal sensitivity is proposed so that the alarm goes off at t_{req}, just as in the medium sized reference room. For the large room the model calculations suggest a higher nominal sensitivity in order to respond at t_{req}.

Diagrams are made to determine nominal sensitivity to given room volumes and required effective sensitivity. The single curve in figure 2 account for one specific effective sensitivity only. Greater detection volume require higher (lower value) nominal sensitivity. The correlation is not linear.

Model Accuracy

Although some assumptions definitely is rough the model accuracy is found superior to existing alternatives by initial experience. The calculations is conservative due to the assumptions made.

Some enhancement may be possible by further development. Albeit model version 1 is proven useful it is in a need of verification and refinement to gain further recognition.

G-Jet is a method for comparative, not specific, analysis. The reference to compare against, such as mass smoke release at time of detection in EN 54 Part 9 tests, may be changed at demand. Model calculations have been verified by realistic full scale tests with real and nuisance smoke. The results confirmed the calculated settings, and no change in settings has been necessary in the applications commissioned so far.

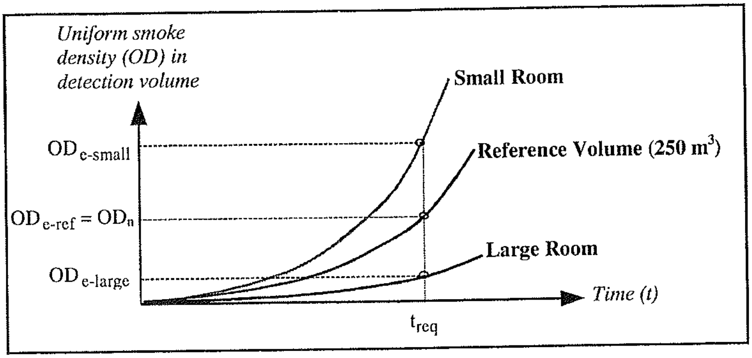

Figure 1 Principle Calculus Regime of Model G-Jet

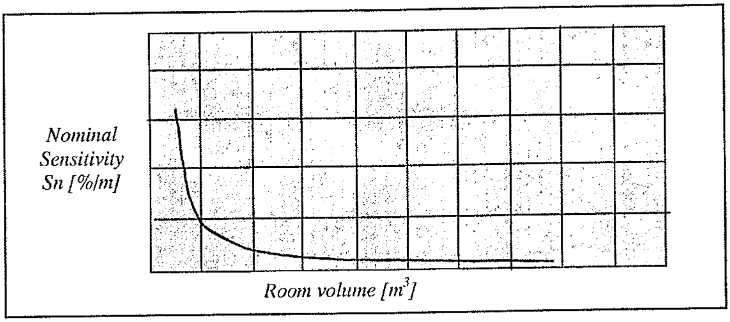

Figure 2 Nominal vs Required Effective Sensitivity, S_{req} = x %/m

Performance

From preliminary experience it seem a paradox that the model emerge a definite improvement given the fair only accuracy. But is explained by the fact that conventional one-size-fit-all fixed smoke detectors by definition could never be properly adapted to applications. In situ smoke tests and experience have consistently proved predictions to be comfortably within expectation. Although fine tuning of the model is feasible it may not be wise to do so as the current version perform to satisfaction. Refining may cause the model to become less accessible for use.

The results indicate some detectors are less suitable in applications as they do not provide the sensitivity required. Experience from use in applications support the results.
An alternative to model smoke detector response is computational fluid dynamics, CFD /15,18/. This is however still a demanding task not suited for design /15/. Computations are made to trace smoke plumes in respect of detector locations by CFD - assuming an intermediate regime between smouldering and flaming fire. G-Jet have relied on smouldering fires as conservative default emphasizing sensitivity rather than location and in doing so proven simple and useful.

Table 1 Results of Sample Computations by G-Jet

Nominal Sensitivities versus Effective Sensitivity Requirements at Some Applications

	Office Cell	Broom Closet	Covered Mall	Production Hall *(welding)*	Computer room *(air conditioned)*
A	3x3.5x2.5	1x1x2.5	80x10x17	50x30x10	5x10x3
B	1.5	1.5	5	20	0.05
C	100 %	100 %	25 %	50 %	100 %
D	14 %/m	78 %/m*	0.4 %/m	0.7 %/m	0.08 %/m*
E	1.5 %/m **	14 %/m **	0.09 %/m	0.4 %/m	0.08 %/m
F	NA	NA	26 %***	31 %***	0.8 %***
G	0.15 %/m	0.02 %/m	19 %/m	36 %/m	0.9 %/m

*NA = Not Applicable * = Not Available ** = Applicable by multiroom sensing configuration only *** Total Light Obscuration*

A: Room geometry (wxdxh). **B**: Required effective sensitivity S_e. **C**: Part of volume presumed to be occupied by uniform smoke cloud. **D**: Calculated nominal sensitivity S_n for point smoke detectors. **E**: Calculated nominal sensitivity S_n for aspirating smoke detectors. **F**: Calculated nominal sensitivity S_n for beam smoke detectors. **G**: Comparing against conventional practice: Effective sensitivity S_e when applying fixed S_n=1.5 %/m point detectors.

Conclusions

An engineering tool to predict response of applied smoke detectors have been designed as outlined in abstract. The limited experience fulfill expectations. The potential for use in engineering design of detection systems to prescriptive codes as well as to performance code requirements is promising. The model may assist development of new detectors and pre-engineered solutions as well and has settled disputes between vendors by use in third-party analysis.

Despite rough assumptions initial use ascertain a definite improvement to conventional one-size-fits-all detection, guesswork or in situ testing. It is questioned whether refining of the model should be carried out as the experienced simplicity in use could suffer. The model await the possibility of verification by independent third parties, in theory and tests, from which a standpoint to the question can evolve.

It is argued that inapt nominal sensitivity is a most prominent cause of unwanted alarms as well as cause of delayed or unsuccessful detection. Guidelines and standards should gain substantial benefits in reliable and nuisance-resistant smoke detection if they state performance requirements by effective sensitivity.

The model G-Jet is developed universal to sensitivity range, design or brand of smoke detectors. It puts the engineer in control and provide documentation of vital factors affecting response of installed detectors. It serve to chose optimum detectors, enhance the use of parametrizible detectors and has proven useful to exploit aspirating systems. The model is a deliberate and simple design in order to attain substantial improvement for practical predictions without ambiguous modeling.

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Praktische Erfahrungen eines Brandschutz-Ingenieurs mit der Installation von Brandmeldeanlagen in der Industrie

0 Abstract

Today fire warning systems are still only then installed when they are required of the institutions. But as the statistics from the fire-brigade and insurance companies show, the protection effekt of the fire warning technique is enormous: fires are detected earliest, fire-brigade are called automatically, damages caused by fire are much less, mankind and real values will be rescued and – very important nowadys, the possibly ruining interruption of the business is minimized. Not in every – but in many cases fire warning systems do rescue.

Very often institutions demand fire warning systems for industry, insurance companies try to make the fire warning technique more attractive by giving discounts. But many companies only show reactions when being under pressure, late or not at all, or they use low quality technique with the result of many false alarms, in case of fire no alarm at all or that the alarm comes too late.

Today a modern fire warning system is one of the most essential supports in the cases of safety of an all including fire safety concept. Fire warning systems which work automatically in the most cases are not to replace through other technical and organizational measurements – these at most can complete the fire warning technique in a sensible way.

1 Einleitung: Sinn, Nutzen und Grenzen der Brandmeldetechnik

Die langjährigen Statistiken der großen Deutschen Schadenversicherer zeigen, daß die Tagbrände in den Industrieunternehmen, also wenn Menschen anwesend sind und arbeiten, verständlicher weise mit 67 % häufiger auftreten als die verbleibenden 33 % der Nachtbrände. Verständlicher weise insofern, denn tagsüber wird gearbeitet und dabei ist die Brandgefahr größer als nachts, wenn eigentlich alles still stehen sollte. Doch die

Tagbrände machen lediglich 38 % der Kosten aus und die 33 % der Nachtbrände verursachen 62 % der Brandschaden-Kosten. Nachtbrände sind durchschnittlich also 3,3 mal so teuer wie Tagbrände. Die automatischen Brandmelder am Tag sind oft die anwesenden Menschen und nachts kann sich, so keine automatischen Brandmelder installiert sind, ein Brand selbständig und unbemerkt ausbreiten. Doch auch tagsüber macht die Technik Sinn: Mehrere verspätet gemeldete Krankenhausbrände mit Todesfolgen und großen Sachschäden zeigen, daß der Mensch als Brandmelder nicht immer geeignet ist – auch wenn „in jedem Zimmer ein Brandmelder liegt“, wie ein Krankenhausdirektor sagte, um die Installation dieser Technik zu verhindern.

Automatische Brandmelder empfehlen sich für praktisch alle Gebäudearten: Private Wohnhäuser, kleine Betriebe, Mittelstand, große Produktionsunternehmen usw.; sie machen auch in nahezu allen betrieblichen Bereichen Sinn: Verwaltung, Lager, Produktion, Technikräume, Dach- und Kellerräume usw.

Doch es gibt auch einige wenige Bereiche, wo die automatische Brandmeldetechnik wenig Sinn ergibt, oder nur zusammen mit anderen Brandschutzmaßnahmen (z. B.: Brandwände, Brandschutztüren, Brandlöschanlagen, Betriebsfeuerwehr usw.); beispielhaft sei hierzu genannt:

- Nicht unterteilte Bereiche mit hohen Brandlasten
- Besonders rauchempfindliche Bereiche, in denen ein Totalschaden schnell eintritt, lange bevor die Feuerwehren vor Ort sind
- Bereiche ohne Brandlasten (kommt extrem selten vor)
- Bereiche, in denen Menschenleben und Sachwerte nicht gefährdet sind.

2 Die Installation von Brandmeldeanlagen in Industrieunternehmen

Industrieunternehmen müssen heute in vielerlei Hinsicht Richtlinien einhalten und Maßstäbe setzen. So gibt es die DIN EN ISO 9000 ff-Zertifizierungen, Auflagen von verschiedenen Behörden und Institutionen, Vorgaben von Abnehmern oder auch der schlichte Selbsterhaltungstrieb, ständig produzieren zu können – um nicht dem Mitbewerber die Kunden nach einem Schadenfall unfreiwillig zu übergeben. Brandmeldeanlagen sind pauschal gesagt für alle Industrieunternehmen heutzutage Stand der Technik geworden und zwar für nahezu alle Bereiche. Man kann über Brandabschnitte, Gebäudeabstände, Mitarbeiter-Schulungen oder die Installation von Brandlöschanlagen diskutieren, eine Brandmeldeanlage ist der Grundstein, vergleichbar mit dem Schutzgurt im Auto. Es mag nur wenige, hier nicht näher beleuchtete Ausnahmen geben, wo automatische Brandmelder tatsächlich nicht nötig sind.

2.1 Interessen der Unternehmen

Unternehmen müssen primär Gewinne erwirtschaften, um weiter zu bestehen. Der Brandschutz mit all seinen verschiedenartigen Möglichkeiten ist neben den verfahrenstechnischen und kaufmännischen Standbeinen eine der wesentliche Stütze, die den Unternehmen ihre Funktionen ermöglichen. Während immer noch relativ viele Unternehmer auf 30 und mehr Jahre ohne Brände zurückschauen und lediglich die Anschaffungs- und Unterhaltskosten der „unproduktiven“ Schutztechnik sehen, erkennen andere die wenn schon nicht humanitäre, so doch die wirtschaftliche Bedeutung des Brandschutzes: Man kann es sich in Zeiten des härteren Wettbewerbs einfach nicht mehr leisten, seine Kunden nicht zu beliefern. Langjährige Verbindungen zählen nicht mehr und sollte die Lieferung unterbrochen werden, so suchen sich viele Unternehmen andere Bezugsquellen – egal, ob es gebrannt hat, ein Streik die Produktion unterbricht oder ob ein anderes schädigendes Ereignis eingetroffen ist. Demzufolge müssen die Unternehmen dafür sorgen, daß es nicht zu Schäden und Unterbrechungen kommt; dies ist insbesondere vor den immer geringer werdenden Lagerbeständen und der offensichtlich wirtschaftlicheren Just-In-Time-Produktion zu sehen. Erfahrungsgemäß investieren angestellte Manager vermehrt und früher in Schutztechniken wie z. B. Brandmeldeanlagen als Firmeninhaber und deren Familienangehörige.

2.2 Anreize und Druckmittel der Versicherungen

Die Versicherungsgesellschaften unterliegen ebenfalls heutzutage einem immensen Wettbewerb und sie haben noch den großen Nachteil, daß ihr Produkt (= Versicherungsschutz) für den außenstehenden Laien identisch mit dem Produkt von anderen Versicherungen gesehen wird; Fazit: „Die bessere Versicherung ist die preiswertere“ denken viele und achten lediglich auf die Prämie. Da praktisch alle Unternehmen gegen Feuer versichert sind kann man nur an neue Kunden herankommen, indem man einem anderen Versicherungsunternehmen einen Kunden abnimmt; dies geht eben meist damit, daß man auf sicherheitstechnische Auflagen des momentanen Versicherers verzichtet und hofft, daß dennoch kein Feuer ausbricht, oder indem man dessen Prämie unterbietet. Insofern haben die Versicherungen eine schwache Position, Druck auf Unternehmen auszuüben, um in Sicherheitstechnik zu investieren; der verstärkte Konkurrenzdruck tut sein übriges dazu. Deshalb versuchen die Versicherungen, mit Rabatten die Investition einer Brandmeldeanlage attraktiv zu gestalten: Je nachdem, welche Qualität die den Alarm entgegennehmende Stelle hat (ständig besetzte Pforte, Werks- oder Betriebsfeuerwehr, Öffentliche Feuerwehr) und welche Qualität die Brandmeldeanlage hat, gibt es zwischen 2 und 20 % Rabatt auf die Prämien für die Feuer- und die Feuer-Betriebsunterbrechungsversicherung.

2.3 Behörden und deren Intensionen

Feuerwehren und Baubehörden haben die Möglichkeit, Vorgaben bzw. Auflagen zu machen. Besonders bei Neubauten oder elementaren Umbauarbeiten werden brandschutztechnische Maßnahmen gefordert. Die Baugesetzgebung ist Ländersache, aber die unterschiedlichen Landesbauordnungen stützen sich auf die Musterbauordnung und weichen hiervon nur unwesentlich ab. Müssen bestimmte Flächen von Brandbereichen überschritten werden, so ist dies oft nur dann genehmigt, wenn (u. a.) eine automatische Brandmeldeanlage vorhanden ist. Der Gesetzgeber fordert jedoch lediglich in der Garagenvorordnung (GaV, § 16), daß für geschlossene Großgaragen (d. h. > 1.000 m^2) Brandmeldeanlagen installiert werden und ggf. auch für geschlossene Mittelgaragen (d. h. > 100 m^2).

Je nach Gebäudegröße und –nutzung werden dem Bauherrn zur Genehmigung seines Betriebs unterschiedliche Brandschutzauflagen gemacht: Brandwände, Sicherheits-Treppenhäuser, automatische Brandmeldeanlagen, Notbeleuchtungssysteme und anderes. Besonders in Gebäuden, in denen sich viele Menschen aufhalten und hier insbesondere in öffentlich zugänglichen Gebäuden fordern die Behörden in der Regel automatische Brandmelder.

2.4 Sicherheitstechnische Produktions- und Installationsunternehmen

Die Vertriebs-Mitarbeiter von Unternehmen verfolgen verständlicher weise das Ziel, die Produkte des eigenen Hauses anzupreisen und zu verkaufen. Insofern kann ein Mitarbeiter eines Herstellers nie objektiv als Berater fungieren, denn er wird immer automatische Brandmelder, eine Sprinkeranlage, Brandschutztüren oder was sein Unternehmen eben herstellt, empfehlen. Ähnlich wie der Errichter von Einbruchmeldeanlagen nicht auf die Notwendigkeit von mechanischen Schutzkomponenten hinweist (und umgekehrt), geht der Mitarbeiter einer Firma von Brandschutz-Produkten nicht auf eventuell alternative (bzw. additive) Schutzwege wie Brandlöschanlagen, Brandmeldeanlagen, Brandwände, RWA-Anlagen, organisatorische Maßnahmen wie Schulungen oder verfahrenstechnische Belange ein.

2.5 Sicherheitsberater

Ein Sicherheitsberater wird in der Regel nicht nach der HOAI bezahlt, sondern pauschal bzw. tageweise. Dies hat für das Unternehmen den Vorteil, daß die Empfehlungen des Beraters objektiv erscheinen: Wirtschaftliche Interessen stehen nicht im Vordergrund, denn das Honorar des Beraters wird nicht erhöht, wenn die von ihm vorgeschlagenen Maßnahmen realisiert werden. Aus diesem Grund kann man den Empfehlungen eines qualifizierten, vertrauensvollen Sicherheitsberaters mehr Bedeutung beimessen als jemanden, der an den Anschaffungen verdienen wird. Allzu oft wird in verschiedenen Bereichen überdimensioniert, um den Umsatz anzukurbeln (allgemeiner Hinweis, nicht auf die Branche der Brandmeldeanlagen-Errichter bezogen).

3 Praxisbeispiele

In nunmehr 13 Jahren Berufspraxis als Brandschutzingenieur gab es eine ganze Reihe von Unternehmen, bei denen die automatische Branddetektion in die eine oder andere Richtung auffällig war; ein paar dieser Fälle werden in den nachfolgenden Unterkapiteln aufgezeigt. Es sollen nicht die spektakulärsten Fälle aufgelistet werden, sondern die lehrreichsten Fälle.

3.1 Positive Erfahrungen

Bsp. 1: Ein kunststoffverarbeitendes Unternehmen hat eine massive, aber nicht geprüfte Holztür zwischen dem Lager (Ausgangs- und Fertigprodukte) und der Herstellung (Spritzmaschinen). Die Unternehmensleitung will von einem externen Sicherheitsberater eine Bestandsaufnahme mit Empfehlungen. Dieses Gutachten sagt u.a. aus: Verschiedene bauliche Maßnahmen sollen bewirken, daß Produktion, Lagerung und Verwaltung jeweils eigene Brandbereiche bilden; eine automatische Brandmeldeanlage soll dafür sorgen, daß die Geisterschicht überwacht wird; usw. Die Unternehmensleitung realisiert zuerst die Installation der Brandmeldeanlage und noch bevor die Holztür gegen eine Brandschutztür ausgetauscht werden kann, beginnt eine der Spritzgußmaschinen nachts zu brennen. Die automatisch gerufene Feuerwehr trifft rechtzeitig ein, um den Brand zu löschen und die Produktionshalle gründlich zu entrauchen. Die Holztür zum Lager hat Rauch, Wärme und Flammen ausgehalten. Der Sachschaden betrug 240.000,- DM, die Betriebsunterbrechung konnte gänzlich kompensiert werden. Ohne Brandmeldeanlage wäre der Sachschaden schnell im 7-stelligen Bereich gelegen und die Betriebsunterbrechung ebenfalls.

Bsp. 2: Ein Energieversorger hat bereits 1994 in seinen modernen Schaltschränken Objektschutzanlagen anbringen lassen; hierbei wurden offene Geräte mit einem speziellen Brandmeldersystem an der oberen Luftaustrittsöffnung überwacht und geschlossene Einheiten wurden angebohrt, um Luft aus dem Gerät zu saugen. Im Detektionsfall wird Alarm gemeldet und die jeweilige Einheit stromlos geschaltet. Bereits dreimal in den vergangenen 4 Jahren wurde somit ein Kabelbrand verhindert, noch bevor er richtig losbrennen konnte. Schuld waren jedesmal schlampig arbeitende Elektriker, die Schraubklemmen nicht fest genug angezogen hatten.

Bsp. 3: Ein großer Bahnhof wird neu konzipiert. Neben vielen technischen Fachplanern, verantwortlich für die Funktionalität des Gebäudes, wird auch ein eigener Sicherheitsberater engagiert. Aufgrund des Standes der Technik, der Gesetzgebung, der Überzeugungsarbeit des Sicherheitsberaters, aber auch aufgrund der Erfahrungen vom Düsseldorfer Flughafenbrand werden überall automatische Brandmelder installiert: In jedem Raum, unabhängig von der Bedeutung und dem geplanten Inhalt kommen die jeweils richtigen Brandmelder; in jedem Bereich eines Raums (abgehängte Decken, Doppelböden, Kabelkanal, Technikschacht, Aufzugsschacht usw.) wird ebenfalls ein Brandmelder installiert. Paralleltableaus werden es möglich machen, im Brandfall verzögerungsfrei und eindeutig den oder die auslösenden Brandmelder ausfindig zu machen.

3.2 Negative Erfahrungen

Bsp. 1: Ein Einkaufszentrum steht kurz vor der Eröffnung; ein Behörden-Kontrollbesuch ergibt, daß die vorgeschriebene Brandmeldeanlage noch nicht installiert ist und noch am selben Tag beginnt eine Firma, diese zu installieren. Eine weitere Behördenkontrolle nach 2 Tagen führt zum abhacken dieses offenen Punktes, das Einkaufszentrum darf dann auch ohne fertig installierte Anlage eröffnet werden. Kaum hat der Beamte das Gebäude verlassen, werden die Mitarbeiter des Errichters, der immer noch keine schriftliche Auftragsbestätigung erhalten hat, nach Hause geschickt. Das Einkaufscenter bleibt für viele Jahre ohne automatische Brandmeldeanlage.

Bsp. 2: Die automatische Brandmeldeanlage in einem Unternehmen, das sich auf 17 Gebäude ausdehnt, ist auf 10 Jahre geleast. Es wurde vertraglich geregelt, daß sich bei Umrüstarbeiten an der Anlage die Vertragsdauer verlängert und da ständig umgebaut wird, schiebt man die 10 Jahre Kündigungsfrist ständig vor sich her. Mittlerweile wechseln die Ansprechpartner beim Errichter mehrfach und offensichtlich aufgrund der scheinbar unendlichen, ständigen Geldquelle aufgrund des Leasingvertrags wird die Qualität der Dienstleistung immer schlechter: Falschmeldungen werden nicht behoben, Reparaturen nicht ausgeführt, längst fällige Nachrüstungen erfolgen erst nach der 4. Erinnerung und zu einem Ortstermin aufgrund ständiger Falschmeldungen kommt ein gänzlich unerfahrener Kaufmann, der weder bereit, noch willens oder fähig war, sich in die Thematik einzuarbeiten; es wird ein zweiter Termin vereinbart, bei dem dieser Mann lediglich mitteilt, man habe im Unternehmen keine Aufzeichnungen mehr über die Dokumentation der Anlage und zudem würde der Wartungsvertrag ja noch 10 Jahre laufen...

Bsp. 3: Eine 7.000 m² große Produktionshalle für elektronische Produkte wird ohne Brandwände errichtet, erhält aber eine feuerhemmende Dachtragekonstruktion; dieses Gebäude genehmigt die Behörde nur mit der Auflage, wenn die 9 m hohe Halle eine Sprinkleranlage erhält. Solide Berechnungen ergeben, daß die Sprinklerköpfe in dieser Höhe wohl kaum öffnen werden, denn die Brandlasten je m² sind einfach zu gering, der Abstand zum Sprinker ist zu groß und die Halle zu weiträumig, als daß in 9 m Höhe ein Sprinkler noch einiger maßen rechtzeitig öffnen würde. Eine automatische Brandmeldeanlage (z. B. mit sensiblen Rauchmeldern, oder mit Rauchgasansaug-Systemen an exponiert gefährdeten Stellen) wäre hier wesentlich sinnvoller – da diese aber nicht gefordert wurde, kommt sie auch nicht in das Gebäude.

4 Lehren für das eigene Unternehmen

Brandmeldeanlagen sollten prinzipiell in jedem Bereich vorhanden sein. Man kann darüber reden, ob eine kleine Tiefgarage, ein angebautes Gebäude mit unwesentlichem Inhalt (und baulicher Trennung), ein Unternehmen, bestehend aus einem einzigen, kleinen Brandbereich oder ein Verwaltungsunternehmen in gemieteten Räumlichkeiten über eine Branddetektion verfügen sollte, oder nicht. Aber in den meisten anderen Fällen sollte eine Brandmeldeanlage vorhanden sein und Lager, Produktion und Verwaltung kontrollieren.

Doch die Brandmeldeanlage soll nur als eines der wesentlichen Mosaiksteinchen des gesamten Brandschutz- bzw. Sicherheitskonzepts gesehen werden. Daneben gibt es eine Reihe von weiteren

- baulichen Brandschutzmaßnahmen (Brandwände; Brandtüren; Kabelabschottungen; Brandschutzklappen; Wandhydranten; Brandbereiche zwischen unterschiedlichen Unternehmensbereichen schaffen; brandresistente Metallschränke für wichtige Unterlagen einmauern uvm.),
- technischen Brandschutzmaßnahmen (brandgeschützte Beleuchtungsanlagen; Brandlöschanlagen; Rauch- und Wärmeabzugsanlagen; Feuerlöscher; Einbruchschutzkonzept; Blitz- und Überspannungsschutzkonzepte umsetzen; korrekte Behälter für VbF-Flüssigkeiten bereithalten uvm.) und
- organisatorischen Brandschutzmaßnahmen (brandgeschützte Abfallbehälter; sicherheitsgerechte Müllentsorgung und –lagerung; Schulungen; Regelung zu privaten Elektrogeräten; Erlaubnisschein für feuergefährliche Arbeiten; Revision der elektrotechnischen Anlage; Begehung mit der Feuerwehr; Versicherungsschutz korrekt abschließen uvm.),die zum umfassenden, hohen Schutz des Unternehmens beitragen.

Die Brandmeldeanlage soll verzögerungsfrei zur Feuerwehr geschaltet sein – 24 Stunden am Tag, 7 Tage die Woche. Man soll darauf achten, daß jeweils die richtigen Brandmelder installiert sind; richtig heißt, daß es erstens keine Falschmeldungen gibt und zweitens im Gefahrfall dennoch rechtzeitig Alarm gemeldet wird. Die großen, soliden Hersteller von Brandmeldern und Zentralen haben hier in den letzten Jahren erhebliche Fortschritte gemacht: Die neuen Meldergenerationen, ausgestattet mit elektronischen Zentralen, die alle Vorteile der Computertechnik ausschöpfen, detektieren nicht nur wesentlich schneller als die Systeme von 1995 und davor, sie sind auch gleichzeitig weniger störanfällig, überwachen sich selbst, verfügen über eine bestimmte „Intelligenz“ und bringen somit wesentlich weniger Falschmeldungen.

Automatische Brandmelder sind prinzipiell konkurrenzlos. Weder bauliche Maßnahmen, noch organisatorische Schritte oder andere technische Sicherheits-Einrichtungen können automatische Brandmelder ersetzen. Auch Brandlöschanlagen (automatische oder manuelle) der unterschiedlichen Systeme sind meist additiv und nur selten alternativ zu einer automatischen Brandmeldeanlage zu sehen.

5 Kosten der Technik

Natürlich ist es nicht möglich, mit einigen wenigen Zahlen alle Fälle abzuhandeln und konkret über die Kosten von Brandmeldeanlagen zu sprechen. Dennoch sollen ein paar Zahlen ein Gefühl, einen Daumenwert geben: Die Planung kostet ca. 5 – 8 % der Nettogerätekosten; Ingenieur-Planungsbüros können auch nach der HOAI abrechnen. Die Kosten für die Zentralen beginnen bei 1.500,- DM, große Anlagen können 10.000,- DM erreichen und überschreiten: Es gibt modulfähige Zentralen, an die weitere Unterzentralen bzw. Speichereinheiten und andere Geräte angeschlossen werden können, diese Anlagen können dann schnell auch 10.000,- DM Anschaffungskosten übersteigen. Je nach Unternehmensgröße kann man als Daumenwert eine Summe von 3,- bis 5,- DM/m² kalkulieren für die gesamte Brandmeldeanlage; bei flächenmäßig besonders kleinen Unternehmen ist der Wert verständlicherweise größer. Die Kostenangabe für die Installation macht nur Sinn, wenn eine gesamte Anlage betrachtet wird. Man kann mit Installations- und Anschlußkosten von 1,50 – 3,50 DM/m² rechnen. Für Inspektionen und Wartungen fallen Kosten von 3 – 5 % der Nettogeräte an. Die Prüfung und Abnahme ist abhängig von der Institution (Versicherung, Baubehörde, TÜV, o. a.), welche die Auflage der Installation der Anlage gemacht hat. Abhängig von der Größe der Anlage können hierfür Kosten von 1.200,- bis 3.000,- DM entstehen.

6 Schlußworte und Aussicht

Die Erfahrung zeigt immer wieder, daß Menschen erst nach Schäden handeln und nur selten vorher; dies gilt ganz allgemein für viele Bereiche des privaten und beruflichen Lebens, aber auch für den speziellen Bereich des Brandschutzes und hier auch für die Installation einer Brandmeldeanlage. Scheinargumente werden von sicherheitstechnischen Laien herangezogen, um die Investition zu umgehen, unabhängig von dem Stand der Technik, von möglichen wirtschaftlichen und persönlichen Folgen. In Zeiten des härteren Wettbewerbs, der geringeren Gewinnspannen und der allgemeinen Rückführung der betrieblichen Kosten fallen unproduktive Dinge wie der gesamte Bereich der Sicherheitstechnik nur allzu oft dem Rotstift zum Opfer. Kaufleute, primär die externen Unternehmensberater können schnell nachweisen, wie viel man jedes Jahr an Geld einspart und wenn die letzten 30 Jahre kein Schaden eingetroffen ist, so wird die jährliche Summe einfach mit 30 multipliziert, die Verzinsung aufgerechnet und der unbedarfte Laie staunt, wenn er sieht, daß man 15 und mehr Mio. DM scheinbar (nicht jedoch anscheinend) vergebens ausgegeben hat. Doch all diese „Rechenkünstler" vergessen nicht nur die existenziell wichtige wirtschaftliche Seite der Sicherheitstechnik, sondern auch die gesellschaftliche und die humanitäre. Und jeder dieser Personen wird, auch wenn bereits mehre 100.000 km unfallfreie Autofahrt hinter ihnen liegt, dennoch jedesmal wieder den Gurt anlegen – nur im Unternehmen wird der Gurt, sprich: die Brandmeldeanlage, weggelassen.

Der Trend in unserer Gesellschaft geht jedoch eindeutig zu einer geringeren Akzeptanz für Schäden und Bedrohungen jeglicher Art und dies insbesonder dann, wenn man ihnen unfreiwillig ausgesetzt ist und demzufolge werden auch Brandschutzmaßnahmen wie Brandmeldeanlagen, Brandlöschanlagen und weitere Techniken vermehrt in den beruflichen, öffentlichen und privaten Bereichen Einzug finden.

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Brandmeldeanlagen aus der Erfahrung eines Brandschutz-Fachingenieurs bzw. der industriellen Feuerversicherung

Abstract

Fire alarm systems: seen through the eyes of an fire protection specialist

The use of micro electronics lead to very complex and sensitive fire alarm systems (FAS). This sensitivity served to minimise the time of response, however it was not possible yet to solve the problem of false alarm. For the decision whether or not to install an automatic FAS, it's efficiency from the financial point of view must be proven by a cost-benefit or a cost-damage analysis.

FAS are not fire fighting devices. They do not prevent smoke emission and smoke spread. They are part of a whole system and only contribute to a better fire protection when

- **it detects a fire reliably,**
- **it detects a fire significantly earlier then people at the place**
- **and when the time saved can be used to more efficient fire fighting and reduction of injurious smoke emissions.**

Finaly it's the whole concept that counts. The concept should make the race, which helps to extinguish a fire as fast as possible. A FAS can be one element of such a concept and should be designed to serve the principle purpose: to reduce damage and the quantity of smoke.

Einleitung

Bei Brandmeldeanlagen hat der Einsatz von moderner Mikroelektronik zu sehr komplexen und z.T. empfindlichen Anlagen geführt. Diese Empfindlichkeit hat einerseits zu weiteren Verkürzungen der Ansprechzeiten geführt, aber das Problem der Falschalarme bisher nicht lösen können. Diese Alarme untergraben immer mehr die Arbeitsfähigkeit und Motivation der Feuerwehren. Die Entschei-

dung über eine automatische Brandmeldeanlagen kann zudem nur dann sachgerecht geführt werden, wenn über eine Kosten-Nutzen- oder eine Kosten-Schaden-Analyse ihre Effektivität nachgewiesen wird.
Brandmeldeanlagen selber beinhalten keine Brandbekämpfung und verhindern keine Rauchfreisetzung, sondern sind Teil eines Gesamtsystems und können nur dann als Verbesserung des Brandschutzes in der gesamten Ablaufkette eines Brandes von der Entstehung bis zur erfolgreichen Bekämpfung gesehen werden, wenn durch die Brandmeldeanlage

- **ein Brand zuverlässig erkannt wird,**
- **ein Brand wesentlich früher als durch Anwesende erkannt wird**
- **und dieser Zeitvorteil sich in der Brandbekämpfung bzw. in der Vermeidung von schädlichen Emissionen als wesentlich erweist.**

Letztlich ist es entscheidend, welches Konzept aus den verschiedenen Brandschutzeinrichtungen die schnelle Brandlöschung erreicht und damit einen Schaden und die Rauchmenge reduziert. Brandmeldesysteme sind daher innerhalb eines Brandschutzkonzeptes schutzzielorientiert einzusetzen.

1 Begriffe und Statistik

Ich werde mich hier nicht an den Diskussionen über Fehl- bzw. Falschalarmen beteiligen, mit der vielfach versucht wird, die Schuld an Fehl- bzw. falschen Alarmen auf Dritte zu schieben, sondern will in diesem Zusammenhang alle Alarme wie in der DIN VDE als Falschalarme betrachten, bei denen die Feuerwehr durch die Brandmeldeanlage gerufen wurde, ohne das ein Brand ausgebrochen ist.

⇒ Statistik

Aus der Statistik der Feuerversicherer zu den Hauptgründen für den Schadenumfang bei Millionenschäden ist v.a. bemerkenswert, daß das Versagen von Brandschutzanlagen keine Rolle spielt (< 2 %).

Andererseits darf ich Fritzen zitieren, der für 1991 im Bereich der Stadt Köln bei 495 Brandmeldeanlagen ermittelt hat:

- 16 echte Alarme = 1 Alarm pro 28 Anlagen oder 3,5 %
- 78 böswillige bzw. 208 sonstige Falschalarme = 17,3 % bzw. 46,2 %

Bei insgesamt 302 Alarmen liegt der Anteil der Echt- zu Falschalarmen bei 1 zu 18. Zu diesem Verhältnis zwischen Echt- zu Falschalarmen braucht ja wohl kaum noch etwas gesagt zu werden (stellen Sie sich vor, von 19 Versuchen würde ihr Auto nur einmal anspringen?).

Ich darf aus einer weiteren Untersuchung zitieren (Voruntersuchung Kiefer zur Diplomarbeit Piel 1996/1997): bei den 35 Druckknopfbrandmeldungen in Bergisch Gladbach lag nicht ein einziger echter Alarm vor, überwiegend waren es böswillige Alarme, jedoch auch Alarme durch nicht gewollte Beschädigung von Druckknopfmeldern in Schulen.

⇒ Können wir uns diese Falschalarmzahl noch leisten?

Müssen Druckknopfbrandmelder in Schulen und ähnlichen Objekten sein? Beziehungsweise anders gefragt: Überwiegt das Risiko der Falschalarm-Bearbeitung bei solchen Meldeanlagen nicht dem Risiko eines vielleicht echten Alarms jenseits der 1 zu 35?

⇒ Gründe für Falsch- und Fehlalarme

In verschiedenen, auch eigenen Untersuchungen wurde eine ganze Palette von wesentlichen Ursachen für Falschalarme ermittelt:

- Böswilligkeit und Unfug, meist an Druckknopfmeldeanlagen; fahrlässige Alarmierungen
- Planungsfehler: ungeeignete Melder und Meldungsverarbeitung
- Fehler bei Bedienung, Revision und Kontrolle der Anlagen, Störungen aus dem Betrieb sowie Arbeiten der Post bzw. Telekom AG
- technische Defekte und Beschädigungen.

2 Schutzziele und Brandschutz-Konzept

Für das Risk Management ist eine Definition der erforderlichen Schutzziele notwendig, deren Festschreibung sich aus der Bewertung

- möglicher Gefahren für Leib und Leben
- betrieblicher Aspekte (Image, Kosten-Nutzen-Optimierung)
- risikotechnischer und versicherungstechnischer Aspekte

ergeben sollte.

Im Hinblick auf drohende Personenschäden sowie zur Minimierung des wirtschaftlichen Schadens gelten folgende Schutzziele:

1. **Personenschutz**
2. **Minimierung der Brand- und Brandfolgeschäden**
3. **Umweltschutz**
4. **Schutz der wirtschaftlichen bzw. finanziellen Interessen**

Wesentliche Schritte bei der Aufstellung eines maßgeschneiderten Schutzkonzeptes sind

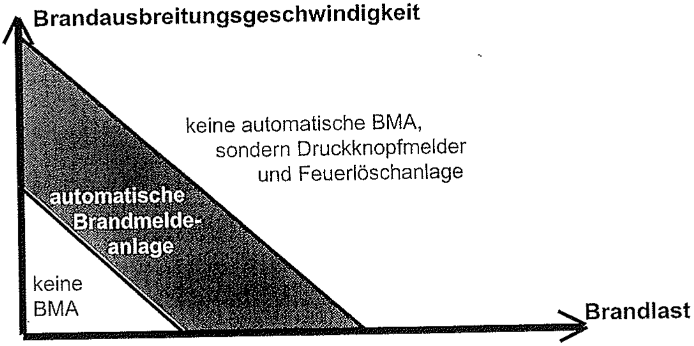
- Feststellung und Beschreibung des Gefahrenpotentials und der Schutzziele
- Beschreibung möglicher und wahrscheinlicher Auswirkungen von Schäden
- Bewertung einzelner Schutzmaßnahmen (incl. negativer Nebenwirkungen) sowie
- eine optimierte Zusammenstellung geeigneter Schutzmaßnahmen

In diesem Zusammenhang stellt sich die wesentliche Frage, wann eine Brandmeldeanlage gefordert wird bzw. wann nicht? Wann ist eine Brandmeldeanlage (automatisch oder manuell ausgelöst) bei den erwarteten Brandszenarien und innerhalb des gewünschten Brandschutzkonzeptes sinnvoll bzw. wann kann sie die in der Einleitung genannten wesentlichen Ziele der Brandmeldeanlagen erreichen. Einerseits sind z.B. in einem

- „brandlastfreien" Betrieb (mobile und immobile Brandlast = null, z.B. einem Stahllager in einem nicht brennbaren Gebäude) andererseits

- in einem hoch branddynamischen Betrieb (z.B. Schaumstoff- oder Recyclingbetrieb)

automatische Brandmeldeanlagen nicht sinnvoll.



Schematische Darstellung zur Notwendigkeit von Brandmeldeanlagen in Abhängigkeit von Brandlast und Brandausbreitung

Im allgemeinen entscheiden die ersten 10-15 Minuten eines beginnenden Brandes und die dann vorliegende Brandfläche darüber, ob er schnell gelöscht und der Brandschaden begrenzt gehalten wird oder der Brand nicht mehr zu stoppen ist.

3 Zukunftsanforderungen an Brandmeldeanlagen

⇒ **Welche Brandmeldeanlage muß wann eingesetzt werden? Brauchen wir Brandmeldeanlagen, die mit jeder Sekunde geizen?**

Oder:

⇒ **Können wir uns Brandmeldeanlagen mit den beschriebenen Falschalarmquoten leisten?**

Um die Falschalarme auf Dauer kräftig zu reduzieren, sind die Brand- und Falschalarmfälle zu analysieren, dazu ist eine wesentlich verbesserte Erfassung und Dokumentation notwendig.

Im folgenden sollen zukünftige Entwicklungsnotwendigkeiten dargestellt werden:

3.1 Organisatorische Maßnahmen zur Falschalarmbekämpfung

Die Zahl der Falschalarme kann von vornherein gering gehalten werden, wenn folgende organisatorische Maßnahmen und Voraussetzungen erfüllt werden:

- ausschließliche Verwendung ausgereifter und herstellerunabhängig geprüfter Techniken mit VdS-Anerkennung
- Planung, Errichtung und Wartung der Technik erfolgt nach den aktuellen technischen Regelwerken (VDE und VdS) durch Fachleute mit nachgewiesener Fachkunde, d.h. VdS-Anerkennung der Errichterfirma, jedoch mit verbesserter Planungsausbildung
- Die Anforderungen an Installationsfirmen müssen erhöht werden: hierzu gehört, daß Installationsatteste nicht nur auf Aufforderung erstellt werden und die Brandmeldefirmen verpflichtet werden, bei drohenden Falschalarmen den künftigen Betreiber ausdrücklich zu warnen.
- Die Anforderungen an Betreiber sollten, z.B. auch durch entsprechende Anschlußbedingungen der Feuerwehr und durch eine hinreichende Ausbildung erhöht werden.
- Bei Häufung von Falschalarmen durch Brandmeldeanlagen sollte die Feuerwehr auf den Betreiber zugehen, um mit ihm (u.U. mit Hilfe eines Sachverständigen) eine Reduzierung der Falschalarme zu erreichen.
- Auch die Feuerwehr bzw. Brandschutzdienststelle müßte hinsichtlich der Techniken und der Organisation von BMA besser informiert werden.

⇒ Planungsprüfung und Dokumentation

Es empfiehlt sich, eine Planungsprüfung mit Hilfe der Dokumentation "Was passiert, wenn ....?" im Sinne des Betriebshandbuches und eine Abschalt-, Maßnahmen- sowie Meldungsmatrix durchzuführen.

3.2 Technische Maßnahmen zur Falschalarmvermeidung

⇒ Grundanforderungen an die Auswahl von Brandmeldern

Innerhalb des notwendigen Brandschutzkonzeptes (aus baurechtlicher bzw. betriebswirtschaftlicher Sicht) müssen alle Brandszenarien durch die Meldeanlagen weitgehend abgedeckt werden. Wenn nicht alle Brände erkannt oder zu langsam erkannt werden, sind primär die Brandarten für die Branderkennung auszuwählen, die potentiell ein großes Schadenvolumen auslösen können, also die schnell verlaufenden Brände und die, die zur größeren Bildung giftiger und korrosiver Rauchgasmengen neigen. Das heißt im Regelfall, daß langsame Schwel- und Glimmbrände nicht zur Grundlage des Brandmeldesystems innerhalb des Brandschutzkonzept ausgewählt werden sollten.

Bei der Auswahl von Brandmeldern sind neben den möglichen Brandszenarien die Falschalarmmöglichkeiten und ihre jeweiligen Wahrscheinlichkeiten zu beachten. Brandszenarien und ihre Wahrscheinlichkeiten können nach den voraussichtlichen Brandprodukten (Rauch, Temperatur, Flammen etc.) definiert und ausgewählt werden.
Falschalarmmöglichkeiten durch Täuschung und Böswilligkeit sind besonders zu beachten, vorrangig solche, die planerisch und technisch vermeidbar sind. Der ausgewählte Meldertyp ist auf mögliche Falschalarme zu untersuchen.

⇒ Weitere technische Maßnahmen

Aus meiner Sicht müssen erhebliche technische Maßnahmen zur Verbesserung der Zuverlässigkeit von Brandmeldeanlagen getroffen werden, z. B.

- Erhöhung der Ansprechschwellen von Rauchmeldern: Multisensortechnik, Alarmverzögerung und Alarmzwischenspeicherung mit Alarmprüfung
- zusätzliche Überprüfung des Eingangssignals auf Relevanz, z.B. durch DUO-Schaltung mit 2-Melder- oder 2-Linienabhängigkeit, Fuzzy-Logik, neuronale Netze
- Ausnutzen von Summationseffekten bei linearen optischen Meldeanlagen,

Rauchabsauganlagen und linearen thermischen Brandmeldeanlagen
- striktere Regeln für das Ausschließen von Falschalarmen durch betriebsbedingte Umstände oder dergleichen
- für Melder oder andere elektronische Bauteile: EMV-Verträglichkeit erhöhen.

⇒ **Fazit:**

Ein langsames Ansprechverhalten ist dann vorzuziehen, wenn es mit einer hohen Falschalarmsicherheit verbunden ist.

3.3 Technische Richtlinien zur Falschalarmbekämpfung

Nach meiner Überzeugung werden auch durch die technischen Richtlinien des VdS bzw. VDE Falschalarme und Kostensteigerungen (siehe Kap. 4) begünstigt. In erster Linie ist eine Orientierung der Richtlinien an den Schutzzielen erforderlich: **relevant ist die Festlegung des Zieles, nicht des Weges:**

Ist der weitgehend generelle Einsatz von Rauchmeldern sinnvoll? Gerade in kleineren Räumen ist der Einsatz von Thermodifferenzial-Maximalmeldern sowohl hinsichtlich der Falschalarmsicherheit als auch hinsichtlich der Auslösegeschwindigkeit völlig ausreichend. Einerseits sind Wärmemelder unempfindlicher gegen Falschalarme. Andererseits ist die Wärmeentwicklung im Deckenbereich nahezu genauso schnell wie die Rauchausbreitung, da der Wärmetransport konvektiv an den Rauch gebunden ist.
Weitere Fragen stellen sich:
- müssen Druckknopfmeldeanlagen im Bereich automatischer Brandmeldeanlagen installiert oder können auch amtsberechtigte Telefone hierfür eingesetzt werden?
- Müssen so viele Bedienungsoptionen sein, warum gibt es für die Programmierung nicht eine Standardschnittstelle zu einem PC statt der komplizierten Menueprogramme, dadurch wäre eine viel bildhaftere Darstellung und fehlerfreiere Programmierung möglich
- Die Begrenzung der Zahl der Melder je Gruppe oder dergleichen halte ich

nicht für sinnvoll, wenn überhaupt müßte die Grobstrukturierung einer Brandmeldeanlage brandabschnittsmäßig gestaltet sein. Zur Identifikation des Meldeortes sind mittlerweile viele Techniken, die eine Begrenzung je Meldeschleife nicht mehr erforderlich machen.

Es sollten keine Sonderregelungen der Feuerwehren oder Brandschutzdienststellen durch örtliche Anschlußbedingungen festgeschrieben werden, die den Zielen aus den VDE-/VdS-Richtlinien bezüglich der Falschalarmvermeidung widersprechen. Die Feuerwehren sollten in ihren Anschlußbedingungen, die Bestandteil der VDE-/VdS-Regeln sein sollten, nur Forderungen stellen, die zur Einsatztaktik und zum technischen Anschluß an die Leitstellen erforderlich sind.

Die Bindung an die VDE- bzw. VdS-Richtlinien muß trotzdem bei der Ausschreibung von Brandmeldeanlagen verstärkt werden, jedoch sollte die Festlegung der Überwachungsfläche abhängig vom **Schutzziel** erfolgen.

Nach den VdS bzw. VDE-Richtlinien sind Kabelkanäle und Kabelschächte eine zulässige Ausnahme von der automatischen Überwachung. Gerade unter den Gesichtspunkten des Betriebsunterbrechungsschutzes, d.h. des Schutzes der besonders wichtigen Engpässe innerhalb eines Unternehmens ist diese Ausnahme schwer verständlich, denn Kabelkanäle und –schächte können mit zu den wichtigsten Verbindungssystemen innerhalb einer Firma gehören.

4 Kostenfragen und Wirtschaftlichkeit

Die Investitionen für Brandmeldeanlagen setzen sich aus den Kosten für die überwachten Flächen (abhängig von der Raumhöhe) und der Zentrale mit Alarmweiterleitungseinrichtungen zusammen. Diese Kosten sind u.a. abhängig

- von der Art des Melders, z.B. Punkt- oder Flächenmelder
- vom Leitungsnetz (Farbe?, E 30 nach DIN 4102 nur in nicht überwachten Bereichen) bzw. Funksysteme insbesondere bei Altbauinstallationen
- von der Zentrale/Notstromversorgung: 72 Stunden? Wann hat es einen

Stromausfall von mehr als 6 Stunden gegeben?

- gibt es überhaupt noch die alte Stand- bzw. Primärleitung und kann ein Funk- bzw. GSM-Netz die gleiche Funktion übernehmen?
- weitere Forderungen aus den Richtlinien, z.B. die Abtrennung zwischen überwachten und nicht überwachten Bereichen durch eine Brandwand, sind kontraproduktiv und äußerst kostensteigernd.

Je nach Einzelfall können Brandmeldeanlagen kostensparender als Insellösung oder als Teil anderer möglicher Gefahrenmeldeanlagen geplant, installiert und betrieben werden.

Laufende Kosten für Wartung, Revision, Kontrollen, Prüfung, Falschalarm und Alarmweiterleitung sind im Laufe eines BMA-Lebens im allgemeinen weit höher als die Investionskosten und insofern von höherer Entscheidungsrelevanz.
Die Versicherer räumen einer flächendeckenden Überwachung mit einer automatischen Brandmeldeanlage (BMA) einen hohen Stellenwert bei Tarifierung und Vertragsgestaltung ein. Bewußt ist jedoch immer mehr Feuerversicherern, daß die Rabatte für BMA nicht ihrem Schadenminderungspotential entsprechen. Voraussetzung für die Anerkennung durch den Versicherer und die Rabattgewährung ist, daß die Anlagen nach den VdS-Richtlinien für Brandmeldeanlagen, unter Verwendung VdS-anerkannter Komponenten geplant und eingebaut werden und bei DUO-Anlagen eine Abnahme durch den VdS erfolgt.

Es sollte grundsätzlich von den Installationsfirmen gefordert werden, daß alle Kosten vollständig dargestellt werden, neben den vollständigen Installationskosten und den Dokumentationskosten auch die Folgekosten über den entsprechenden Lebenszeitraum sowie die Kosten bei Falschalarmen. Die Kosten eines Feuerwehreinsatzes beim Meldealarm (standardmäßig wird hierzu ein Löschzug der Feuerwehr mit bis zu 4 Fahrzeugen und bis zu 18 Feuerwehrangehörigen alarmiert) liegen bei ca. DM 2.000,--.
Hierzu eine Anmerkung: Maßgeblich kann z.B. das Angebot einer Installationsfirma für den Schweizer Markt sein, bei selbstprojektierten, -installierten und -

gewarteten Brandmeldeanlagen eine 3-jährige Garantie auf Fehlalarmfreiheit zu geben.

5 Zusammenfassung und Schlußbemerkung - Resümee

Zur Durchführung wirksamer Schadenbekämpfung, sprich Löscharbeiten und der Sicherstellung des Personenschutzes ist die frühzeitige Branderkennung und Alarmweiterleitung an die Hilfskräfte zwingend erforderlich. Daher sind flächendeckende Meldeanlagen bei den relevanten Brandszenarien unbedingt erforderlich, jedoch nur, wenn die Brandmeldeanlagen innerhalb des Schutzkonzeptes ausreichend wirksam und das Problem der Falschalarme gelöst wird.
Nur, was ist vorrangig:

- Zuverlässigkeit vor Schnelligkeit?
- Falsch- zu Echtalarmen mindestens 1 zu 1!
- preiswert statt maximaler Komfort – Investitionen/laufende Kosten!

Ist es wirklich notwendig, daß eine Brandmeldeanlage mit jeder Sekunde geizt?
Ziel muß es sein, die Falschalarmquote innerhalb der nächsten 10 Jahre drastisch zu senken!

Erfahrungen mit Brandmeldeanlagen, Statistiken und Schadenanalysen haben dazu geführt, daß die Akzeptanz sowohl auf der gesetzlichen als auch auf der Industrieseite soweit gestiegen ist, daß sehr viele Fachleute heute ein Brandschutzkonzept für gewerbliche und öffentliche Objekte (Gebäude besonderer Art oder Nutzung) ohne mindestens eine automatische Branderkennung und Alarmweiterleitung nicht mehr akzeptieren wollen.

Die Entscheidung für eine automatische Branderkennung kann jedoch nur dann sachgerecht geführt werden, wenn die in der Einleitung genannten Bedingungen erfüllt werden. Letztlich ist es entscheidend, welches Konzept aus den verschiedenen Brandschutzeinrichtungen die schnelle Brandlöschung erreicht und damit den Schaden reduziert.

Schrifttum/Literatur

Schrifttum/Literatur

Fritzen, Benno: Brandmeldeanlagen: Reduzierung von Fehlalarmen; Zeitschrift Brandschutz 4/93, Seite 289ff

Verband der Schadenversicherer VdS e.V.: Millionenschadenstatistik in der industriellen Feuerversicherung; Köln, 1989 bis 1995

Hinweis: Eine ausführlichere Version dieses Aufsatzes ist verfügbar
a more detailed version of the paper is available
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Compatibilité électromagnétiques des installations de détection incendie

Abstract

Since 1996, the CE mark requires, for electrical and/or electronic devices to fulfil the minimum requirements of electromagnetic immunity and emission. These requirements from the European directive 89/336/CEE are described in generic standards or, in the case of security electronic systems , in a product family standard (EN 50 130-4). However it can be possible that an electromagnetic glitch perturbs the fire detection system.

My lecture consists in explaining the electromagnetic requirements for a fire detection system and to analyse the good adequacy to the environmental conditions in which they are installed. I'll give then, an investigation method in the case of the search of an electromagnetic glitch. The purpose of this method is to determine the nature, the identification of the glitch, the search of its source and the possible solutions which have to be brought to eliminate the failure.

Introduction

Une installation de détection incendie peut se situer dans des environnements électromagnétiques très différents. Les produits qui vont composer le système sont marqués « CE », et ont normalement déjà subi des essais d'immunité aux parasites électromagnétiques. Les exigences en matière de compatibilité électromagnétique, sont elles suffisantes pour garantir le bon fonctionnement du système dans son environnement ?. Du fait, qu'à l'heure actuelle, il y a encore beaucoup de dysfonctionnements qui ont pour origine des parasites électromagnétiques, nous serions tentés de répondre à cette question négativement. Dans ce cas, serait-il raisonnable de durcir les sévérités d'essais pour l'immunité aux parasites électromagnétiques ?. Il est clair que les exigences d'immunité pour les produits qui sont proposés dans le cadre de la directive CEM ont pour objectif d'éliminer la majeure partie des dysfonctionnements en fonction de son environnement d'utilisation. Les normes génériques référencées par les textes de la directive CEM définissent deux types d'environnement : l'environnement domestique, commercial et industries légères et l'environnement industriel. Il est ensuite possible, si on est capable de mieux modéliser l'environnement électromagnétique d'un produit, de créer une norme harmonisée, appelée norme famille de produits. C'est le cas, en ce qui concerne les matériels électroniques de sécurité (et donc a fortiori des systèmes de détection d'incendie) avec la norme européenne EN 50 130-4, où les exigences d'immunité aux parasites ont été adaptées à l'utilisation de ces systèmes.

On peut néanmoins affirmer que les équipements peuvent être exposés, dans certaines installations à des parasites électromagnétiques beaucoup plus puissants que ceux auxquels ils sont soumis lors des essais d'immunité dans le cadre de leur conformité à la directive (nous verrons dans la suite de cet exposé comment ceci est possible). Ceci signifie qu'un appareil satisfaisant entièrement aux exigences de la directive CEM puisse encore avoir des dysfonctionnements dont l'origine est justement un parasite électromagnétique.

Afin de mieux cerner les problèmes de compatibilité électromagnétique dans les installations de détection incendie, nous allons recenser les différents types de parasites électromagnétiques et étudier respectivement leurs modes de couplages. Nous étudierons ensuite quels sont les moyens de détecter sur site, la présence ou non de parasites électromagnétiques, ainsi que leurs identifications et leurs provenances. Enfin, afin de solutionner un dysfonctionnement dû à un parasite, nous verrons qu'il y a principalement deux solutions qui s'offrent à nous : l'élimination du parasite à sa source, ce qui dans certains cas peut représenter une grande difficulté, et on pourra, alors préférer la méthode du durcissement du produit concerné vis à vis de ce parasite.

LES DIFFERENTS TYPES DE PARASITES ELECTROMAGNETIQUES :

On va, dans un premier temps essayer de caractériser le parasite électromagnétique en définissant trois paramètres :

- **sa fréquence** : est il composé de basses fréquences ou de hautes fréquences ?,

- **son mode de propagation** : est il conduit ou rayonné, et
- **sa présence** : est il transitoire ou permanent ?.

La détermination de ces trois paramètres vont permettre de mieux cerner la nature du parasite considéré en donnant des informations sur sa source et donc sur les méthodes à utiliser pour sa complète identification.

Afin de mieux comprendre ces phénomènes, nous allons nous intéresser aux différents types de couplage

Le couplage par rayonnement électromagnétique :

Comment une onde électromagnétique peut elle influencer le fonctionnement d'un appareil ?. La réponse est en partie contenue dans l'explication du fonctionnement d'une antenne. Prenons par exemple un tronçon de câble électrique, ce tronçon peut être schématisé comme nous le montre la figure 1.

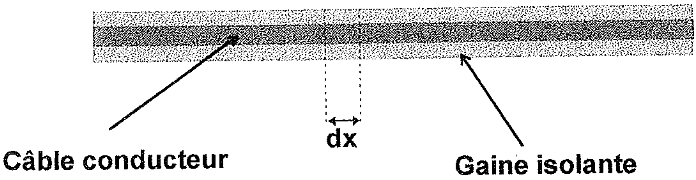

Figure 1 : représentation d'un tronçon de câble électrique

Il n'existe pas encore de conducteur électrique parfait, cela signifie que chaque conducteur va posséder une impédance intrinsèque. Dans le cas d'un câble, on parlera d'impédance linéique qui va représenter une valeur d'impédance par unité de longueur (on parlera de résistance linéique, d'inductance linéique, de capacité linéique et de conductance linéique). Si on s'attache à modéliser le tronçon de câble représenté en figure 1, il faudrait le diviser en parties élémentaires de longueur dx, pour lesquelles on peut affecter les valeurs élémentaires d'impédance (**r** pour la résistance, ℓ pour l'inductance, **c** pour la capacité et **g** pour la conductance). Ces parties vont être mises en série pour reconstituer le tronçon de câble.

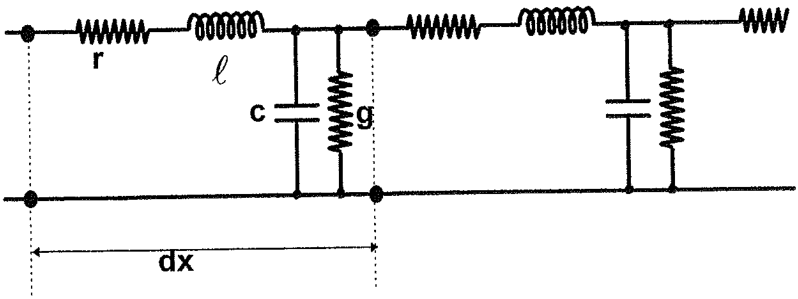

Figure 2 : modélisation électrique d'un tronçon de câble

En considérant que la tension à l'entrée de dx est **v** et que le courant qui y circule est **i** et en appliquant la loi d'Ohm généralisée, on obtient deux équations que l'on nomme équations du télégraphistes :

$$\frac{\partial^2 v}{\partial x^2} = \ell c \frac{\partial^2 v}{\partial t^2} + (\ell g + rc)\frac{\partial v}{\partial t} + rgv$$

$$\frac{\partial^2 i}{\partial x^2} = \ell c \frac{\partial^2 i}{\partial t^2} + (\ell g + rc)\frac{\partial i}{\partial t} + rgi$$

En considérant que le tronçon de câble est alimenté par une tension sinusoïdale de forme v = v(x)cos(ωt), alors la résolution des équations devient immédiate et on trouve une valeur d'impédance caractéristique qui peut être représentée selon la courbe donnée en fonction de la longueur d'onde à la figure 3. La représentation de l'impédance, donnée par la courbe de la figure 3 correspond, en fait, à la possibilité pour un brin de fil d'avoir plus ou moins de facilité à bien pouvoir capter un signal à une fréquence donnée. En fait, une onde arrivant à proximité de ce brin de câble, verra un circuit électronique dont l'impédance d'entrée sera proportionnelle au ratio entre la longueur du brin de câble et la longueur d'onde de l'onde. Dans ce cas, si la longueur du brin correspond au quart de la longueur d'onde de l'onde, l'impédance d'entrée du câble vue par l'onde est nulle, le brin de câble est alors considéré comme un court circuit par l'onde et véhiculera une partie de son énergie, on a alors affaire à une antenne.

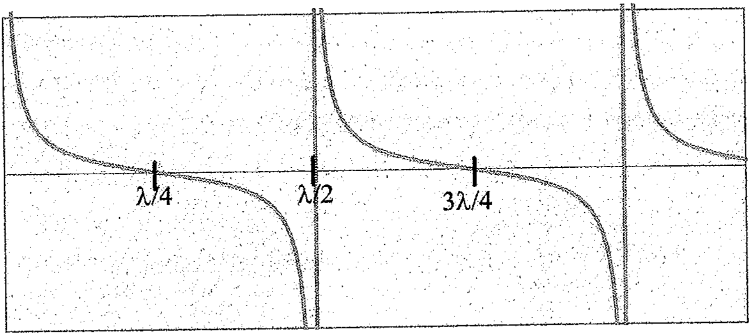

Figure n°3 : Impédance d'une ligne ouverte en fonction de sa longueur

Ce qui s'applique pour un tronçon de câble, va s'appliquer aussi à une piste en cuivre d'un circuit électronique. On peut donc imaginer que, pour un câble ou une piste électronique, en fonction des impédances qui seront connectées en amont et en aval, certains signaux à des fréquences bien déterminées pourront s'engouffrer dans ce câble, ou dans cette piste. Le matériel n'est pas prévu à la base pour traiter ces types de signaux, il va donc falloir les filtrer ou travailler l'électronique du système afin de les éviter au moment du traitement. Bien souvent, les moyens qui sont mis en œuvre pour éliminer ce type de signal au niveau de l'électronique va être dimensionner afin de respecter les exigences d'immunité au champ électromagnétique rayonné ou induit (en général d'après les CEI 1000-4-3 et CEI 1000-4-6). Il est cependant possible, sur certaines installations de rencontrer des parasites ayant des niveaux plus importants que ceux prévus par ces normes, ces parasites seront susceptibles de perturber le matériel installé. Si cela est le cas, il va falloir prendre des dispositions complémentaires, que nous aborderons dans la suite de cet exposé.

Le couplage par conduction :

Il existe d'autres moyens, pour un parasite électromagnétique de s'introduire dans les circuits électroniques d'un appareil, notamment par couplage inductif.

Un phénomène a été mis en évidence au XIX^{ème} siècle par BIOT et SAVART, puis par AMPERE. Ce phénomène est le suivant : un courant électrique parcourant un conducteur électrique va créer un champ magnétique dans l'espace environnant le conducteur. De même, un conducteur électrique se trouvant dans un champ magnétique, va se voir parcourir par un courant électrique que l'on appellera courant induit (voir figure n°4).

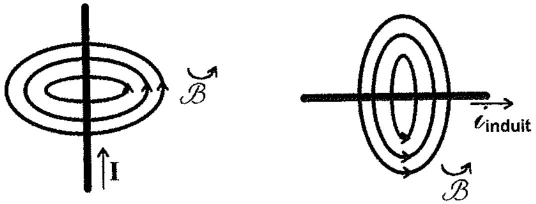

Figure n°4 : Principe d'Ampère : création d'un champ magnétique par un conducteur parcouru par un courant électrique et induction d'un courant électrique pour un conducteur placé dans un champ magnétique.

A partir de ce phénomène, on peut s'imaginer ce qui arriverait, lorsque l'on a deux conducteurs électriques (soit deux pistes sur une carte électronique, soit deux câbles) se jouxtant., Si sur un des conducteurs on a , par exemple un signal numérique qui circule à une certaine fréquence, on va retrouver aux environs de ce conducteur un champ magnétique dont l'intensité sera directement proportionnelle à l'intensité du courant électrique qui y circule. On va retrouver alors, sur l'autre conducteur un courant induit, proportionnel, celui-là, au champ magnétique dans lequel il est plongé. Ceci signifie que s'il n'y a pas de protection de style blindage au niveau des deux conducteurs, on va retrouver sur le deuxième conducteur une copie atténuée du signal qui transite sur le premier conducteur. Là encore, les normes d'immunité préconisées par les textes d'application de la directive CEM (entre autre la CEI 1000-4-4) vont exiger un certain degré de protection contre ce style de parasites, mais là encore, il se peut que dans certaines installations on rencontre ce genre de parasites à une intensité plus importante que celle prévue par les normes. Il faudra aussi, dans ces cas apporter des précautions complémentaires au niveau de l'installation que l'on développera ultérieurement.

Les perturbations conduites par le réseau d'alimentation :

D'autres types de perturbations électromagnétiques peuvent survenir par l'alimentation secteur de l'appareil. Ces perturbations sont assez nombreuses, les plus importantes sont :

- les creux de tension, coupures brèves et microcoupures,
- les coupures de longue durée,
- les surtensions,
- le flicker ou fluctuations rapides de tension,
- les harmoniques,
- les variations lentes de tension,
- les déséquilibres de tension,
- les variations de fréquence

En ce qui concerne les creux de tension, les coupures brèves et les microcoupures, les normes préconisées par la directive CEM les prennent assez bien en compte, et si l'appareil est conforme à ces normes, il ne doit pas y avoir de dysfonctionnement dû à ces phénomènes.

Dans le cas de coupures de longue durée (c'est à dire supérieures à une minute), elles ont généralement pour origine un défaut permanent interne ou externe au système et pour lequel le seul moyen d'y remédier est de résoudre ce défaut qui n'est pas intrinsèquement un problème de compatibilité électromagnétique.

En ce qui concerne les surtensions, il faut en distinguer deux types : les surtensions internes au système qui peuvent être provoquées par exemple par des commutations d'interrupteur ou de thyristors ou par la résonance d'un circuit de type LC qui auront des conséquences pouvant aller jusqu'à la destruction de circuits électroniques (en général des circuits d'alimentation). Ce type de surtension est généralement bien pris en compte au niveau du produit lors de sa mise en conformité aux normes de détection incendie. Le deuxième type de surtension est un peu plus délicat à traiter, il s'agit des surtensions lentes à haute énergie générées dans la majorité des cas par les impacts de foudre. Ces surtensions sont généralement dues à la circulation d'un courant de foudre dans le réseau ou à la création d'un courant induit par un impact de foudre ayant eu lieu à une distance pouvant aller jusqu'à 2 kilomètres. Les conséquences de ces surtensions peuvent, dans certains cas, entrainer la destruction de cartes électroniques. La directive exige que les appareils soient protégés jusqu'à un certain niveau de surtension mais les règles d'installation électrique exigent elles aussi l'installation d'équipement visant à l'absorption de ces surtensions. Ces équipements (parasurtenseurs) doivent être choisis en fonction du niveau Kéraunotique de la région (nombre moyen d'impacts de foudre par année sur la région concernée). Il se peut toutefois que des surtensions plus importantes provoquent la destruction d'une partie d'un matériel, il faudra alors envisager son remplacement ou sa réparation. Si le phénomène se reproduit un peu trop souvent, il faudra alors envisager une protection de l'équipement ou de l'installation électrique mieux adaptée.

Pour ce qui est du flicker, celui-ci survient généralement au démarrage d'appareils (tubes d'éclairage fluo ou moteurs asynchrones par exemple) nécessitant pour leur mise en œuvre d'une puissance électrique importante, cela se traduit par une chute de tension du secteur pendant cette période de démarrage pouvant aller jusqu'à 10%. Une norme visant à limiter ce phénomène va entrer en application en 2001 (EN 61000-3-3). De plus, les matériels doivent être immunisé, comme nous l'avons vu précédemment, aux variations de la tension secteur. Il sera donc très rare de rencontrer des installations en état de dysfonctionnement à cause de ce phénomène.

Les harmoniques : lorsqu'un système consomme un courant électrique non sinusoïdal, il va déformer la forme sinusoïdale de la tension du secteur. Cela va être le cas de tous les systèmes de détection incendie, dont l'alimentation des cartes électroniques se fait sous forme continue ; une transformation de la tension sinusoïdale en tension continue devant être effectuée. Les conséquences liées à la génération d'harmoniques vont essentiellement porter sur l'échauffement de câbles ou le vieillissement prématuré de certains composants comme les condensateurs par exemple.

Lorsqu'il y a une ligne d'alimentation secteur à proximité avec présence d'harmoniques, les lignes de communication peut être perturbé comme nous l'avons vu précédemment par induction et les parasites (notamment ceux générés par une alimentation à découpage) pourront gêner le traitement du signal et provoquer des signalisations intempestives. Tout comme pour le flicker, une norme va être applicable après 2001 (il s'agit de la EN 61000-3-2). Lors de la détection de ce phénomène sur un conducteur électrique, seul un filtrage adéquat pourra se montrer efficace.

Les variations lentes de tension sont les conséquences d'une modification lente de la charge se trouvant sur le réseau, les normes de CEM les prennent bien en compte.

Le déséquilibre des tensions arrive sur les alimentations secteur en triphasé, lorsqu'une ou deux phases peuvent à un moment donné être beaucoup plus chargées que les autres. Là, il n'y a que la prise en compte de ce problème lors de l'installation qui pourra résoudre ce déséquilibre.

Les variations de fréquence du réseau surviennent essentiellement lors de la mise en forme sinusoïdale de la tension réseau par une source d'alimentation secondaire comme un onduleur par exemple. Seule la mise en conformité de ce dernier solutionnera ce problème.

Les décharges électrostatiques :

L'accumulation de charges électrostatiques par le corps humain est à l'origine de ce phénomène. Lorsqu'une personne chargée électrostatiquement va se trouver suffisamment proche d'un matériel, une décharge se produit brusquement à travers l'air ou au contact de l'objet à la manière d'un condensateur qui se décharge. Une décharge électrostatique entre une personne et un matériel peut atteindre 12.000 Volts et durer quelques dizaines de nano-secondes, ce qui peut être suffisant pour endommager un composant électronique. La directive demande que les matériels soient immunisés à ce style de parasite (la norme la plus couramment utilisée est la CEI 1000-4-2), ce qui va procurer au matériel un bon degré d'immunité.

Marche à suivre dans le cas d'un problème de CEM sur une installation de détection incendie :

Nous avons mis en évidence, au début de l'exposé, 3 questions qui vont nous permettre de caractériser et de palier à un parasite. Ces questions sont :

- **sa fréquence** : est il composé de basses fréquences ou de hautes fréquences ?,
- **son mode de propagation** : est il conduit ou rayonné, et
- **sa présence** : est il transitoire ou permanent ?.

La logique d'une bonne investigation sur site est de traiter dans un ordre préférentiel : les problèmes permanents avant les problèmes aléatoires, les parasites conduits avant les parasites rayonnés, les parasites basse fréquence avant les parasites haute fréquence et enfin, les parasites de mode commun avant les parasites de mode différentiel.

Les parasites basses fréquences vont être très facilement mesurables (avec un oscilloscope par exemple). De plus si celui-ci est conduit, il sera facilement identifiable en fréquence et en amplitude. Il suffira alors, d'identifier sur quel câble se situant à proximité on retrouve ce même parasite avec une amplitude la plus grande possible pour en déterminer son origine. Cette mesure pourra s'effectuer avec une pince de courant et un oscilloscope. Il suffira alors d'éloigner le câble du système sur lequel se fait le couplage de la source du parasite ou alors de lui améliorer son blindage. Dans le cas d'un parasite basse fréquence rayonné, le couplage ne pourra s'effectuer que par champ magnétique, en général impulsionnel et plus rarement de manière entretenue. Dans ce cas, les méthodes de blindage sont très difficilement applicables et il convient d'identifier la source afin d'en éloigner l'appareil perturbé (en général les sources de ce type de perturbations sont des transformateurs provoquant des champs de fuite, des tubes cathodiques, etc.)

Pour ce qui est des perturbations basses fréquence transitoires, elles sont beaucoup plus rares, et on peut noter comme origines principales le rayonnement provoqué par un court circuit de ligne ou le réenclenchement d'une ligne haute tension ou bien le rayonnement provoqué par le chemin d'ionisation d'une décharge de foudre. Ces phénomènes sont assez rares et très furtifs pour que l'on s'intéresse ici à leur résolution.

En ce qui concerne les parasites à haute fréquence (c'est à dire au delà de 1 MHz), le problème devient un peu plus délicat car tout câble ou piste électronique devient une antenne à sa fréquence de résonance et les problèmes d'identification et de résolution deviennent beaucoup plus sensibles.

Les perturbations haute fréquence en conduction vont essentiellement, s'il s'agit de parasites permanents, provenir du bruit de commutation de moteurs à balais qui vont générer des étincelles et provoquer sur les câbles d'alimentation des courants à haute fréquence avec des fronts de montée très brefs, ou par induction sur des câbles de communication d'un bruit HF si les câbles sont assez rapprochés. On les rencontrera aussi avec des systèmes qui comporteront des convertisseurs à découpage (alimentation à découpage par exemple) et ils seront aussi susceptibles de perturber les alimentations électriques du système ou les câbles de communication se trouvant à proximité par induction. L'identification de ce style de parasite peut se faire à l'aide d'un bon oscilloscope (les fréquences à observer dans ces cas peuvent aller jusqu'à 5 MHz. La résolution de ce type de problème peut passer par un nouveau routage des câbles de communication après avoir identifié l'origine la plus forte de ce parasite à la pince de courant, ou bien par le filtrage adéquat de l'alimentation électrique du système.

Si l'on considère les parasites haute fréquence conduit mais en mode transitoire, ceux-ci vont provenir essentiellement de la coupure de composants comme les bobines, les relais, etc. il suffira dans ce cas de placer un limiteur de surtension en parallèle à la bobine. Mais ils pourront aussi être générés par les décharges électrostatiques, dans ce cas, les matériels conformes aux exigences de la directive CEM sont bien immunisés et il est rare de retrouver ce type de source de problème sur site.

En ce qui concerne les parasites à haute fréquence en rayonnement, on va être confronté à un problème de couplage de type antenne et ensuite on se retrouve avec une perturbation à haute fréquence conduite. Il est à noter, dans ce cas, que tous les câbles électriques du système ainsi que toutes les pistes conductrices de ces circuits électroniques pourront jouer le rôle d'antenne. Dans ce cas c'est la fréquence du parasite qui déterminera par quel biais s'effectuera le couplage. En effet, plus la fréquence du parasite sera élevée, moins la longueur du conducteur par où s'effectuera le couplage sera faible et inversement. On incriminera donc plus les câbles de communication pour des hautes fréquences relativement peu élevées et les pistes conductrices des circuits électroniques pour des fréquences beaucoup plus élevées. En général, en fonction de la fréquence du parasite on va concentrer l'investigation vers des conducteurs ayant une longueur proche du quart de la longueur d'onde du parasite. L'identification du parasite, notamment sa fréquence, se fera à l'aide d'un analyseur de spectre et d'un kit d'antenne permettant une bonne couverture des fréquences suspectes. La résolution d'un tel problème peut passer par l'ajout d'un filtre passe-bas sur les lignes de communication ou par la vérification de la bonne continuité du blindage. Au niveau de fréquences plus élevées, on pourra aussi utiliser des ferrites correctement dimensionnées et installées pour atténuer ce parasite.

Aucun problème de perturbation électromagnétique n'est simple à résoudre sur une installation en cours de fonctionnement et seule une démarche rigoureuse et exhaustive permettra l'identification du parasite et de sa source afin de pouvoir proposer des solutions efficaces.

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Immunity Performance of Fire Detectors against Radiated Electromagnetic Field

Abstract

Because of the development in wireless communication technology, an enormous amount of wireless communication equipment is introduced in general homes, offices and medical institutions, etc. Circumstances in which electrical equipments installed in automatic fire alarms being exposed to electromagnetic noises are increasing. In equipments included in automatic fire alarms, erroneous workings owing to electromagnetic noises are occurring. Further increase of these troubles can be predicted.

How much immunity performance do automatic fire alarms have against electromagnetic noises in the present situation? In Japan, a standard for immunity of radiated electromagnetic fields has not yet been included in the inspection standard. This paper reports immunity performance of equipments of automatic fire alarms against radiated electromagnetic fields by carrying out the immunity test to expose a variety of equipments of automatic fire alarms to radiated electromagnetic fields.

1 Introduction

Owing to overcrowding of city, large electric equipments are used near business and residential district. Additionally, for the purpose of miniaturizing package and saving electric power, electrical appliances are assembled into resinous parts and electric elements run by low voltage. As a result, electrical appliances are susceptible to electromagnetic noises and are liable to radiate them. It is a fact that the news media reports erroneous workings of medical equipments by radio waves from portable mobile phones and incorrect workings of a machine tool by electromagnetic noises of electric sparks which are generated by workings of a hoist crane in a manufacturing plant1).

Circumstances in which automatic fire alarms being exposed to electromagnetic noises are increasing alike. Erroneous workings of automatic fire alarms are actually occurring. Further increase of danger in future can be predicted.

In Japan, the national type approval for automatic fire alarms does not include a standard for radiated electromagnetic fields yet2). Therefore, to investigate how much immunity performance against radiated electromagnetic fields does the present automatic fire alarms have, equipments of automatic fire alarms were tested against radiated electromagnetic fields. The tendency of immunity performance against radiated electromagnetic fields was confirmed.

2 Experimental methods

When the experiment was carried out, the test standard IEC 61000-4-3 (Radiated, radio-frequency, electromagnetic field immunity test)[3] was referred. The strength of the electric field and the uniformity of the electric field over the test sample were measured in advance. The experiment proceeded while output power and frequency of the signal generator were being controlled by the computer. Considering IEC 61000-4-3, the high frequency side was extended to 3200 MHz for the experiment. Because, ranges of frequency used by mobile communications including portable mobile phones are shifting to higher frequency these days.

Before the immunity test, preliminary experiments were made to determine modulation method and cable type. Amplitude modulation was compared to frequency modulation in the preliminary experiments. As a result, appropriate modulation method was determined as influential amplitude modulation. The modulation factor was 80% and the signal wave was 1 KHz sinewave.

In order to check the work of equipment correctly, the cable which is less susceptible to electromagnetic noises was chosen to connect the equipment under test (EUT). Vinyl insulated cable was compared to shield cable. By this, it was confirmed that shield cable is less affected by radiated electromagnetic field than vinyl insulated cable, and therefore, it was adapted for the actual experiment.

2-1 Configuration of experimental equipments

The equipments used for the experiment were as follows:

1) Signal generator (Hewlett Packard)
2) Power amplifier (MILMEGA)
3) Power meter (Hewlett Packard)
4) Computer (Fujitsu)
5) Antenna (Biconical (80 - 200 MHz), Log periodic (200 - 1000 MHz), Double ridged guide horn (1 - 3.2 GHz))

The radio anechoic chamber and arrangement of experimental equipments are as shown in Figure 1. The radio anechoic chamber is 8 m long, 6 m wide and 4 m high. The walls and the ceiling inside the chamber are covered with electromagnetic absorbers and the floor is partly covered with electromagnetic absorbers for diagonal incidence between the antenna and the EUT. The distance between the antenna and the EUT was 3 m.

2-2 Conditions of radiated electromagnetic field

Frequency	80 - 3200 MHz
Modulation	amplitude modulation
Modulation factor	80 %
Signal wave	1 KHz sinewave
Electric field strength	10 V/m
Plane of polarization	vertical polarized wave and horizontal polarized wave

(As for detectors, three different planes of polarization were tested (see Section 2-3 (2).)

Rate of sweep 1 % step size

2-3 Installation of EUT

(1) Receiving equipment and code-transmitter

Assuming as if installed upon a wall, these equipments were exposed squarely to radiated electromagnetic fields. The indicators (displays and operating panels) of the receiving equipments were exposed to radiated electromagnetic fields from the antenna, as shown in Figure 2.

(2) Detectors

In order to test three different planes of polarization in one sweep test, the board (EUT-board) was prepared as Figure 3. Assuming that detectors normally installed on a ceiling, detectors were fixed in different directions on the EUT-board and the antenna was set just below the EUT-board. In the case of a projected beam type smoke detector, the detector was fixed on the EUT-board as shown in Figure 4. This detector was experimented with vertical and horizontal polarized waves.

2-4 Record

When the EUT erroneously worked, the frequency and contents were recorded at every equipment.

2-5 EUT (Equipment Under Test)

The equipments of automatic fire alarm systems produced by main six manufacturers in Japan were tested. The equipments under test are as follows.

(1) Receiving equipment•••11 models (P-type•••5 models, R-type••• 6 models)
(2) Code-transmitter•••14 models
(3) Detector•••36 models (spot type fixed temperature detector•••5 models,
rate-of-rise spot type detector•••3 models,
spot type photoelectric smoke detector•••12 models,
spot type ionization smoke detector•••5 models,
projected beam type smoke detector•••1 model,
spot type infrared detector•••7 models,
spot type ultraviolet detector•••3 models)

3 Experimental results

3-1 Receiving equipments

P-type equipments did not work erroneously.

R-type equipments went erroneous working when the frequency was 80 - 260 MHz at 3 out of 6 models (Figure 5 (1)). Contents were the indication of break down of emergency announcement, the lighting of back-light of liquid crystal display (LCD), the flickering of LCD, the lighting of warning lamp, the malfunction of stand-by battery and the repetition of electricity failure and return.

3-2 Code-transmitters

Code-transmitters erroneously worked at 7 out of 14 models (Figure 5 (2)). The fire alarm occurred when the frequency was 110 - 117 MHz, 158 - 162 MHz, 175 - 182 MHz and 410 - 600 MHz. The lighting of polling lamp, the unusual communication and the warning of open circuit or short circuit occurred when the frequency was 85 - 190 MHz, 210 - 360 MHz and 410 - 600 MHz.

3-3 Detectors

(1) Fixed temperature detector

Detectors running mechanically were removed from objects of the test. Fixed temperature detectors under the test were analog type detectors. These detectors erroneously worked at 3 out of 5 models (Figure 5 (3)). Erroneous workings such as the malfunction, the no response and the prealarm occurred when the frequency was 120 MHz, 210 MHz, 187 - 200 MHz, 206 - 218 MHz and 232 - 239 MHz.

(2) Rate-of-rise detector

Detectors running mechanically were removed from objects of the test. Rate-of-rise detectors under test were analog type detectors. These detectors erroneously worked at 1 out of 3 models (Figure 5 (4)). The no response occurred when the frequency was 148 MHz, 155 - 188 MHz, 197 MHz, 220 MHz, 751 MHz and 766 MHz.

(3) Photoelectric smoke detector

Photoelectric smoke detectors erroneously worked at 8 out of 12 models (Figure 5 (5)). Erroneous workings such as the fire alarm, the no response, the abnormal output signal and the unusual communication occurred when the frequency was 190 - 280 MHz, 700 - 800 MHz, 872 MHz, 898 MHz, 1200 - 1800 MHz, and 2000 - 2500 MHz.

(4) Ionization smoke detector

Ionization smoke detectors erroneously worked at 3 out of 8 models (Figure 5 (6)). The fire alarm occurred when the frequency was 100 - 190 MHz, 1232 - 1257 MHz, 1763 - 1890 MHz, and 2000 MHz.

(5) Projected beam type smoke detector

Only one type was tested. The fire alarm occurred when the frequency was 80 - 92 MHz and 116 - 184 MHz (Figure 5 (7)).

(6) Infrared detector

Infrared detectors erroneously worked at 3 out of 7 models (Figure 5 (8)). The fire alarm occurred when the frequency was 197 - 266 MHz and 1100 - 2200 MHz.

(7) Ultraviolet detector

Ultraviolet detectors did not show any erroneous working.

4 Discussion

4-1 Receiving equipments

The casing covers of P-type equipments were made of resin; however, P-type equipments did not go erroneous working. It was revealed that P-type equipments had high immunity performance against radiated electromagnetic fields. Reason for this is that input signals from detectors were ON/OFF signal and the great difference of input level between ON signal and OFF signal.

R-type equipments erroneously worked at low frequency range (80 - 260 MHz). Contents of erroneous workings were the malfunction of LCD and the lighting of LED in the operating panel. FM radio broadcasting, TV broadcasting, the maritime mobile station and the land mobile station are included in the frequency range which can cause erroneous working. It is possible that receiving equipments are exposed to radio waves from mobile stations. The casing covers of R-type equipments are made of metal; however, radio waves can enter through the display and the operating panel which are partly made resin. As a result, the working of LCD is susceptible to radiated electromagnetic fields.

4-2 Code-transmitters

Erroneous workings occur in the frequency range including mobile stations, TV broadcasting, the amateur radio, the fire radio and the police radio, therefore, erroneously work of code-transmitters inside buildings can be predicted. Code-transmitters are frequently installed in large buildings, and they are generally installed in the metallic box inside the EPS (electric pipe shaft). As a consequence, the influence of electromagnetic noises seems to be a little. As for code-transmitters, erroneous working tends to be the fire alarm, reliable construction is necessary.

4-3 Detectors

(1) Fixed temperature detector

Only analog type was used. Although the fire alarm did not occur, the prealarm occurred in some cases. The frequency range that caused erroneous workings includes the aeronautical radio, the mobile station, the amateur radio and TV broadcasting. Fixed temperature detectors are rarely affected by radio waves inside buildings.

(2) Rate-of-rise detector

One analog type detector erroneously worked. The content of an erroneous working was the no response caused by unusual communication. The detector erroneously worked at the frequency range of the maritime mobile station, the land mobile station and the specified low power radiostation. This type of detector is comparatively resistant against electromagnetic noises though it is possible to be affected by radio waves from the mobile station.

(3) Photoelectric smoke detector

Over 70% of detectors under the test erroneously worked when frequency was about 200 MHz and 700 MHz - 2.5 GHz. Because this frequency range includes the portable personal telephone (cellular system) and PHS (personal handy-phone system), this type of smoke detectors are often exposed to radio waves of these frequencies range inside buildings. As the content of an erroneous working was often the fire alarm, it is necessary that detectors are installed in a safety spot away from electromagnetic noises.

(4) Ionization smoke detector

As P-type detectors, the content of an erroneous working was the fire alarm. Radio waves of lower frequency range which includes the maritime mobile station and the land mobile station and radio waves of upper range which includes the specified low power radiostation and PHS caused erroneous workings. Because the specified low power radiostation and PHS have the output power of several 10 mW, real life effect of radio waves is small.

(5) Projected beam type smoke detector

This detector erroneously worked at lower frequency range (80 - 184 MHz). Although the metal casing cover, radio waves easily entered the equipment through the glass lens. Being installed on the upper part of a wall of atrium, it is impossible for a person to approach directly to the detector. The actual influence caused by radio waves of the frequency range including FM radio broadcasting, TV broadcasting and the mobile station is small.

(6) Infrared detector

Like photoelectric smoke detectors of P-type, infrared detectors are not digitally transmitted in exchanging data. However, infrared detectors are susceptible to electromagnetic noises. Erroneous workings centres on the frequency range of 200 MHz and 1.5 - 2 GHz. For the reason that this frequency range can be specified, a method of shielding mainly against this frequency range is effective. For a content of erroneous working is the fire alarm, special attention should be paid in installing detectors at environment which erroneous workings do not occur.

The structure of shield varied even in the detectors under test and the trouble situation also differed one another. The frequency range of erroneous works includes the mobile station, the portable personal telephone, the aeronautical radio and the space mobile station. The uses of portable personal telephone and the mobile station near the detectors are highly possible.

(7) Ultraviolet detector

In the detecting element of this detector, a photo tube is used. It is necessary to ionize gas in a photo tube in order to run a detecting element.

(a) Energy of radiated electromagnetic fields in the experiment is too low to ionize gas.

(b) Wavelength of radiated electromagnetic fields in the experiment is longer than ultraviolet.

(c) Difference between current level of ON and OFF is great.
As a result, ultraviolet detectors are immune to electromagnetic noises.

4-4 General consideration

P-type automatic fire alarm systems have higher immunity performance against electromagnetic noises than R-type systems. Difference between input signal level and noise level is great, namely, S/N is big.

Relating to R-type systems:
(a) R-type systems communicate in digital, therefore, digital signal waves which are rectangular wave including many frequency constituents are susceptible to a variety of frequency noises.
(b) LCD or a plasma display is used.
(c) Electric circuit boards inside the equipments of R-type systems have many OP-amplifiers and IC chips.
As a result, R-type systems including code-transmitters are susceptible to electromagnetic noises.

Detectors which have electric circuits to amplify signals from a sensing element several times tend to be susceptible to electromagnetic noises. In this case, the voltage of output signal of sensor is low. For this reason, when a slight electromagnetic noise affects the fore circuit of amplifying circuit, the noise gets amplified and reaches the level of the fire alarm. Photoelectric smoke detectors and infrared detectors in the equipments under test are applicable to this case.

Even in the same kind of detector, degree of influence caused by electromagnetic noises was found to be different by the structure inside detectors. In the case of infrared detectors, there were detectors which have the same electric circuit board inside the casing but the different shield methods. In comparison of these detectors, degree of occurrence of erroneous workings was found to be very different. One did not erroneously work at all, another erroneously worked at the broad frequency range. In the case of a detector which has a metallic cover for the shield, the effect of the shield was confirmed.

Photoelectric optical smoke detectors, ionization smoke detectors and infrared detectors frequently worked erroneously when the frequency was 1 - 3.2 GHz. Because utilization of radio waves in this frequency range (1 - 3.2 GHz) tends to increase in future, the necessity to shield from electromagnetic noises of this frequency range seems to increase.

5 Conclusions

The immunity test was conducted for equipments of automatic fire alarm systems produced by main manufacturers in Japan. The experimental conditions were 10 V/m in strength of electric field, amplitude modulation in modulation, 80 - 3200 MHz in frequency and 1 % step size in sweep rate.

The equipments of R-type systems were found to be more susceptible to electromagnetic noises than equipments of P-type systems. There were detectors of high and low immunity performances. It was found that the effect of the shield is differed when manufacturers use various shield methods.

When the frequency was 1 - 3.2 GHz, there were several detectors working erroneously. Because utilization of radio waves in this frequency range tends to increase in future, measures against electromagnetic noises of this frequency range seem to be required.

It is necessary to confirm the strength of electric field by considering actual possible situations, such as while using portable personal telephones or transceivers, inspectors work maintenance, and a mobile station communicates on the adjoining road.

Acknowledgments

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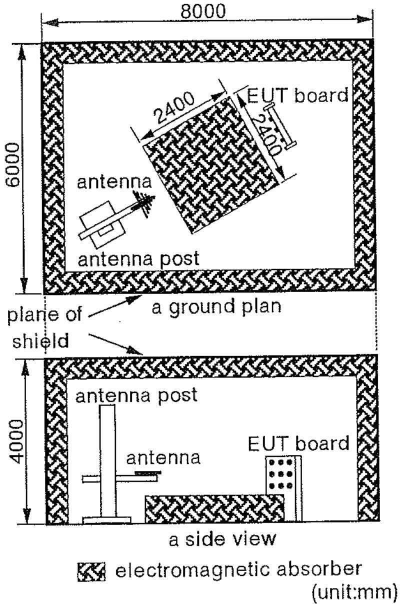


Figure 1. Radio wave anechoic chamber and arrangement of experiment equipments

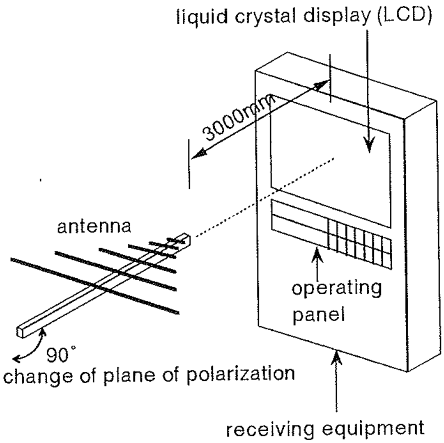


Figure 2. Location of receiving equipment and antenna

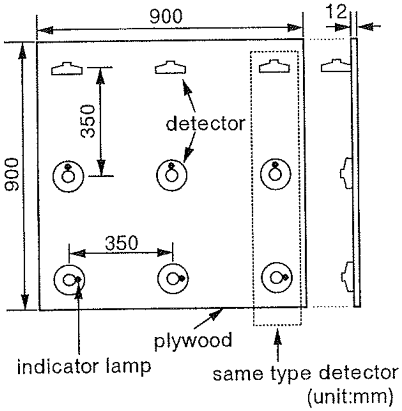


Figure 3. Installation method of detectors (EUT-board) (to experiment on three different planes of polarization in one sweep test)

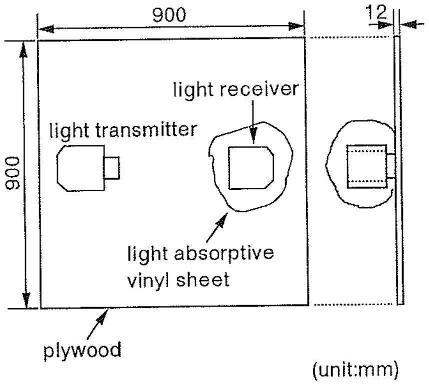
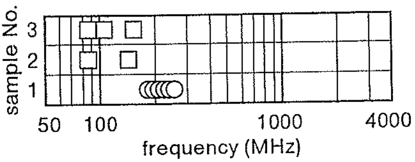
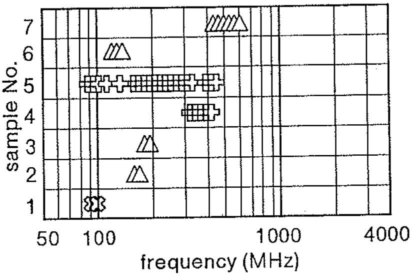


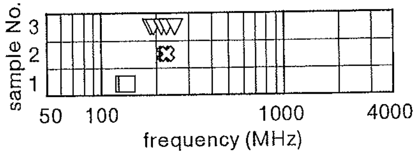
Figure 4. Installation method of projected beam type smoke detector (EUT-board)



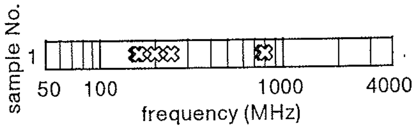
(1) R-type receiving equipment



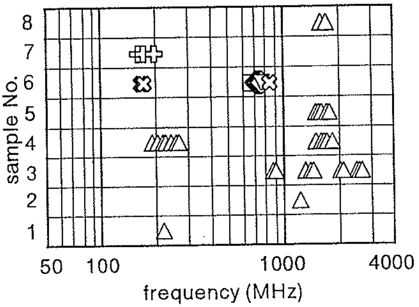
(2) code-transmitter



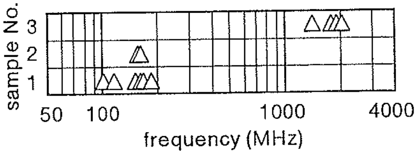
(3) spot type fixed temperature detector



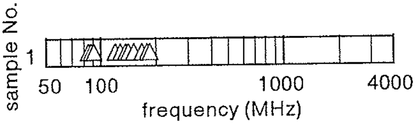
(4) rate-of-rise spot type detector



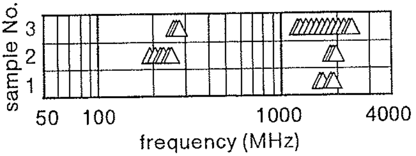
(5) spot type photoelectric optical smoke detector



(6) spot type ionization smoke detector



(7) projected beam type smoke detector



(8) spot type infrared detector

explanatory notes

△ fire alarm	○ unusual action of LCD
▽ prealarm	◇ abnormal output signal
✖ no response	☐ lighting of warning lamp
✚ unusual communication	

Figure 5. Relation between occurrence of false alarm and frequency

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Laser Spot Detector Technology For Early Warning of Smoke

Abstract

A very early warning smoke detection system has been developed which uses a focused laser light source to scatter light in the presence of smoke. The system combines a powerful central computer with a large number of remote laser sensors. Advanced software algorithms are used to analyze the analog signals sent from the sensors. It will be shown that this type of light source gives different signatures for smoke than for dust and other particles. In addition, further differentiation between smoke and non-smoke particles can be obtained by using multiple sensors in one room, and observing differences in their analog light scattering signals. Using these methods, an early warning fire detection system can be constructed which will discriminate between smoke and non-smoke particles, yet does not require filters or moving parts, and therefore offers a very reliable, cost-effective method for very early detection of smoldering fires.

Prior Art

Early warning smoke detection systems used over the last 10 or 20 years have usually been based on the air sampling concept. A fan is used to mechanically draw air though a piping network from sampling ports located throughout the protected space. The sampled air is usually passed through a filter which is designed to pass the smaller smoke particles, but block larger dust and other non-smoke airborne particles. The air then passes though an extremely sensitive smoke detection chamber using a xenon or laser light source. This technology has been proven to be successful in detecting fires at a very early stage.

However, this air sampling method has several inherent disadvantages. Since it requires a network of pipe rather than wire, the initial installation has relatively high material and labor cost. Since it has moving mechanical parts and filters, it has higher maintenance cost than all-electronic systems. Since it uses a central detection chamber supporting many remote air sampling points, it cannot locate the area of the fire within the protected space (it cannot tell which of the ports actually sampled the smoke). Although the central detection chamber has a very high sensitivity rating, the effective sensitivity of the system is inversely proportional to the area of the protected space. Smoke from a smoldering fire may soon reach one or two sampling ports, but in a large area many other ports remote from the fire dilute this smoke with clear air.

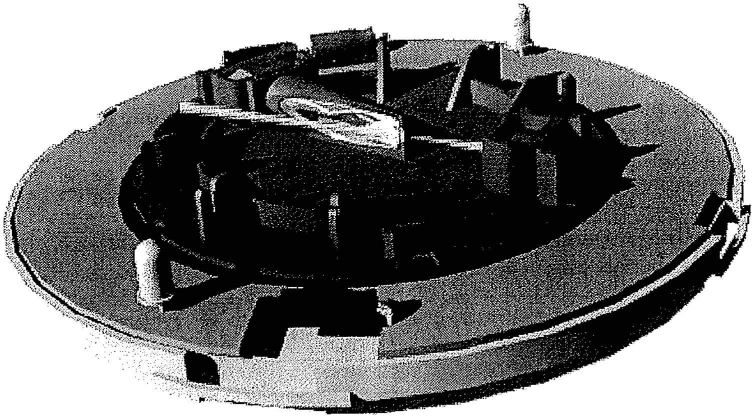
General Description of the System

The new technology system is called VIEW™, for Very Intelligent Early Warning. It consists of the three major sections: (1) Multiple laser spot detectors; (2) A control panel with very fast signal processing capability; (3) Special software algorithms in the control panel to process the signals from the detectors and separate true smoke signals from non-smoke signals. All of these three elements must be present for the system to perform properly. For example, if a laser sensor as described were to be used on a control panel without the signal processing algorithms, it would easily false alarm if any dust particles were present, and therefore would not be a practical product.

The Laser Detector

The laser detector is small in physical size, 104mm in diameter, and 43mm in height. The detector connects to the control panel over two wires, and has top housing and chamber covers which are easily removable for cleaning. With these covers removed the detection chamber appears as shown below:

Figure 1 Laser Sensor



The detector light source is a low cost laser diode, coupled to a lens such that it creates a narrow but very intense light beam. The light beam travels across the detector and is absorbed by a light trap on the opposite side. Since the light beam touches no surfaces, the detector is not susceptible to reflections from the detector walls (with existing technology photoelectric detectors, such reflections can occur, and become more prevalent as gray dust accumulates on the black surfaces). When smoke particles enter the chamber, the light strikes the particles and is scattered in all directions. Some of this scattered light reaches the photo receiver, which provides the system with the basic indication of smoke. The design includes a special cylindrical mirror, that reflects additional scattered light into the photo receiver, acting as an optical amplifier.

To conserve power, the laser diode is flashed for a few milliseconds once every 5 seconds (approximately). A sample and hold circuit is used to retain this signal between flashes, and the panel algorithms are designed with the understanding that the analog data is only updated once every 5 seconds.

Communications Protocol

Over a single pair of wires, the control panel can power and communicate with up to 99 laser detectors. Each detector has its own unique address so that the control panel can identify the physical location of each smoke measurement. The system is programmed such that it is aware of the physical adjacency of detectors, and can consider readings from more than one detector in making an alarm decision.

An improved version of this protocol, called FlashScan™, transmits all information in digital form for improved precision and noise immunity. It extends the loop capacity to 318 points, of which 159 may be laser sensors. It includes a polling method that samples ten input or output points at one time, and can identify an alarm from any of 318 points in less than one second. It can activate up to 159 output points in less than one second.

Although digitized, the information sent from the detector to the panel actually represents analog information. The signal processing and alarm decision is made not in the head, but in the panel. This is a fundamental requirement of the VIEW system because the signal processing algorithms, described below, require readings from adjacent sensors to reject signals from airborne fiber particles. The VIEW system adds a new dimension to signal processing algorithms beyond all other systems in use today: **space**.

Although the VIEW alarm decision is in fact made in the control panel, the communications protocol also supports decision-in-head detectors. In fact, certain multisensor detectors provided by Notifier use this type of communications as follows. The multisensor detector, using internal algorithms, processes signals from multiple sensors and compares the signals to one of several profiles, representing increasing levels of confidence in detection of a true fire. When the detector microprocessor senses that the detector has reached the first (lowest probability) criterion, it "snaps" the analog output signal from its normal baseline to a known analog level and holds it at this plateau. As the detector measures a progressively stronger indication of fire, it snaps the level to higher values. The application program in the panel sets each detector to one of several "sensitivity" levels, corresponding to the analog plateaus.

This above method is compatible with the VIEW software algorithms and decision-making in the panel previously described, yet allows distributed processing (in the head) for very complex multi-criteria detectors. In fact the spatial dimension of the Notifier algorithms can be retained for multisensor detectors, because the panel software can process plateau levels from two detectors, each below the alarm threshold, and equate it to one higher plateau above the alarm threshold. In this way the Notifier protocol can mix detectors and either make the alarm decision in the head or in the panel, selecting the method on its merits for each detector type. For the VIEW system, fine measurement of analog signals from multiple sensors is essential, therefore the main processing algorithms must reside in the control panel.

Control Panel

The control panel is based on a very fast (RISC) microcomputer, that can process complex calculations simultaneously for many detectors. The computer memory must have capacity to store past readings of all detectors for signature analysis. Tests at Notifier have shown that over 300 VIEW detectors can be supported using a single high performance 16-bit microcomputer of today's technology.

Drift Compensation Algorithm

The laser sensor, like most smoke sensors, is susceptible to environmental phenomena that can cause its baseline (clear air) analog signal to drift. The most likely cause is dust accumulation on the optical elements of the detection chamber. Other factors include aging of electrical components. Although this drift is usually toward the alarm level giving a false alarm possibility, it can move in the opposite direction, which could threaten the detector performance in a real fire situation. With a detector as sensitive and precise as the VIEW sensor, bi-directional drift compensation is an essential requirement. The system must also have defined limits of compensation, so that a warning can be issued before a detector drifts out of its linear region, and its performance is thereby compromised.

The VIEW drift compensation algorithm provides a running average that is re-calculated at every detector sample, by adding a very small percentage of the present detector reading with a large percentage of the past average. For example, the running average could be updated by adding 9,999 parts of its last value to 1 part of the present reading, and dividing by 10,000. With samples every 5 seconds, it would take almost a day for a large signal change to significantly bias the alarm level. This slow filtering is necessary to discriminate between the rather slow signal growth of a smoldering fire, and the extremely slow effects of dust accumulation.

Dust Rejection Algorithm

Since the laser sensor does not use a filter or forced air movement, it is susceptible to airborne dust particles. Even in a reasonably clean environment, such as a computer room or telephone switching center, dust particles exist in sufficient quantities to have a dramatic negative effect on the laser sensor output signal. Through sparse, the dust particles are much larger than those of smoke, and a single particle can scatter enough of the laser light to reach the analog alarm threshold for the VIEW detector.

The geometry of the laser sensor is used to reject these dust particle signals. Refer to Figure 1. The dust particle must scatter the laser light in only a very small volume, represented by a section of the conical focused beam between the septum and the region above the mirror amplifier. Since the dust particles are very sparse, and because this light beam volume is very small, the probability of a dust particle being in this critical area during a laser light flash is small. Even with extremely slow air velocities, the dust particle will drift out of the light scattering area before the next laser flash (5 seconds). If the light beam cross sectional diameter is 2 mm, for example, a velocity of .002/5sec=1.44 meters/hour will pass the particle through the beam before a second flash can be scattered. This is in contrast to smoke particles, which are far smaller and much more dense, such that many particles must scatter light in order to create a sufficiently large signal at the photo receiver. Therefore, if the algorithm can reject this large dust transient, discrimination between dust and smoke is achieved.

Experiments in a factory environment, using many laser sensors over a long period of time, have shown that the probability of a dust particle (large enough to scatter an alarm level signal at the most sensitive VIEW setting) appearing in a flash of the laser light beam is on the order of once in 2 hours. This transient is rejected, but what if two dust particles appear back-to-back in the light beam? If the probability of a single transient is once in 2 hours (once per 1440 flashes), then the probability of two independent particles is once per $(1440)^2$, or once per 2×10^6 flashes. This is once per 10 million seconds or about 3 months. Suppose a system consisted of 30 detectors. Then, even with single transient rejection, the system would be expected to false alarm every few days!

If the system algorithms can reject two transients back-to-back, the system is now susceptible to three transients in a row, with a probability of $(1440)^3$, or once per 3×10^9 flashes. This is once per 300 detector-years, or once per 10 years with 30 detectors, a reasonable level. Much greater false alarm rejection capabilities are possible with relaxation of the detector sensitivity setting. Obviously, detector false alarm rejection can be dramatically increased with even tighter light beam focus.

The basic VIEW algorithm for discrimination between dust and smoke is called "MIN-3". For every detector, at least two previous samples are stored. As a new sample is taken, it is compared to the two previous samples of the same detector. The smallest (Minimum) of these three samples is used to replace the present sample. See Figure 2. This algorithm does not just filter the dust spikes, it completely truncates them.

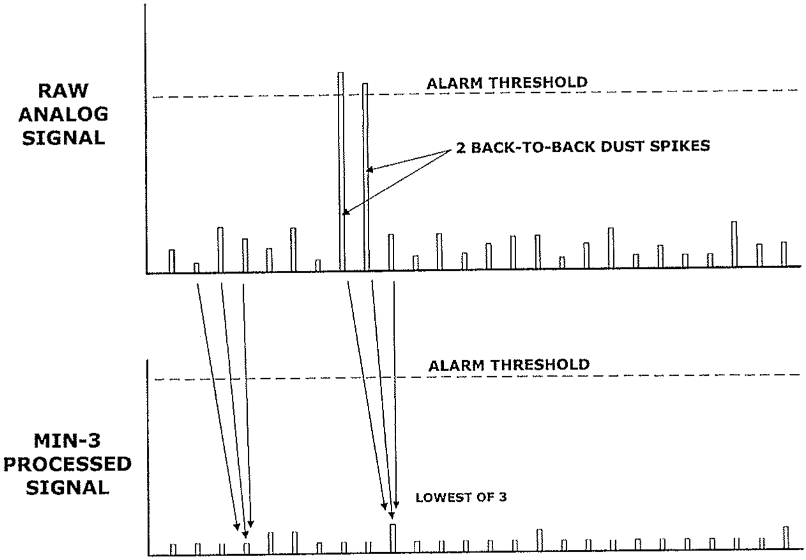


Figure 2 Dust Rejection

Figure 3 shows the effect of a true fire on the system. Since the signal is persistent, not transient, the algorithms accept the signal and alarm the system. The MIN-3 algorithm, similar to any conceivable false alarm rejection method, has the disadvantage of time delay, in this case about 10 seconds. However this delay is small relative to the signal phenomena of smoldering fires, typically requiring several minutes before a reasonable signal appears. Further, the very high sensitivity of the VIEW system allows a much lower alarm threshold, and therefore will, in fact, detect a fire long before a conventional system would with low sensitivity and quick algorithms.

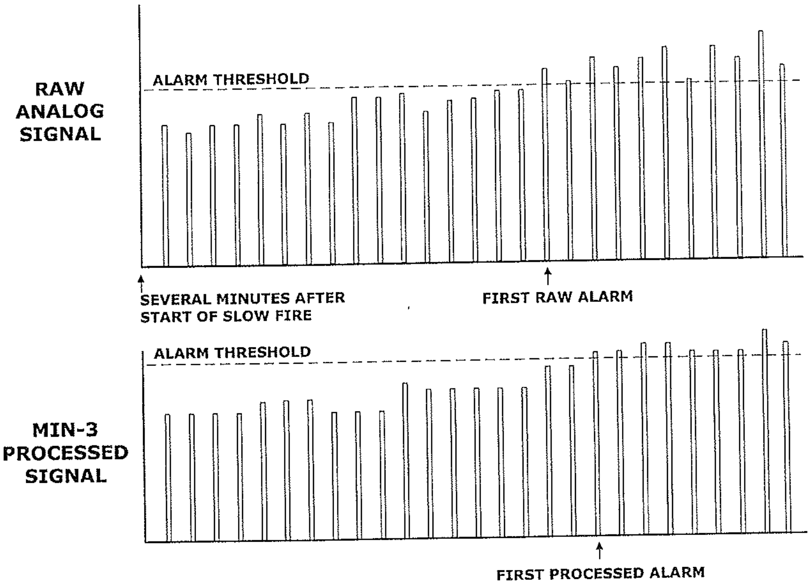


Figure 3 Alarm Processing

Smoothing Algorithms

For higher frequency noise sources such as electrical transients, a form of filtering, called smoothing, is used. This algorithm is similar to drift compensation, except that it operates much more quickly. The smoothed value from the last sample is updated by adding a percentage of the present reading to a complementary percentage of the smoothed reading. The VIEW smoothing algorithms change these percentages, and therefore the degree of smoothing, based on the sensitivity selected for each detector. Low sensitivity detectors require little or no smoothing, but need fast reaction to fast fires. High sensitivity detectors require more smoothing, and since they are searching for very slow smoldering fires, require more time to make the correct decision.

Cooperative Multi-Detector Algorithms

A key factor in the VIEW system performance is the cooperative multi-detector algorithm. In making the alarm decision for each laser detector, smaller analog readings from adjacent sensors can be considered. This is done by a statistical process, where the reading from each sensor is squared, then all squared readings are added, and finally a square root is taken of the sum. In this way the effective sensitivity of a detector is increased without a corresponding increase in susceptibility to false alarms.

For example, a protected room could have a large number of laser detectors that cooperate in the alarm decision. If smoke were to equally enter three adjacent detectors, the alarm threshold would be effectively lowered by 1/√3, or to 58% of its single detector level.

Fiber Particle Discrimination

Very large airborne particles, including fibers such as lint and human hair, create a special problem, in that they can land on a surface while protruding into the light beam volume. See Figure 4. Although this may seem unlikely, tests at Notifier have shown that it cannot be discounted if the system is to be reliable. Tests have been run for millions of detector-hours in an air conditioned factory environment (for example a 1000 detectors running for 1000 hours is considered to be a million hours). These tests showed that fiber particles could force a detector into alarm once every few hundred thousand hours. If a system consisted of 50 detectors, 200,000 detector hours would equate to about two false alarms per year, which is not acceptable.

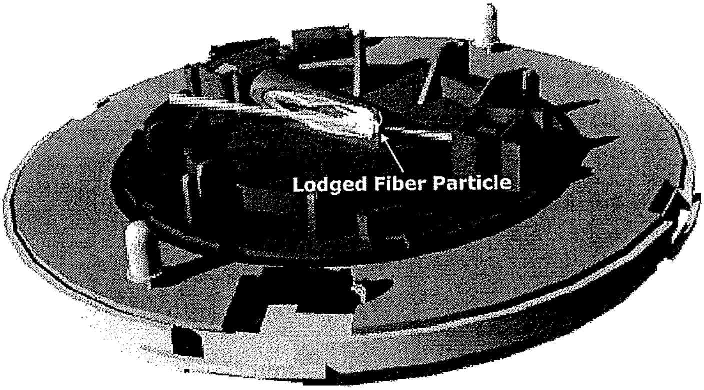


Figure 4 – Fiber Particles

Although detector screens intuitively seem to provide protection from fiber entry, tests have shown that fibers have a surprising ability to breach them. Apparently, once one end of the fiber touches a screen hole opening, the fiber then threads completely through the opening. Therefore mechanical screening methods are not practical, and a software solution is necessary.

When a fiber lands in the light-scattering volumetric region, its typical signature is that of a step function. This fiber signature is quite different from smoke, which is an oscillating signal that has a relatively slow rise time from the clear air base level to the alarm threshold level. See Figure 5. As a first requirement to identify a signal as caused by a fiber particle, the VIEW algorithms identify a characteristic where at least 2 samples are below a certain level (level 1 in the Figure 5), followed immediately by a sample that is above level 2. This defines a sharp step edge. As additional samples are taken they must also be above the second level for the software to remain in suspicion of a lint problem. If the level drops below level 2 at any time, the algorithm processes the signals normally.

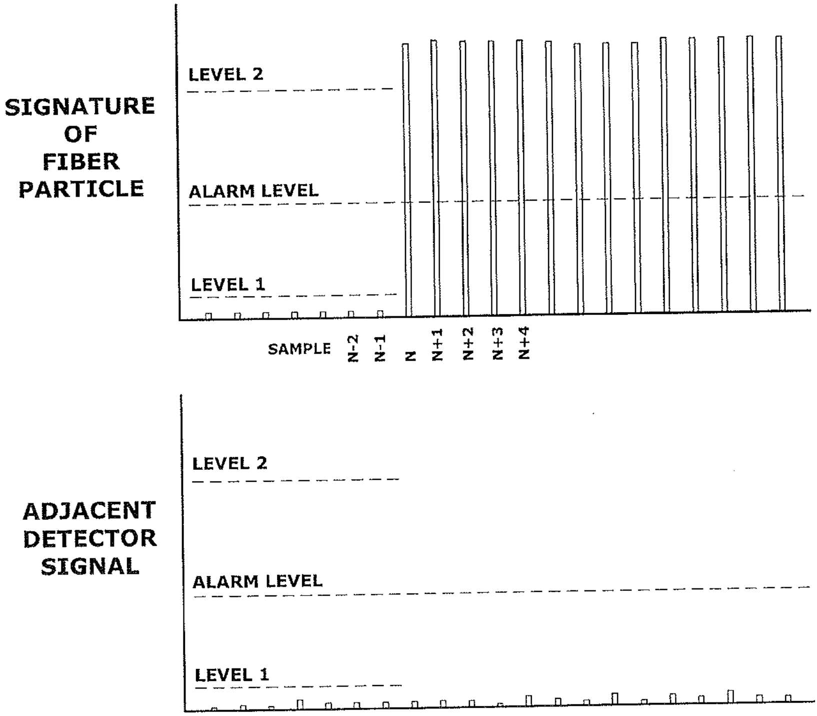


Figure 5 Fiber Particle Algorithm

The second part of the fiber discrimination algorithm involves the cooperative multi-detector capability. This part of the algorithm requires that at least two laser detectors exist in the each protected room. At the same time that the algorithms are verifying that a step function exists in a first detector, they are also checking all adjacent detectors. If a second detector in the area indicates a smoke concentration above level 1 (see Figure 5), the algorithms assume that the signal is not cause by a fiber, and an alarm is sounded for the first detector.

Assuming all signal parameters described above continue, the detector remains in a mode of possible fiber contamination. After a period of time in this mode, approximately 1 minute, the panel will indicate a special fault condition for this detector.

Summary

A very early warning system based on laser spot detectors can provide reliable performance without mechanical air movement or filters. This has been proven in VIEW system installations around the world. The VIEW system has also proven to be very fast in detecting smoldering fires in comparison to other systems based on aspiration technology. Tests have been successfully performed at telecommunications facilities and cleanrooms around the world.

Figure 6 shows a sample of these tests. The 4 tests shown were performed at a modern telecommunications facility in southern England. A VIEW system was installed next to a new aspiration system (already installed by the authorized distributor). The tests were conducted by representatives from the telecommunications company, using the standard UK smoldering wire test (BS6266). The view system was set to less than its maximum sensitivity, yet provided superior performance in all 4 tests.

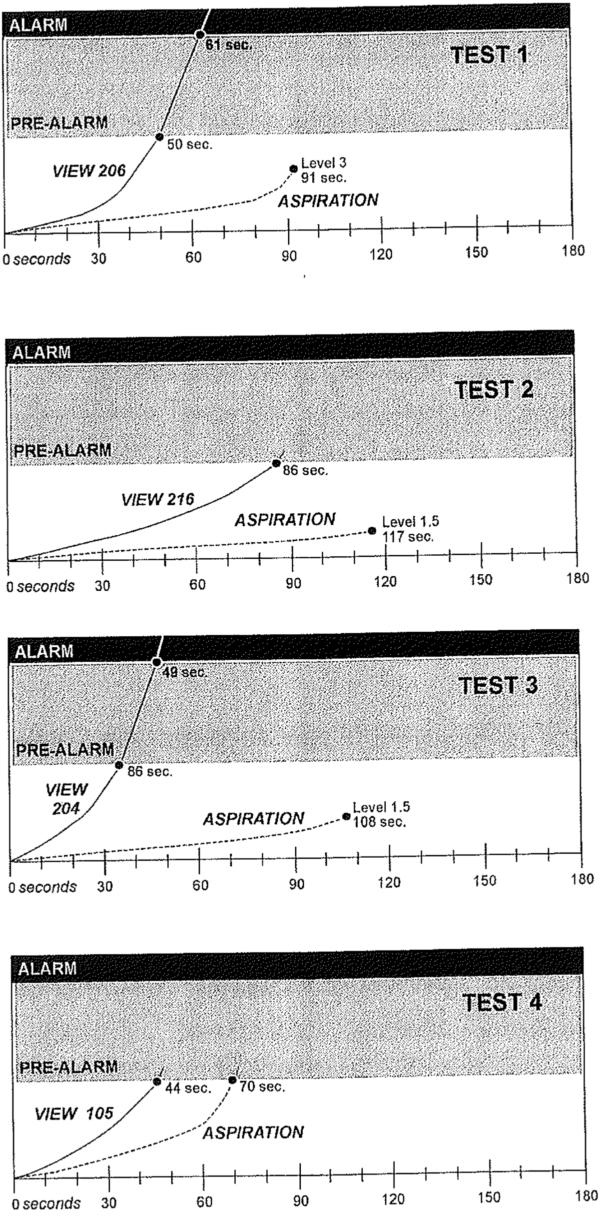


Figure 6 VIEW Performance Tests

S. Penney

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Development of a New Fire Detection Technology

Abstract

Use of a new fire detection technology requires a radically different development approach from that of detectors utilising established technologies. This work describes the development process to take carbon monoxide fire detection from the theoretical concept to an operational marketable detector to complement existing smoke detectors.

Background investigation of sensitivity to fire, for example fire type, effects of room ventilation, siting, and possible sources of false alarm, must be carried out in parallel with characterisation of possible approaches and how well they withstand the diverse operational and environmental constraints required of fire detectors.

Following the development process extensive proving trials in typical and extreme detector locations, are required to demonstrate the reliability of carbon monoxide fire detection technology for protecting the lives and property of potential customers.

Introduction

This paper is a summary of the 10 years development work that was involved in producing the new Tyco low profile carbon monoxide fire detectors. It can obviously only cover some aspects of the development process, but will hopefully provide an insight into some of the obstacles faced in developing a fire detector based on a completely new detection approach. In order to embark on such an extensive project several major issues had to be addressed, they were:

(i) What phenomena can be used for fire detection? Is there an **indicator** of fire, **other than** smoke, heat or flame that could be used?

(ii) How could it be detected? What **technologies** are available for detecting this fire indicator?

(iii) Could any of these technologies be used in a **commercial** fire detection system and, how would such technologies have to be adapted?

(iv) What alarm level should the new detector be set at? What level above background signifies the presence of fire?

(v) Is the new method any better? Where do strengths and weaknesses lie? Will it reduce false alarms?

(vi) Can the new technology compete commercially? What can be done to **prove** the effectiveness of the new detectors to potential customers?

Background

The carbon monoxide fire detector development came out of research at the Thorn EMI Central Research Laboratories, which attempted to address the first question - finding a suitable fire indicator.

The work started in 1987 with a literature study on the feasibility of using chemical sensors in fire detection; [ref. 1] this was followed by a detailed investigation of gases, smoke and temperature levels in EN54 Pt 9 standard test fires. [ref. 2] These tests revealed carbon monoxide above anticipated ambient levels was consistently present in early stages of fires.

The results were sufficiently supportive of the principle of fire detection using carbon monoxide that the scale of the project increased to address the second question - what are the available carbon monoxide sensing methods.

Potential Sensing Technologies

In 1988-9 a feasibility study was made to examine any technology available that might be used in a carbon monoxide based fire detector. [ref. 3] The choice of appropriate technology is determined by power requirements, susceptibility to other gasses, reliability and cost. Considering these factors, only two possibilities emerged: electrochemical cells and solid-state semiconductor oxide sensors, [ref. 4&5] with preliminary research on each during 1988-9.

At this stage the characteristics of a carbon monoxide detector had not been tightly defined and the 2mW upper ceiling on sensor power consumption had not been fixed, so low power heated solid-state sensors were potentially useable. AEA Harwell low- or room-temperature metal oxide sensors were evaluated, work was also done on sputtered tin oxide (SnO_2) films with a degree of success, [ref. 6] and a CASE studentship on microfabricated, thermally isolated sensor structures incorporating the tin oxide film, was started at Cambridge University. As understanding of sensing technologies improved the third question - adapting the technology to operate as a fire detector, had to be addressed.

Viability of Available Technologies

Power requirements of detectors set a 2mW limit on power dissipation, which ruled out heated sensors of any practical dimension. The room temperature metal oxide sensors were plagued with unreliability and instability problems, and demonstrated sensitivity to ambient humidity that would require significant compensation. This left electrochemical cells, where work focused on developing a cell that would be suitable for fire detectors, with stable, cheap, active, long life electrodes, and reliable connections from the electrode to the outside world.

Before further development was carried out, confirmation was required that the principle of carbon monoxide fire detection was viable, and an answer was needed to the fourth question - what should the alarm level be.

Carbon Monoxide Levels in Fires

Fire tests were carried out in a simulated hospital ward, [ref. 7] and department store in October 1990; and in January 1990 in a corridor outside a room containing a fire. These confirmed that carbon monoxide sensing could be advantageous in detecting real fires with a threshold level of 40 parts per million (ppm) carbon monoxide in air. [ref. 8] From a literature study it was determined that this level was enough to avoid spurious alarms, even in areas that normally encounter high ambient carbon monoxide levels. [ref. 9-15]

In 1991-2 progress was sufficiently encouraging to start developing a pilot cell to prove out the technology prior to manufacture. Shortly after this development programme began, doubts arose as to the adequacy of the early fire test results, and the advantages over smoke detection methods needed confirmation. Consequently it was decided to embark on an extensive series of comparative fire tests. [ref. 16]

Fire tests using prototype cells

Unfortunately the fire tests early in 1993 showed only that the ignition source is critical in how fires develop, and that large or flaming fires provide no useful discrimination between detector types. This meant that further tests were required to investigate carbon monoxide as a fire indicator, and a second set of tests were performed in the autumn of 1993. [ref. 17] Typical of findings from this extensive set of tests was that:

Fires started in confined areas such as storerooms gave significant carbon monoxide levels (4-500 ppm), both in the room, and adjacent rooms prior to other combustion products.

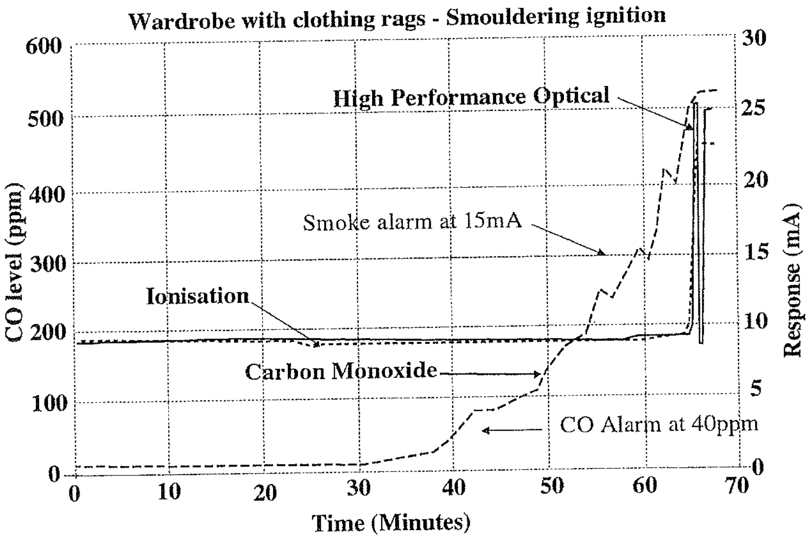

Figure 1: Clothing fire in an enclosed cupboard.

This was revealed dramatically in one fire (Figure 1), when carbon monoxide levels reached 50ppm, 25 minutes before any smoke detector responded. The smoke detectors only responded as the fire burnt through the doors, and exploded into a fireball, 65 minutes after ignition.

The conclusion of these tests was that carbon monoxide fire detection offered sufficient advantages to be worth pursuing.

However during this time commercial electrochemical cell design had improved; and was by then almost suitable for use in a prototype detector. This resulted in a shift in emphasis away from developing a sensor, towards working with a gas detection company adapting an already available cell for use within a fire detector. By the end of 1995 with the development of a new range of smoke detectors, came a prototype of the carbon monoxide fire detector using a commercial cell. At this point, the fifth question arose - where do the advantages of a carbon monoxide fire detector lie?

"Realistic" fire scenario tests

The previous fire research work, although significant, did not provide enough background information as to how a gas based fire detector would respond in many of the environments that are encountered in real installations. [ref. 18] This led to the "Real Scenario" fire tests, to investigate detector siting, ventilation, and room shape, which were completed in September 1995. [ref. 19]

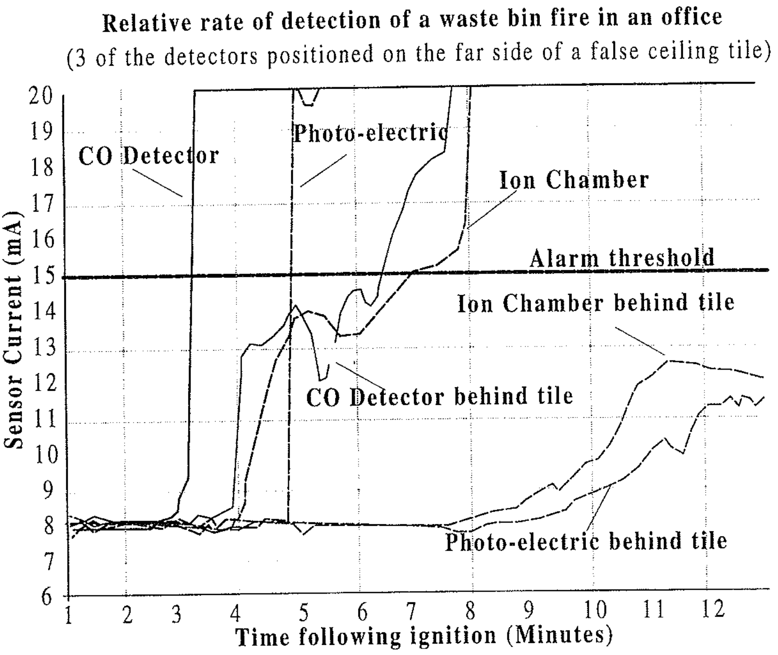

Figure 2: Waste paper bin fire in an office

The work showed carbon monoxide as a good fire indicator in most scenarios including those with forced ventilation and the preferential fire indicator when fires are likely to start in the smouldering phase, for example residential areas and offices. In these fires significant carbon monoxide levels can be present hours before smoke is detected giving significant advantages over traditional smoke detectors. The tests also proved carbon monoxide to be the best detection method in areas where smoke plume movement is impeded, behind ceiling tiles, by thermal layering effects, or when fires start in confined areas. However, a commercial fire detector must also be resistant to possible false alarm situations.

False Alarm Investigation

Consequently, part of the research, was into the susceptibility of a carbon monoxide fire detector to possible false alarm sources, including long term data logging in environments that were anticipated to be problematic. Many causes of spurious alarm for ionisation and photo-optical detectors that **do not** produce carbon monoxide and therefore **do not** cause false alarms for carbon monoxide detectors were also measured.

The positive results from both the fire and false alarm tests gave new impetus to the project, and showed that the **advantages** of carbon monoxide based fire detection could not be ignored, even when existing smoke detection methods are well established, understood, and do not require adaptation of current practices. Here lies the final question - What demonstration of effectiveness is required to gain acceptance for carbon monoxide fire detection.

Trialing the Detector in Real Situations

Test fires such as those used in EN54 and other smoke detector approvals are unsuitable to demonstrate the potential effectiveness of carbon monoxide as a fire indicator, as they do not provide a comprehensive insight into the nature of real fires, and how detectors behave in real environments.

Application tests

Although the earlier fire tests simulated real fires in carefully created realistic situations pre-production detectors needed evaluation in **real** conditions to verify the test results. To accomplish this number of fully operational, monitored, analogue addressable fire detection systems, had carbon monoxide fire detectors installed in parallel with the smoke detectors.

The trial sites were intended to check the immunity to false alarms, determine any installation problems, whilst checking the functionality of detectors in genuine environments. Many of the detectors were sited in areas where false alarms made smoke detectors impractical.

School - Detectors were installed in a large residential school in a cross-section of areas including accommodation, near showers in a sports changing room area, in the boiler room, in the corridor directly outside kitchens, a small laundry, a sanatorium, and various storage rooms. The school theatre had previously burned down because artificial smoke was being used on stage so the smoke detectors had to be disabled, which meant that the genuine fire remained undiscovered. So in the rebuilt theatre, all smoke detectors were **replaced** with carbon monoxide.

The only problem was that alarm conditions occurred in the Chemistry block when all the Bunsen burners were alight and set to yellow flame. This was found to be due to a build-up of carbon monoxide in the laboratory - which subsequently became the subject of a safety investigation!

Cruise Liner - On a cruise liner detectors were installed in parallel with the main fire detection system in cabins, library, gym, corridors and laundry area including washing, dry cleaning, drying, ironing producing steam, cotton dust etc.

Food Processing Factory - A number of detectors were located in a warehouse for green coffee beans with excessive coffee bean dust and diesel forklift trucks.

Other sites - Other sites included the Tyco warehouse in the UK, a major film processing company's premises, a clubhouse with detectors installed in the kitchen, restaurant, bar, hall area, reception and generator room, a major department store, and in various problem environments on an aircraft manufacturing site.

Fire detected! - Trials started without any expectations of a real fire on any of the trial sites. However, the benefits of the carbon monoxide detection system were proven when a fire in one of the test site boiler rooms was detected. The incident did not develop due a carbon monoxide detector in an adjoining office detecting the rise in carbon monoxide through the breeze block wall before any smoke or flames developed. This demonstrated a key advantage that carbon monoxide molecules can pass through very small gaps that are impervious to smoke, to reach detectors more effectively.

Summary

From the field trials and all the technological, false alarm, and fire test research it has become clear that the carbon monoxide fire detector is an effective fire detection method. Where spurious alarms have generated problems for current smoke detection techniques, replacement of smoke detectors with carbon monoxide detectors, could provide an instant solution.

Conclusion - Detector Approvals

Although in Europe there are no standards for testing carbon monoxide fire detectors, LPCB in England agreed to test and approve carbon monoxide fire detectors against a test schedule based on EN54 part 7. [ref. 20] In Australia the 1603.2 smoke detector standard is worded differently and carbon monoxide detectors have been approved against that standard, although they are now developing a standard specifically for carbon monoxide fire detectors. [ref. 21] However UL and marine approvals bodies are unwilling to approve a fire detector that is not based on the already accepted smoke, heat, and flame technologies.

Therefore, a question remains for those of us in the industry. Do we want to continue to develop new fire detection technologies that could save more lives, or are we satisfied with what we currently do? As can be seen from this presentation, If we wish to develop new fire detection technologies, it will always demand considerable investment of time and effort; but if lives are saved it is all worth while.

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Untersuchungen über den Einsatz mobiler Brandmeldeanlagen

Übersicht

Auf mehreren Baustellen innerhalb eines Großklinikums wurde der Einsatz von mobilen Brandmeldeanlagen erprobt. Eine weitere Anlage wurde in einer Turnhalle installiert, um Vandalismus mit Brandstiftung rascher zu erkennen. Die Anlagen arbeiteten erst dann zufriedenstellend und weitgehend ohne Störungs- und Falschalarme, nachdem die Beschäftigten auf den Baustellen die Installationen akzeptiert hatten. Als Ergebnis der Untersuchungen wurde eine Richtlinie für den Einsatz und Betrieb mobiler Brandmeldeanlagen ausgearbeitet.

Abstract

Temporarily fixed fire detection systems were installed and put on test on various construction sites of a major health care facility. Another system was installed inside a gymnasium to help detect vandalism through fire setting. The system worked properly and with a reduced number of erranous and false alarms only after their operation was integrated into the work processes of the construction sites. From these experiences guidelines for the installation and operation of semi-fixed fire detection system were devised.

1 Einleitung

Bei brandschutztechnischen Untersuchungen der Flucht- und Rettungswege in einem Großklinikum ergab sich die Frage, wie die zahlreichen Baustellen innerhalb der einzelnen Kliniken besser auf Brandgefahren überwacht werden könnten. Krankenhäuser sind brandschutztechnisch sehr sensible Objekte. Dazu kommt, daß insbesondere Baustellen als Orte mit erhöhter Brandgefahr gelten. Wenn Bauarbeiten - häufig verbunden mit Schweißen, Brennschneiden und Löten - in unmittelbarer Nachbarschaft zu mit Kranken belegten Stationen durchgeführt werden müssen, dann ist vor allem in kritischen Zeiten – nachts, an

Wochenenden und Feiertagen und während der Bauferien – eine zusätzliche Überwachung notwendig.

Schon Otto hat 1977 vorgeschlagen, Baustellen mit Schweißarbeiten durch mobile Brandmeldeanlagen (mBMA) überwachen zu lassen [1]. Nur stand das anlagentechnische Know-how damals noch nicht zur Verfügung. Inzwischen wird aber die Signalübertragung per Funk erfolgreich für Einbruchmeldeanlagen und Brandmeldeanlagen genutzt (naturgemäß haben beide Anlagentypen vieles gemeinsam). Neben Baustellen können Funk-Brandmeldeanlagen vorteilhaft in Bereichen eingesetzt werden, in denen nur vorübergehend auf Brandgefahren herrschen, z.B. in Hallen, die temporär für die Lagerung von Gütern genutzt werden. Die Berufsfeuerwehr Essen berichtet über einen erfolgreichen Einsatz von Funk-Brandmeldeanlagen auf dem Essener Weihnachtsmarkt und in zwei Hallen zur Überwachung einer Ausstellung bzw. des Umbaus einer Lüftungsanlage [2].

Unsere Aufgaben war es nun, auf dem Markt vorhandene Funk-Brandmeldeanlagen beim praktischen Einsatz zu erproben und zu klären, wie sich die Anlagen in die Organisation der Bauarbeiten integrieren lassen . Zusätzlich wurden einige Brand- und Verrauchungsversuche durchgeführt. Als Ergebnis der Arbeiten entstand der „Entwurf einer Richtlinie für die Installation und den Betrieb mobiler Brandmeldeanlagen“ ausgearbeitet [3, 4].

Funk-Brandmeldeanlagen, mobile Brandmeldeanlagen

Funk-Brandmeldeanlagen bestehen i.a. aus folgenden Komponenten:

1. batteriebetriebene Funkbrandmelder,
2. Funkmeldezentrale, die ggfs mit einer Wählautomatik ausgerüstet und die über Funk oder auch drahtgebunden mit einer
3. Alarmzentrales verbunden ist.

Brandmelder

Grundsätzlich können für Funk-Brandmeldeanlagen alle Brandmelder eingesetzt werden, die man auch in konventionellen BMA verwendet. Weil auf Baustellen insbesondere die rechtzeitige Entdeckung von Feststoffbränden mit länger andauernde Schwel- und Glimmphasen während der arbeitsfreien Zeiten und in nicht beobachteten Bereichen Schwierigkeiten bereitet, sind Rauchmelder nach dem Streulichtprinzip am besten geeignet. Für diese Melder liegen meisten Erfahrungen vor, und sie sind auch am weitesten entwickelt.

Wärmemelder eignen sich für den Einsatz auf Baustellen im allgemeinen nicht, weil sich der für das Ansprechen erforderliche Wärmestau bei der Brandentwicklung auf den häufig offenen Baustellen kaum ausbilden kann. Für Flammenbrände könnte man auch Flammenstrahlungsmelder einsetzen. Sich rasch ausbreitende offene Brände, z.B. beim Verlegen von Schweißbahnen auf Dächern, werden aber von den Beschäftigten sofort erkannt und im allgemeinen auch unmittelbar danach gemeldet.

Neben den Rauchmeldern nach DIN EN 54-7 werden von einigen Herstellern aus Kostengründen auch für den Privatbereich konzipierte Brandmelder eingesetzt, die z.B. den Anforderungen nach BS 5446 P.1 entsprechen. Der langandauernde Piepton, den solche Melder abgeben, wenn sie z.B. auf Staubentwicklung oder Schweißrauch ansprechen, kann aber für die Beschäftigten auf der Baustelle durchaus lästig sein.

Brandmeldezentrale

Als Brandmeldezentralen (BMZ) für mobile Anlagen werden häufig Funkeinbruchmeldezentralen (EMZ) verwendet, die sich durch geringe Modifikationen anpassen lassen. Im allgemeinen brauchen die BMZ eine netzabhängige Spannungsversorgung. Bei Spannungsausfall kann ein Akku 12 – 72 Stunden den Notbetrieb gewährleisten. Bei einigen Einbruchmeldezentralen gewährleisten die Batterien auch einen Betrieb über Monate.

Die Geräte sollten einen Historyspeicher enthalten, in dem Vorgänge wie Inbetriebnahme, Alarm, Störung usw. gespeichert werden. Auf diese Weise können die letzten fünf bis zehn Meldungen auf einem Display oder auch in der Alarmzentrale abgerufen werden. Die Signale von mehreren Meldern, bei EMZ bis zu 50, können zu Linien oder Gruppen zusammengefaßt werden. Die Signalübertragung erfolgt in dem für allgemeine Anwendungen freigegebenen ISM-Band zwischen 433,05 – 434,79 MHz (70-cm-Wellen) mit einer maximalen Sendeleistung von 10 mW. In dem genannten Frequenzbereich ist aber mit Funkstörungen durch andere ISM-Anwender, auf Baustellen insbesondere durch Steuerungen für Baukräne oder LPD-Handys, bzw. durch geräte mit starken elektromagnetischen Feldern zu rechnen. Daher ist eine getrennte Anzeige von Alarm- und Störungsmeldungen an der BMZ auf jeden Fall zu empfehlen. Melder und BMZ können entweder unidirektional (Brandmelder ist Sender und Zentrale Empfänger) oder bidirektional (beide Geräte sind jeweils Sender und Empfänger) miteinander kommunizieren. Bidirektionale Systeme haben den Vorteil, daß alle

Meldungen bestätigt werden können. Bei fortgeschrittenen unidirektionalen Systemen erwartet die Zentrale ein Signal und setzt eine Störungsmeldung ab, wenn es ausbleibt. Auf die funktechnischen Maßnahmen, die zu treffen sind, um eine möglichst ungestörte Übertragung zwischen Melder und Zentrale zu gewährleisten, wird hier nicht eingegangen.

Bei der Konzeption einer mobilen Brandmeldeanlage ist die begrenzte Reichweite bei den schwachen Sendeleistungen besonders zu berücksichtigen. Weiter verringert wird die Reichweite durch die verminderte Durchdringung von 70-cm-Wellen durch verschiedene Baustoffe. Sie beträgt z.B. bei Holz und Gips 90 – 100 %, bei Backstein 65 – 95 %, bei armiertem Beton 10 – 70 % und bei Alukaschierung sogar nur 0 – 10 % im Vergleich zu Luft. Bei Stichversuchen in einem Gebäudekomplex wurden erwartungsgemäß beträchtliche Unterschiede bei den Reichweiten festgestellt, die zum Teil von den Herstellerangaben abwichen. Mit dem Baufortschritt auf Baustellen, etwa durch das Errichten von Wänden, das Einziehen von Zwischendecken und das Einsetzen von Türen kann also auch die Funkverbindung beeinträchtigt werden. Dies ist besonders bei Anlagen älterer Bauart zu berücksichtigen, bei denen die Funkverbindung nicht automatisch überwacht wird (siehe oben) , das heißt, eine Unterbrechung der Verbindung oder der Ausfall eines Melders an der Zentrale unbemerkt bleiben kann.

Alarmzentrale

Auch die BMZ einer mBMA muß mit einer Alarmzentrale in einer ständig besetzten Stelle verbunden sein, z.B. mit einer Leitzentrale eines Gebäudekomplexes, mit dem Pförtner oder direkt mit der Einsatzleitstelle einer Feuerwehr. Die Verbindung kann entweder über Funk oder über eine Standleitung hergestellt werden. Bei einer Funkverbindung sind die bereits erwähnten Probleme zu beachten. Zusätzlich ergeben sich aber einige organisatorische Besonderheiten: Jede Änderung der mBMA, beispielsweise ein Versetzen der Brandmelder muß am Standort der Alarmzentrale dokumentiert werden. Sofern die Feuerwehr nicht selbst bei der Installation der Anlage beteiligt ist, sollte sie bei einem Brandalarm mindestens auf eine Skizze der Standorte der Melder zurückgreifen können. Eine derartige Skizze kann einen Feuerwehreinsatzplan bzw. einen Installationsplan einer Brandmeldeanlage zwar nicht ersetzen, aber mindestens sinnvoll ergänzen.

Untersuchungen und Ergebnisse

Brand- und Verrauchungsversuche

Um das Ansprechen der Rauchmelder von mBMA unter schwierigen aber typischen Einsatzgebieten zu überprüfen, wurden einige Brand- und Verrauchungsversuche durchgeführt. Die Bedingungen und die Ergebnisse sollen hier nicht im einzelnen dargestellt werden (siehe dazu [4]). Die Stichversuche liefern Hinweise für die Installation der Brandmelder, die allerdings durch systematische Untersuchungen ergänzt werden müssen.
Der Abbrand von Brandlasten in der Größenordnung der Testfeuer nach DIN EN 54 erzeugt in großen Räumen zu wenig Rauch, um die Rauchmelder immer zum Ansprechen zu bringen. Der Rauch kann auch durch Luftzug im Raum zu stark verweht werden. Verrauchungsversuche mit Rauchpatronen führten auf jeden Fall zum Erfolg. Auch Zugrichtungen waren gut zu erkennen. Allerdings läßt sich der Auftrieb von warmem Brandrauch nicht ausreichend simulieren.

Eine flächendeckende Überwachung mit mBMA, wie sie nach den VdS-Richtlinien für stationäre BMA vorgesehen ist, ist auf Baustellen praktisch nicht möglich. Es ist daher zweckmäßig, die Melder so zu installieren, daß Rauch an Öffnungen und Übergängen zu Nachbarbereichen detektiert werden kann. Dabei sind die vorherrschende Luftzugrichtungen zu beachten.

Betriebsversuche

Durch die Betriebsversuche sollte vor allem geklärt werden, wie sich mobile Brandmeldeanlagen in einen Baustellenbetrieb integrieren lassen. In einer ersten Versuchsreihe wurden vier Anlagen auf den Baustellen eines Krankenhauses für 132 bis maximal 142 Tagen installiert. Die Mitarbeiter auf den Baustellen und das in den Kliniken betroffene Personal wurde zunächst gründlich auf den Einsatz der Anlagen vorbereitet und speziell geschult. Durch Aushänge auf den Baustellen wurde auf die Installation der Anlagen hingewiesen. Zwei Brandmeldezentralen waren in Elektroverteilungen, je eine in einem alten Telefonverteilerschrank sowie in einer Klimazentrale untergebracht. Die Alarmzentrale befand sich beim Pförtner, der das jeweils zuständige Personal zu alarmieren hatte. Auf eine Durchschaltung des Alarms zur öffentlichen Feuerwehr wurde wegen des Probebetriebs der

Anlagen bewußt verzichtet. Das Klinikum selbst verfügt bis jetzt nicht über eine Werkfeuerwehr oder Betriebsfeuerwehr.

In keinem Fall stellten die Anlagen einen realen Brand fest. Dennoch detektierten zwei Anlagen je sechs Alarme, die zum Teil als Täuschungsalarme identifiziert, zum Teil aber nicht zugeordnet werden konnten, weil die Melder keine Einzelmelderkennung besaßen. Wegen der Häufung von Alarmen unbekannter Ursache wurde eine dieser Anlagen für 29 Tage außer Betrieb genommen.

Eine weitere Anlage wurde in der Turnhalle einer Grundschule installiert, in der es wiederholt zu Akten von Vandalismus und auch Brandstiftung gekommen war. In diesem Fall war die Alarmzentrale mit der Feuerwehr verbunden. Nachdem es aber hier – wahrscheinlich wegen eines defekten Melders – wiederholt zu Falschalarmen kam, wurde die Anlage zunächst stillgelegt.

Die Betriebsversuche wurden durch eine zweite Versuchsreihe mit insgesamt neun, zum Teil verbesserten Anlagen ergänzt. Am Anfang dieser Versuchsreihe wurde der Anlagenbetrieb auf einigen Baustellen massiv gestört, indem Melder „herunterfielen“ sowie einige Melder und eine Batterie entwendet wurden. Nach intensiven Belehrungen und einer Gewöhnungsphase besserte sich die Situation aber grundlegend. Die Installationen der Anlagen und die Versuchsergebnisse während des ungestörten Betriebs sind in Tabelle 1 zusammengefaßt.

Im Vergleich zur ersten Versuchsreihe nahm die Zahl der Falschalarme drastisch ab. Offensichtlich wurden die Anlagen von den Beschäftigten allmählich besser akzeptiert. Es zeigte sich auch, daß die Mitarbeiter ihr Verhalten änderten und überwachte Baustellen ordentlicher und aufgeräumter gehalten wurden; vor allem betriebliche Brandschutzmaßnahmen wurden besser beachtet (Entfernung von Verpackungsmaterialien, Vorhaltung von Feuerlöschern). Weil aber ein Alarm auf einer Baustelle, z.B. durch Verletzung des Rauchverbots, innerhalb kurzer Frist zu einer Kontrolle geführt hätte, wurden Zigarettenkippen nun vermehrt außerhalb des engeren Baustellenbereichs gefunden. Es läßt sich nur schwer abschätzen, ob Gewöhnungseffekte auf die Dauer nicht wieder kontraproduktiv wirken, das heißt, ob sich nicht bei regelmäßiger und langandauernder Überwachung der Baustellen wieder ein gewisser Schlendrian einschleicht.

Mit Ausnahme einer Anlage wurden die Anlagen im kontinuierlichen Betrieb eingesetzt. Diese Betriebsart umfaßt ständige Betriebsbereitschaft einschließlich kurzer Abschaltzeiten einzelner Melder sowie der gesamten Anlage zur Überprüfung oder Wartung. Eine Baustelle auf der mit starker Rauch- und Staubentwicklung gerechnet werden mußte, wurde nichtkontinuierlich überwacht, daß heißt, hier wurde die Anlage an Arbeitstagen von 7.00 – 16.00 Uhr abgeschaltet. Eine stichprobenartige Befragung der Mitarbeiter ergab, daß das Wiedereinschalten der Anlage durchschnittlich zweimal pro Monat vergessen wurde. Hier wäre also der Einsatz einer Zeitprogrammschaltung mit Berücksichtigung von Wochenenden und Feiertagen vorteilhaft. Der Betrieb der Brandmelder während der Einschaltzeiten der Anlage wurde durch die vorherige Rauch- und Staubexposition nicht beeinträchtigt.

Tabelle 1: Installationen der mobilen Brandmeldeanlagen und registrierte Alarme

Baustelle Nr	Meldertage[1]	Gebäudebereich	Anzahl der Alarme	Bemerkungen
1	40	Klinik1, 1.OG		—
2	96	Klinik 2, 3.OG		—
3	648	Klinik 3, Dachboden		auslösender Melder nicht identifiziert
4	40	Klinik 4		—
5		Klinik 1, EG		—
6	596	Klinik 2, 4. OG.		auslösender Melder nicht identifiziert
7	264	Klinik 2, 2. + 3.OG		—
8a	184	Klinik 5 umfangreicher Erweiterungsbau		techn. Störungen
8b	40			techn. Störungen
8c	680			Raucher; Umhängen der Melder
9	1260	Turnhalle[2]		—

[1] Zahl der Melder x eingesetzte Tage

[2] Überwachung auf Vandalismus und Brandstiftung

Die Weiterleitung eines Alarms an eine ständig besetzte Stelle war während der gesamten Versuchszeit gewährleistet, so daß eine Intervention im Fall eines echten Brandalarms immer möglich gewesen wäre. Zur Alarmbearbeitung wurde auch stets ein Techniker bzw. Werkstattpersonal der Kliniken hinzugezogen. Die Anlagen sollen auch nach den Versuchsreihen weiterbetrieben werden. Bei der Anlage in der Turnhalle war durch den Aufbau einer Telefonkette eine ständige Eingreifmöglichkeit gewährleistet.

Weitere Folgerungen aus den Ergebnissen

Auf Baustellen folgen einander im allgemeinen unterschiedliche Gewerke. Hier ist für einen reibungslosen Informationstransfer über die Baustellenüberwachung durch Brandmelder zu sorgen. Außerdem ist auch an die ausländischen Beschäftigten zu denken; Hinweise müssen in den jeweiligen Landessprachen gegeben werden, entsprechende Aushänge sollten vorhanden sein.

Für die Installation, die Unterrichtung der Baustellenmitarbeiter, sowie die Kontrolle und Wartung der Anlagen muß ausreichend qualifiziertes Personal vorhanden sein. Die dafür notwendigen Zeiten und Kosten sind bei der Kalkulation der Gesamtkosten der mBMA zu berücksichtigen. Bei den eigenen Untersuchungen wurden für die nachfolgend aufgeschlüsselten Tätigkeiten zusammen durchschnittlich 1,5 – 2 Stunden je Baustelle benötigt:

1 Überprüfung der Anlage vor der Installation;
2 Baustellenbegehung, Feststellen der kritischen Übergänge; Festlegen der Installationsorte der einzelnen Melder sowie der Anbringen der Brandmeldezentrale;
3 Installation der Komponenten;
4 Testen der Anlage auf ordnungsgemäße Funkverbindungen;
5 Anfertigen einer Installationsskizze;
6 Anbringen der Hinweisschilder;
7 Information der Mitarbeiter.

Wir empfehlen nach den eigenen Erfahrungen, bei einer wöchentlichen Begehung eine Sichtkontrolle entsprechend dem Baufortschritt durchzuführen und die Melder entsprechend dem Baufortschritt zu versetzen. Bei einer monatlichen Kontrolle sind zusätzlich die folgenden Arbeiten durchzuführen:

1 Funktionstest der Melder und Überprüfung der Stromversorgung;
2 Überprüfung der Funkverbindungen.

Außerdem ist sicherzustellen, daß Mitarbeiter neuer Gewerke ausreichend über die Funktion der Anlagen informiert werden.

Verbleibt eine Anlage länger als ein halbes Jahr bei einem Betreiber, so sind nach dieser Zeit die Batterien auszutauschen und die Anlageteile zu reinigen und zu pflegen. Alle Arbeiten und Änderungen an den Anlagen sind in einem Betriebsbuch zu dokumentieren. Der Zeitbedarf für die Kontrollen und Wartungsarbeiten hängt sehr stark von den örtlichen Bedingungen ab und läßt sich nur schwer verallgemeinern.

Wenn eine Feuerwehr (Werk- oder Betriebsfeuerwehr, in Einzelfällen auch eine öffentliche Feuerwehr) nicht selbst die Betreuung der Anlagen übernimmt, muß der Betreiber der Baustelle oder der Bauherr eine verantwortliche Person bestimmen, am besten jemand, der auch sonstige Aufgaben im Brandschutz wahrnimmt, z.B. den Brandschutzbeauftragten. Das Interesse von Errichterfirmen von stationären Brandmeldeanlagen mBMA zu installieren, zu warten oder an Baustellenbetreiber vermieten ist wegen des hohen Aufwandes bisher eher gering.

Erstellung einer Richtlinie für den Einsatz mobiler Brandmeldeanlagen

Im Zusammenhang mit den Untersuchungen wurde der **Entwurf einer Richtlinie für Installation und Betrieb mobiler Brandmeldeanlagen** ausgearbeitet. Die Richtlinie enthält folgende Teile:

1 Allgemeine Bedingungen für den Einsatz mobiler Brandmeldeanlagen
2 Begriffsbestimmungen und Beschreibung der Technik
3 Projektierung
4 Installation
5 Betrieb
6 Organisatorische Maßnahmen
7 Sonstige zu beachtende Normen und Richtlinien
8 Installationsbeispiele

Anhang: Aushänge auf Baustellen.

In der Richtlinie wurden die Erkenntnisse aus den bisherigen Untersuchungen verarbeitet. Es ist in diesem Zusammenhang zu betonen, daß die Überwachung eines Bereichs durch eine mBMA andere Brandschutzmaßnahmen nicht ersetzen, sondern ergänzen kann. Dies gilt besonders für die Nachschau auf eine eventuelle Brandentstehung nach Schweißarbeiten.

In dem Entwurf, der der Fachwelt vorgestellt werden soll, befinden sich auch Installationsbeispiele.

Die Autoren bedanken sich bei der Westfälischen Provinzial-Feuerversicherungsgesellschaft, Münster für die Förderung der Arbeiten.

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Täuschungsalarme von Brandmeldeanlagen durch Löschgasübertragung in Nachbarbereiche

Abstract

The release of extinguishing systems using gaseous agents can result in false alarms of the automatic fire detectors due to the accompanying effects of a discharge and can bring about the unwanted release of further extinguishing systems.

With due consideration of the extinguishing agent applied, choice of the automatic fire detectors, structure and control of the extinguishing system as well as of structural aspects, protection concepts can be developed capable of almost excluding such scenarios.

Einleitung

Freitag, den 26.12.1997, 04:11:54 Uhr. In einem Rechenzentrum kommt es im Gebäude 2, Raum 102 aus ungeklärter Ursache zur Auslösung der zum Schutz der insgesamt 9 Datenroboter installierten CO_2-Feuerlöschanlage.

Durch die Auslösung dieser Einrichtungsschutzlöschanlage werden 600 kg CO_2, bevorratet in 20 Stahlflaschen à 40 Liter Inhalt, in die Datenroboter eingeblasen.

Wenige Augenblicke später kommt es zum Ansprechen der im Raum unter der Decke installierten automatischen Brandmelder. Mit dem Erreichen des Brandmeldezustandes erfolgt über die Ansteuereinrichtung der Brandmelderzentrale der Löschbefehl an die elektrische Steuereinrichtung und der Auslösebefehl an die Löscheinrichtung zum Schutz des gesamten Raumes. Nach Ablauf der Vorwarnzeit werden von dieser zweiten Löschanlage ca. 3000 kg CO_2 in den Raum eingebracht.

Kurz darauf erfolgt die Auslösung einer Löschanlage im angrenzenden Flurbereich. Diesmal handelt es sich um eine Sprühwasserlöschanlage, die ebenfalls über eine automatische Brandmeldeanlage angesteuert wird.
An Hand des Ausdruckes der Brandmelderzentrale läßt sich später nachvollziehen, daß der indifferente Zustand der Anlage vor 04:11:54 Uhr herrschte, da die danach aufgezeigte Folge der Alarmierungs- und Löschvorgänge den vorgegebenen Mustern und sicherheitstechnischen Vorgaben entsprach.

Im folgenden werden die Ursachen dieser „Kettenauslösung" von Löschanlagen sowie Möglichkeiten zur Vermeidung derartiger Schadenfälle erörtert.

Ursache

Bei Gaslöschanlagen kommt es während der Flutung durch das Einbringen des Löschmittels häufig zu Staubaufwirbelungen. Beim Einsatz von CO_2 entsteht durch das Unterschreiten des Taupunktes zusätzlich Wassernebel.
Aufgrund des während der Flutung entstehenden Überdrucks strömt ein Teil des Löschgases durch Öffnungen, aber auch durch übliche Raumundichtigkeiten (z.B. Fenster-, Türritzen) in die umliegenden Räume, in denen es dann ebenfalls zu Staubaufwirbelungen und ggf. zur Bildung von Wassernebel kommen kann. Durch diese Begleiterscheinungen der Flutung von Gaslöschanlagen kann es zu Täuschungsalarmen von automatischen Brandmeldern kommen. Dienen diese Brandmelder zur automatischen Ansteuerung einer Löschanlage, so kommt es zur Auslösung der Löschanlage obwohl kein Brand vorliegt.
Im geschilderten Schadenfall führten die Begleiterscheinungen der Flutungen von CO_2-Feuerlöschanlagen zu Täuschungsalarmen der Brandmeldeanlage und damit zum Auslösen weiterer Löschanlagen.

Befinden sich mehrere Löschbereiche innerhalb eines Gebäudekomplexes, ist bei der Realisierung des Schutzkonzeptes auf eine gegenseitige Beeinflussung durch Löschgasübertragung zu achten.

Zu berücksichtigen sind:

- die Zusammensetzung des verwendeten Löschmittels,
- die Art der Branderkennung,
- die Steuerung der Löschanlage,
- die baulichen Abtrennungen.

Aufbau und Steuerung von automatischen Löschanlagen

Die **Branderkennung** im Löschbereich erfolgt durch:

- Brandmeldeanlagen oder
- Branderkennungseinrichtungen (meist ohne elektrische Energie, z.B. Seilzüge mit Schmelzlotelementen oder pneumatische Anregerohrnetze)

Dabei unterscheidet man folgende Arten von Branderkennungselementen:

a) Branderkennungselemente, die mechanisch wirken (z.B. Schmelzlotfühler und Thermotrennglieder)
b) Branderkennungselemente, die pneumatisch wirken (z.B. Wärmefühler)
c) Branderkennungselemente, die elektrisch wirken (z.B. Stabtemperaturfühler)
d) Branderkennungselemente, die den Richtlinien für automatische Brandmelder entsprechen (z.B. EN 54-7)

Brandmeldeanlagen können in den feuerlöschanlagenrelevanten Meldebereichen die unter c) und d) genannten verschiedenen Branderkennungselemente enthalten.

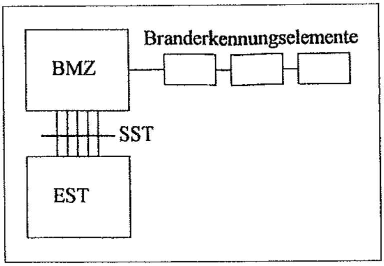
Zu jeder automatischen Feuerlöschanlage gehört auch eine **Steuereinrichtung**.

Steuereinrichtungen werden von Brandmeldeanlagen oder Branderkennungseinrichtungen angesteuert und steuern den ordnungsgemäßen Funktionsablauf der Löschanlage.

Steuereinrichtungen werden nach Art der Energie, mit der sie arbeiten, unterteilt in elektrische Steuereinrichtungen und nichtelektrische Steuereinrichtungen.

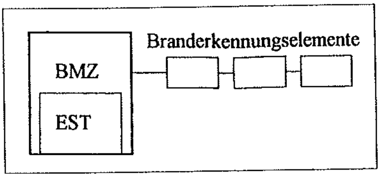
Ist für die Branderkennung im Löschbereich eine Brandmeldeanlage vorgesehen, wird immer eine elektrische Steuereinrichtung benötigt.

Die Ansteuerung der elektrischen Steuereinrichtung einer Löschanlage durch die Ansteuereinrichtung einer Brandmelderzentrale muß grundsätzlich über eine Schnittstelle erfolgen. Die Schnittstelle verseht sich als Übergang an der Grenze zwischen zwei Funktionseinheiten, dem Branderkennungsteil und dem Löschteil der Feuerlöschanlage, mit vereinbarten Regeln für die Übergabe von Daten und Signalen (siehe VdS 2496 Richtlinien für die Ansteuerung von Feuerlöschanlagen).



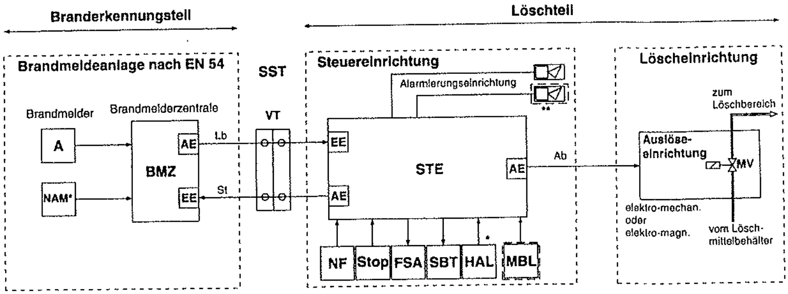
Anschaltung über Schnittstelle

Unter besonderen Umständen kann bei der Ansteuerung die Schnittstelle entfallen. In diesem Fall übernimmt die Brandmeldeanlage neben der reinen Branderkennung auch Aufgaben der Löschanlagensteuerung.



Anschaltung ohne Schnittstelle

Die nachfolgende Darstellung zeigt das Beispiel einer elektrisch, über eine Brandmeldeanlage ausgelösten CO_2 -Feuerlöschanlage.



Erläuterungen:

A	Brandmelder nach EN 54 (bzw. nach Systemanerkennung)
Ab	Auslösebefehl
AE	Ansteuereinrichtung
BEE	Branderkennungselement (z.B. Stabtemperaturschalter)
BMZ	Brandmelderzentrale
EE	Empfangseinrichtung
FSA	Feuerschutzabschluß
HAL	Handauslösung
Lb	Löschbefehl
MBL	Blockiereinrichtung
MV	Magnetventil
NAM	Nichtautomatischer Brandmelder
NF	Nachfluten
SBT	Steuerung Betriebstechnik
SST	Standardschnittstelle
St	Störungsmeldung
STE	Steuereinrichtung
Stop	CO_2-Stop
VT	Schnittstellenverteiler
*	Anschaltung als Handauslösung an BMZ oder STE
**	2. Alarmmittel (pneumatsich)
— —	mechanisch/pneumatisch wirkendes Gerät

Alle Bauteile müssen auf ein funktionsfähiges Zusammenwirken abgestimmt sein. Bei VdS SCHADENVERHÜTUNG wird dies durch ein Bauteil- und Systemanerkennungsverfahren sichergestellt.

Lösungsansätze

Das zu Beginn geschilderte Problem von Täuschungsalarmen und ungewollten Auslösungen von Feuerlöschanlagen aufgrund von Löschgasübertragung besteht nur bei Feuerlöschanlagen, die über automatische Brandmeldeanlagen angesteuert werden. Eine weitere Eingrenzung kann bei der Auswahl der Branderkennungselemente vorgenommen werden.

Erfahrungen aus der Praxis haben gezeigt, daß die Begleiterscheinungen einer Flutung (Staubaufwirbelungen, Wassernebel) ausschließlich bei Rauchmeldern zu Täuschungsalarmen führen.

Bauliche Abtrennung

Als Maßnahmen zur Vermeidung von Täuschungsalarmen durch Löschgasübertragungen in Nachbarbereiche sind an erster Stelle bauliche Vorgaben einzuhalten.

Handelt es sich beim Schutzbereich der Löschanlage um ein gesamtes Gebäude oder einen Gebäudeteil, einen Raum oder eine umschlossene Einrichtung, müssen die Umfassungsbauteile ausreichend gasdicht sein, um so die löschwirksame Konzentration bis zum Ende der Einwirkzeit sicherzustellen. Wanddurchbrüche für Leitungen, Kabel, Rohre usw. müssen durch entsprechende Abschottungen verschlossen werden. Absperrvorrichtungen gegen Brandübertragung in Lüftungsleitungen müssen automatisch schließen, Türen müssen selbstschließend eingerichtet werden.

Da übliche Raumundichtigkeiten (z.B. Fenster- und Türritzen) zulässig sind und darüber hinaus auch baulich nicht umschlossene Einrichtungen geschützt werden, ist auf die Auswahl und Projektierung der automatischen Brandmelder ein besonderes Augenmerk zu richten.

Melderauswahl

Neben den üblichen Maßnahmen zur Vermeidung von Falschalarmen, wie der Zwei-Melder- oder Zwei-Gruppen-Abhängigkeit, kann es sinnvoll sein, die Auslösung der Feuerlöschanlage nicht nur von den Meldungen zweier

Brandmelder, welche die gleiche Brandkenngröße detektieren (z.B. Rauch), sondern zudem von zwei unterschiedlichen Brandkenngrößen (z.B. Rauch und Wärme) abhängig zu machen.

Dabei kann ein Staffelschutz realisiert werden. Eine erste empfindliche Brandmeldergruppe sichert die Früherkennung durch Vorinformation (interne optische und akustische Anzeige z.B. an der ständig besetzten Stelle -kein Löschalarm) und kann zur Steuerung von Betriebsmitteln (z.B. Abschaltung von Lüftern, Schließen von Brandschutzabschlüssen) genutzt werden. Erst in Verbindung mit einer zweiten Meldung (z.B. von einem Wärmemelder) wird die Feuerlöschanlage, gegebenenfalls mit notwendigem Löschalarm und anderen Sicherheitseinrichtungen, ausgelöst. Eine eventuelle Vorinformation/ Vorwarnung vor Ort muß sich dabei eindeutig vom Löschalarm unterscheiden. Ebenso kann der Einsatz von Mehrfachsensormeldern sinnvoll sein. Mehrfachsensormelder gelten jedoch nicht als integrierte Zwei-Melder-Abhängigkeit, da eine örtliche Trennung der verschiedenen Sensoren nicht gegeben ist.

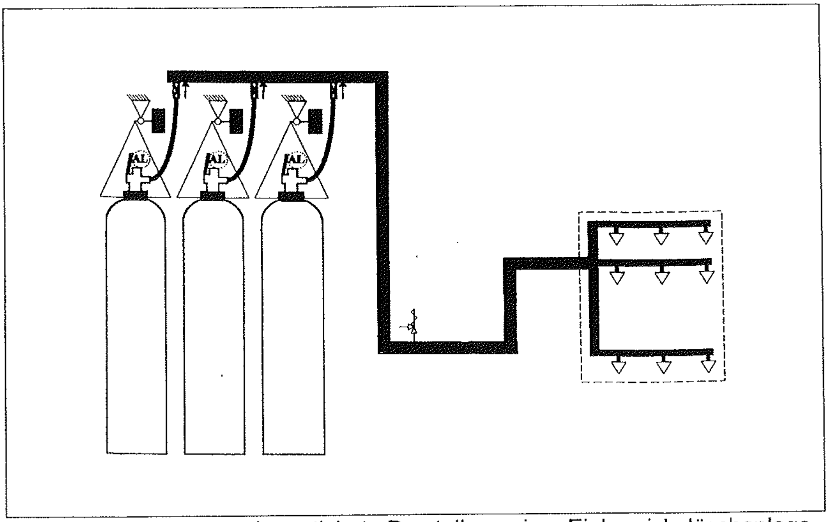
Bei der Installation von Neuanlagen bietet sich der Einsatz von Meldern an, die mit Hilfe von Algorithmen eine weit aufgefächerte Differenzierung der Täuschungsphänomene und damit eine markante Steigerung von Detektionssicherheit und Täuschungsimmunität aufweisen.

Steuerung der Löschanlage

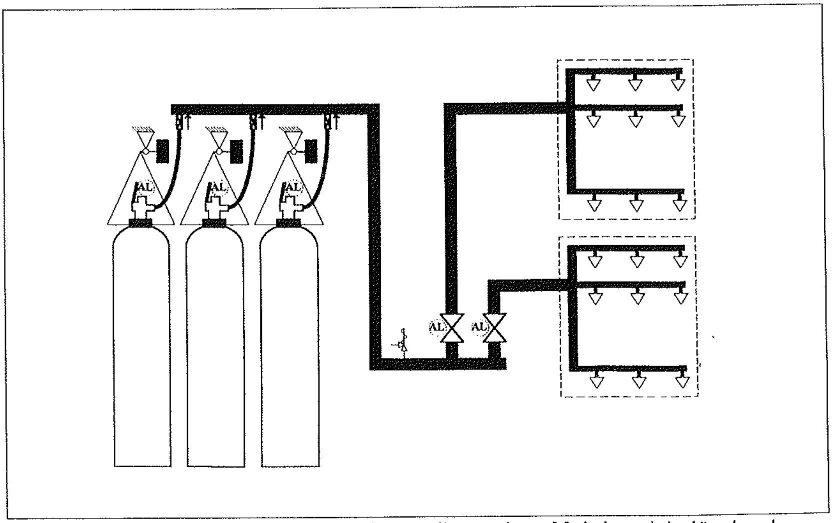
Gaslöschanlagen werden entweder als Ein- oder Mehrbereichslöschanlagen aufgebaut.

Bei der Ausführung als Mehrbereichslöschanlage wird für mehrere Löschbereiche eine gemeinsame Löschmittelbevorratung zur Verfügung gestellt.

Je nachdem in welchem Löschbereich eine Branddetektion erfolgt , wird durch das Öffnen von Bereichsventilen das Löschmittel in den entsprechenden Löschbereich geleitet.



schematisierte Darstellung einer Einbereichslöschanlage



schematisierte Darstellung einer Mehrbereichslöschanlage

Kommt es bei Mehrbereichslöschanlagen während der Flutung wegen einer Löschgasübertragung zum Öffnen weiterer Bereichsventile benachbarter Löschbereiche, besteht die Gefahr, daß für den Löschbereich, in dem es tatsächlich brennt, die dafür notwendige Löschmittelmenge nicht mehr voll zur Verfügung steht und somit den Löscherfolg der Anlage gefährdet.

Aus diesem Grund kann es sinnvoll sein, bei Ansteuerung über eine Brandmeldeanlage eine automatische Verriegelung der verbleibenden Bereichsventile vorzunehmen. D.h., bei einer Mehrbereichslöschanlage werden nach der Ansteuerung des ersten Flutungsbereiches die übrigen Flutungsbereiche nicht mehr angesteuert (automatische Verriegelung der übrigen Löschbereiche).

Bei der Realisierung derartiger Verriegelungen müssen die Randbedingungen in jedem Einzelfall genau beachtet werden. Grundsätzlich gilt:

- Die Verriegelung darf die Ansteuerung von Bereichen, die gleichzeitig mit dem ersten Bereich geflutet werden müssen, nicht behindern.
- Die Branderkennung und die Brandmeldung dürfen dadurch für keinen Löschbereich beeinflußt werden.
- Die Verriegelung darf keine Störungsmeldung verursachen und muß mit dem Rückstellen der Steuereinrichtung automatisch aufgehoben werden.
- Werden benachbarte Löschbereiche durch verschiedene autarke Ein- oder Mehrbereichslöschanlagen geschützt, so darf die Ansteuerung eines Löschbereiches der einen Löschanlage die Funktion der anderen Löschanlage nicht beeinflussen.

Zusammenfassung

Das Auslösen von Gaslöschanlagen kann aufgrund der Begleiterscheinungen einer Flutung zu Täuschungsalarmen automatischer Brandmelder führen und dadurch ungewollt weitere Löschbereiche auslösen.

Unter Berücksichtigung des verwendeten Löschmittels, Auswahl der automatischen Brandmelder, Aufbau und Steuerung der Löschanlage sowie der Berücksichtigung baulicher Aspekte lassen sich Schutzkonzepte realisieren, die ein solches Szenario nahezu ausschließen.

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Development and Testing of a Self-Contained Smoke Alarm for Trucks

Abstract

The truck cabs of modern trucks have increased considerably in size and comfort to meet the demands from to day's driver who lives in the cab for long periods of time.

To additionally enhance the security of the driver when staying in the sleeper compartment of a truck cab, for instance during sleeping hours, Consilium Security Systems AB in cooperation with Volvo and DELTA, has developed a self-contained smoke alarm to be installed in the cabs of Volvo trucks.

A severe test specification was developed to cover the worst case environmental scenario of a truck cab and the smoke alarm was then type tested according to these extreme test conditions.

In addition to the type testing at DELTA, Volvo has performed test fires inside different types of Volvo trucks with smoke alarms mounted in the cab.

1. Introduction

Since many truck cabs are furnished with a sleeper compartment behind a curtain at the back of the cab where the driver can rest or sleep during a long voyage it was an obvious conclusion to install a self contained smoke alarm in the cab to alert the driver in case of fire.

For this purpose an optical smoke alarm has been developed and environmentally tested according to Volvo specifications which reflected the extreme environmental conditions expected to exist in many places around the world where the trucks are in use.

This paper describes the development and testing of the smoke detector as well as the evaluation of the results.

2. Development of the smoke detector

An optical smoke alarm was developed by Consilium Security Systems AB in cooperation with Volvo and tested by DELTA. The basis for the development was an optical smoke alarm intended for installation in domestic living (indoor) locations with additional requirements corresponding to installations in caravans. On top of these requirements, the particular environmental requirements for smoke alarms to be mounted in trucks were incorporated by Volvo.

The socket and detector housing which is made of plastic material has been developed and specified by Volvo to correspond to the types of plastic materials used for other components mounted in a truck cab.

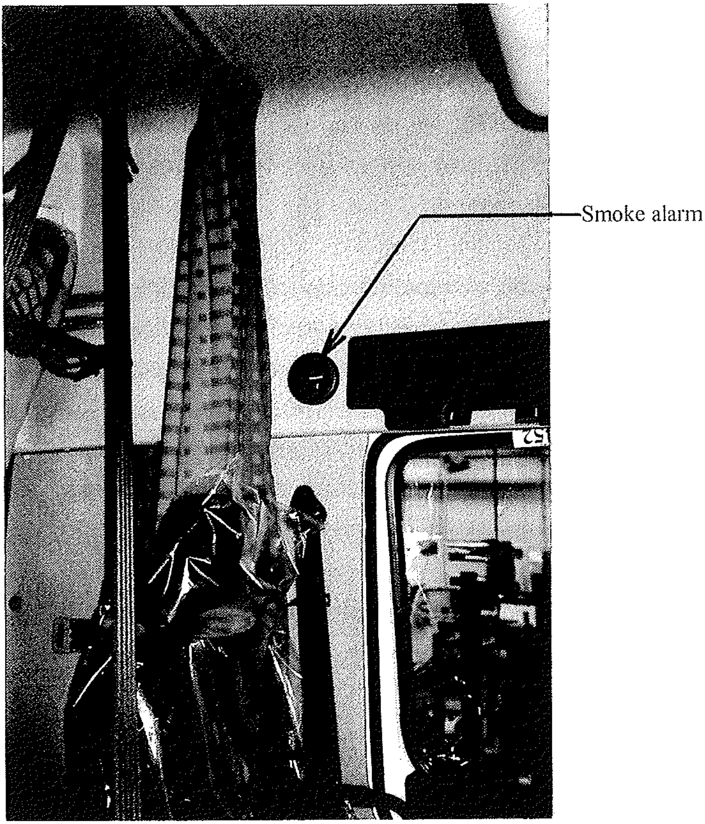
The shape of the first developed smoke alarm was circular like normally seen for such alarms but then Volvo decided to develop a new version of the smoke alarm with a square housing and socket since this shape is more in line with the design of all other parts of the cabs.

In the Volvo cab types used for Europe, the detector is placed beside the driver above the side window as shown on the photo below.

In the cab types used for USA, the detector is mounted in the roof of the sleeper compartment behind the curtain just behind the driver compartment. This is possible because there is an opening between the curtain and the roof. These smoke alarms can be remotely controlled from a reset/timer pushbutton mounted at the dashboard so that a possible alarm can be manually reset by the driver during driving.

During alarm condition the beeper gives an intermittent sound. The sound signal can be stopped by activating the reset/timer button on the smoke alarm. After having pressed the button shortly, the timer function is activated and prevents further alarm signals for about 10 min. The smoke alarm is self-resetting if the smoke concentration is lowered to a certain level during the alarm condition.

The smoke alarms are also equipped with a warning signal if the battery is low. The battery low warning signal is indicated by short soundings of the beeper every 40 s.



3. Environmental testing and test fires

The smoke alarm was tested according to Volvo specifications. These Volvo specifications basically refer to the Nordtest method NT ELEC 004, approved 1984-09 including the additional requirements for class 2 which is applicable to alarms to be installed in caravans.

NT ELEC 004 is used by all Scandinavian countries for type testing of self-contained smoke alarms.

NT ELEC 004 refers to IEC 68 series of standards for the environmental tests and to the EN54 part 7 for the measurements of the response threshold value before, during (if specified) and after each environmental test.

In all the environmental tests, the ratio between the maximum and minimum Response Threshold Values measured shall be less than 1.6 and the smoke alarm shall give no false alarms during the exposure.

The EMC immunity tests specified in the NT ELEC 004 are not applicable today and cannot be used as a basis for the CE marking in relation to the EMC directive. Therefore, additional EMC immunity tests were carried out according to the generic immunity standard for industrial environment, EN50081-2, as well as the product family standard for EMC immunity of fire, intruder and social alarm systems, EN 50130-4. Also EMC emission test was carried out according to the generic emission standard for residential, commercial and light industry, EN 50081-1.

In addition to the above specifications the particular environmental requirements for smoke alarms to be mounted in Volvo trucks were incorporated.

The complete type testing was performed as follows:

Audibility test

Since the smoke alarm has to be mounted very close to the truck driver the sound level pressure of 95 dB(A) in 1 m's distance from the smoke alarm, as required by NT ELEC 004, was found to be too high. If an alarm with this high sound level pressure should occour during the driving the driver could be stressed too much which would perhaps lead to reduced traffic security.

Therefore, the sound level pressure starts at 65 dB(A) ± 3 dB(A) and increases up to a level of 85 dB(A) in about 15-20 s. These levels are measured at a distance of 1 m from the beeper. The maximum level of 85 dB(A) corresponds to 70 dB(A) at the ear of the driver in bed.

Short term stability: The Response Threshold Value, RTV was measured 6 times on the same randomly chosen detector.

Long term stability: The detector was energised for 21 days and the RTV measured after 7 days and after 21 days and compared with the RTV value from the short term stability test.

Directional dependence: The RTV was measured for 8 different orientations of the smoke alarm in angle intervals of 45° around its vertical axis.

As could be expected, the square type of housing caused a problem with the directional dependence during the type testing. The problems were solved by altering the mutual position of the internal main parts such as the battery, the printed circuit board including the beeper and the optical measuring chamber and by optimising the distance between the detector and the cover and the openings of the cover.

Deviation between test specimens: The RTV of 10 smoke alarms was measured. The smoke alarms were numbered 1 to 10 so that the smoke alarm number 1 was the alarm that had the smallest RTV (highest sensitivity to smoke) and the smoke alarm number 10 had the greatest RTV (lowest sensitivity to smoke). Depending on its sensitivity to smoke, the smoke alarm was used for the individual environmental tests or the test fires in according to the specification NT ELEC 004.

Effect of air velocity: The RTV of smoke alarms number 1 and 10 was measured at an air velocity of 1.0 m/s.

Stray light: The RTV of smoke alarms number 1 and 10 was measured at different conditions of switching on and off 4 flourescent light sources and it was monitored that no false alarm occured.

Supply voltage dependence: The RTV of smoke alarms number 1 and 10 was measured at $U_{max} = 1.1 \times U_{batt}$ and at $U_{min} = U_{batt.\,min}$ which for the Volvo smoke alarm is $U_{max} = 1.1 \times 9$ V = 9.9 V and $U_{min} = 7.7$ V ($U_{batt.\,min}$ was measured as the lowest battery voltage just before the battery low condition was indicated).

Temperature dependence: Smoke alarms number 1 and 10 were mounted in the test tunnel and stabilised at a temperature of 23.0 ± 5°C. then the temperature was increased to 50.0 ± 2°C with a rate of rise equal to or lower than 1°C/min. After 2 hours at the high temperature, the RTV was measured.

After the measurement, the test tunnel was ventilated and the temperature was reduced to 0 ± 2°C with a rate of decrease equal to or lower than 1°C/min. After 2 hours and still at the low temperature, the RTV was measured.

Damp heat steady state (endurance): Smoke alarm number 9 was deenergised and subjected to the damp heat steady state endurance test for 21 days. After the recovery the RTV was measured.

Dry heat (operational): The dry heat temperature was changed from 70°C which is specified in the NT ELEC 004 to a temperature of 90°C as specified by Volvo.

A 9 V battery type Varta, Alkaline Eblock, 6LR61, 6AM was used for powering the smoke alarm during the test.

Since it was not possible to procure any information from the battery manufacturer about the functioning of the 9 V battery at a temperature of 90°C, it was very interesting to experience that the battery functioned satisfactorily during the complete test and the battery voltage measured after the test was only 0.1 V lower than when measured before start of the test.

Smoke alarm number 2 was subjected to a dry heat test exposure of 90°C for 16 hours. After the test, the RTV was measured.

During inspection after the test it was found that the test switch could no longer be activated. This was due to the fact that the plastic tube around the LED - which is also the rod for activating the reset switch - had become hardened during the high temperature and was fastened to the LED.

The problem was solved by using another type of plastic material and re-designing the reset switch rod.

Cold (operational): The temperature was changed from -25°C which is specified in the NT ELEC 004 to a temperature of -40°C as specified by Volvo.

Since it was not possible to procure any information from the battery manufacturer about the functioning of the 9 V battery at a temperature of -40°C, it was very interesting to experience that the battery functioned satisfactorily during the complete test and the battery voltage after the test was only 0.02 V lower than before.

Smoke alarm number 2 was exposed to the cold (operational) test and after the test the RTV was measured.

Damp heat, cyclic: The IEC 68-2-30, test Db, damp heat cyclic with 6 cycles of 25°C/40°C and a humidity of 93% RH was replaced by specification IEC 68-2-38 test Z/AD, composite temperature/humidity test, with 6 cycles of 25°C/75°C/-40°C followed by 2 cycles of 25°C/75°C and a humidity of 93% RH at the positive temperatures.

The selected upper temperature of 75°C was the maximum possible temperature of the climatic chambers used since the humidity was based on water. Since 70°C is normally regarded as the maximum temperature which can be measured on the surfaces of the interior of a car cab when exposed to direct sun, the 75°C was accepted as the maximum temperature.

Smoke alarm number 2 was exposed to the damp heat cyclic test and after the test the RTV was measured.

The detector gave false alarms during some of the temperature increases from 25°C to 75°C and in connection with moving the detector from -40°C to +25°C, but the false alarms at these fast temperature increases together with the high humidity conditions were acceptable for a truck cab smoke alarm.

Vibration: Smoke alarm no. 10 was exposed to random vibration comprising a functional exposure and a durability exposure. The smoke alarm was energised during the functional exposure and de-energised during the durability exposure.

Functional exposure:	Frequency range	:	10-150 Hz
	Total rms level	:	9.81 m /s^2 (1 g)
	ASD level 10-20 Hz	:	1.9 m^2/s^3 (0.02 g^2/Hz)
	ASD level 20-150 Hz	:	-3 dB/octave
	Number of axes	:	3
	Duration of the vibration	:	At least 2 min. for each axis
Durability exposure:	Frequency range	:	10-150 Hz
	Total rms level	:	22 m /s^2 (2.2 g)
	ASD level 10-20 Hz	:	9.6 m^2/s^3 (0.1 g^2/Hz)
	ASD level 20-150 Hz	:	-3 dB/octave
	Number of axes	:	3
	Duration of the vibration	:	At least 30 min. for each axis

After the vibration test the RTV was measured.

Impact: Smoke alarm no. 10 was energised and exposed to impact pulses of defined energy and velocity applied parallel to the mounting surface of the smoke alarm.

Impact energy : 1.9 J (0.7 J).
Hammer velocity : 1.5 m/s
Number of impacts per direction : 1
Number of directions : 2

During the impact test of the first version of the smoke alarm with the square housing, the cover fell off and the PCB was moved inside the housing. The problem with the PCB was solved by reinforcing the plastic parts of the smoke alarm housing and the socket. The problem with the cover which fell off was completely solved in one of the tested directions by reinforcing the plastic material for the locking taps which locks the cover to the housing. In the other direction, the cover fell off at the maximum energy level of 1.9 J. Since an energy level for the impact pulse of 1.9 J was regarded to be much higher than necessary in the truck cabs, the level of 0.7 J was accepted.

After the impact test, the RTV was measured.

Shock: Smoke alarm no. 10 was energised and exposed to shock pulses as follows:
Shock impulse type : Half sine
Pulse duration : 11 ms
Peak acceleration : 50 g
Number of directions : 6
(One shock direction was perpendicular to the mounting surface of the smoke alarm).
Pulses per direction : 3
After the shock test the RTV was measured.

RF electromagnetic field, AM and PM: The test was carried out as a combined test according to EN50082-2 as well as EN 50130-4 which specifies a frequency range of 80-1000 MHz. Because the frequency of 27 MHz is often being used for radio communication between trucks, a frequency range of 26-1000 MHz was selected for the RF electromagnetic field, amplitude modulation test.

The pulse modulation test was only carried out according to EN 50082-2 which means 900 ± 5 MHz.

Type of modulation	**AM**	**PM**
Frequency range	26-1000 MHz	895-905 MHz
Field strength	10 V/m	10 V/m
Modulation	80%, 1 kHz sine wave	Pulsed signal, 50% duty cycle, 200 Hz repetition frequency

The test was performed in a semi-anechoic room, where the walls and the ceiling were covered by RF absorbers. In the frequency range above 30 MHz, the field was generated using linearly polarised broadband antennas. In the frequency range below 30 MHz, the field was generated using a stripline.

The test was carried out for 3 different combinations of orientation of the smoke alarm and the polarisation of the antenna as specified in EN50130-4.

Smoke alarm no. 1 was energised and exposed to the RF electromagnetic field.

After the RF electromagnetic field, AM and PM test the RTV was measured.

Supplementary RF electromagnetic field tests were carried out for the type of smoke alarm with remote resetting/timer facility. The tests were carried out by Volvo and revealed that the smoke alarm was capable of withstanding up to 100 V/m without any false alarms after having added a 100 nF decoupling capacitor over the optocoupler output for the reset/timer pushbutton.

Electrostatic discharge: The test was carried out as a combined test according to EN50082-2 as well as EN 50130-4.

Smoke alarm no. 3 was energised and exposed to electrostatic discharges as follows:

Air discharge : 8 kV

Contact discharge : 6 kV
Energy storage capacitance : 150 pF
Discharge resistance : 330 Ω

The reference electrode of the test generator was connected to ground. Discharges were made on all parts of the test object likely to be touched by personnel.

After the electrostatic discharge test the RTV was measured.

Emission: No test was carried out. The radiated frequency electromagnetic field emission from the smoke alarm was evaluated by examination of its constructional documentation. It was evaluated that the emission would be within the specified limit of EN 50081-1 and EN50022, class B.

Fire sensitivity: The smoke alarms number 1, 3, 8 and 10 were exposed to test fires type TF2, TF3, TF4 and TF5, successively, according to the specification prEN54-9. The test fire type TF1 is not relevant for an optical type of smoke alarm and, therefore, was not carried out.

The smoke alarm passed the test and was classified as follows:

Test fire	**Results**	**Requirements of NT ELEC 04**
TF1 Open cellulosic fire (wood)	No test	None
TF2 Smouldering pyrolysis fire (wood)	Class C	Class C
TF3 Glowing smouldering fire (cotton)	Class B	Class A or B
TF4 Open plastic fire (polyurethane)	Class B	Class A or B
TF5 Liquid fire (η-heptane)	Class C	Class C

4. Test fires carried out inside truck cabs

In addition to the environmental tests and fire sensitivity tests carried out at DELTA, test fires have been carried out inside the truck cabs by Volvo, Consilium and SP (Swedish National Testing and Research Institute) to find out the right location of the detector for the cabs type FH (Europe) and VN (USA).

The fuel, in those smoke tests, consisted of granulated material from all interior materials.

For the US market, where the cab volume is up to 16 m^3, it was necessary to choose a detector location in the middle of the roof together with a remote control at the dashboard.

For the FH cabs with not so big a volume, it was possible to have the detector at the side of the roof, showed at the picture in part 2.

5. Evaluation of results

The smoke alarm fulfilled the specification NT ELEC 004 and the additional EMC and Volvo requirements with only a few comments as described above.

The smoke alarms are now mounted in all Volvo trucks delivered for the European market and can be delivered as an option for the US market.

20,000 smoke alarms have now been in operation for one year in Europe without any fire alarm reported. Also no faults or false alarms have been reported so far from any of these smoke alarms.

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Untersuchungen über Veränderungen der Ansprechschwelle von Rauchmeldern in der Praxis

Abstract

Over the years, the response threshold of smoke detectors is subject to certain changes which affect their functioning. The study concerns threshold limit smoke detectors working on the scattered light and ionisation chamber principle which have been in operation for five and seven years.

1. Einführung

Vorschriftkonforme Brandmeldeanlagen - vorwiegend mit Rauchmeldern bestückt - gelten als Frühwarnanlagen und erfüllen im Brandschutz speziell im Zusammenhang mit der Personensicherheit aber auch des Sachwertschutzes eine wichtige Aufgabe. Sie sollen einen Entstehungsbrand über die gesamte Lebensdauer rechtzeitig erfassen. Die Ansprechschwelle der Rauchmelder verändert sich im Laufe der Jahre vor allem durch Verschmutzung und Abdrift von der ursprünglichen Einstellung. Die meisten Länder kennen in ihren einschlägigen Richtlinien Regelungen bezüglich der Betriebsbereitschaft von Brandmeldeanlagen. Dabei wird verlangt, dass periodisch Wartungs- und Instandhaltungsarbeiten sowie Funktionskontrollen durchzuführen sind. Dies bedeutet auch, dass Rauchmelder nach einer gewissen Zeit einer sogenannten Werkrevision unterzogen und diese gereinigt und neu eingestellt werden müssen.

2. Typenprüfung und Zertifizierung

Die Anforderungen für Rauchmelder sind in den Normen EN 54 Teil 7 und 9 festgelegt. Diese bilden die Grundlage für die Typenprüfung und die Zertifizierung resp. Zulassung. Dabei müssen Rauchmelder unter anderem eine bestimmte Ansprechempfindlichkeit innerhalb eines festgelegten Toleranzbereiches aufweisen. Diese wird unter anderem durch verschiedene Testfeuer überprüft. Die Ansprechempfindlichkeit bildet eine wichtige Aussage für die Zertifizierung und Zulassung im behördlichen Bereich. Die Auflagenbehörden und Versicherer erwarten, dass die Ansprechempfindlichkeit der eingesetzten Rauchmelder während der gesamten Lebensdauer in etwa gleich bleibt. Nur so kann davon ausgegangen werden, dass Brandmeldeanlagen speziell im Bereich der Personensicherheit und des Sachwertschutzes der Risikominderung dienen.

3. Referenz

Bezüglich der Alarmschwelle der Rauchmelder stellt sich die Frage, welche Referenz als Bezugsgrösse dienen soll und welche Abweichungen in der Praxis toleriert werden können.

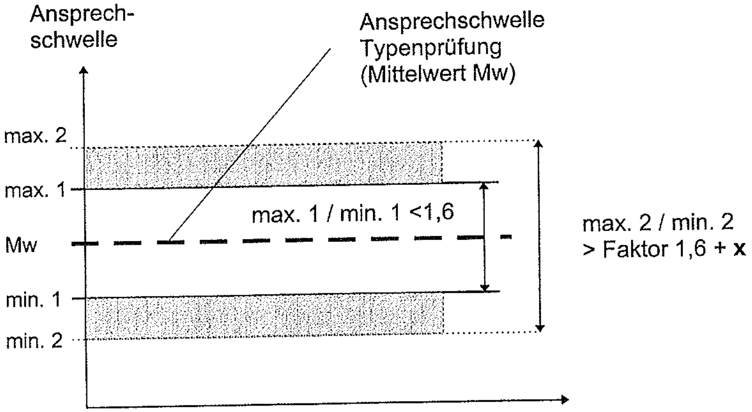

Bild: Bezugsgrösse zum Beurteilen der Abweichung der Ansprechschwelle

Als Bezugsgrösse lässt sich die Ansprechschwelle heranziehen, welche im Rahmen der seinerzeit durchgeführten Typenprüfung für den betreffenden Rauchmelder festgestellt wurde. Gemäss der E-Norm 54 Teil 7 darf das Verhältnis von maximaler zu minimaler Ansprechschwelle einen Faktor von 1,6 nicht übersteigen. Dies gilt sowohl für Optische- wie auch Ionisations-Rauchmelder.

Für Rauchmelder, welche einige Jahre im Einsatz sind, muss eine zusätzliche Abweichung toleriert werden.

Letztlich stellt sich die recht heikle Frage, bei welcher Abweichung die Rauchmelder gereinigt, neu eingestellt oder nachreguliert werden müssen.

4. Projekt

Um eine Antwort auf die Frage zu finden, wurde eine breit abgestützte Untersuchung mit einigen hundert Rauchmeldern (Grenzwertmelder) durchgeführt. Am Projekt sind drei Grossbanken sowie die bedeutendsten Errichter von Brandmeldeanlagen in der Schweiz sowie die Vereinigung Kantonaler Feuerversicherungen VKF beteiligt.

Insbesondere sollen Antworten oder mindestens Hinweise auf Tendenzen zu den folgenden Fragen resultieren:

- Welche Abweichungen von der ursprünglichen Ansprechschwelle ergeben sich nach fünf und sieben Jahren bei Optischen- und Ionisations-Rauchmeldern?
- Welche Einfluss haben eher saubere und eher staubige Räume auf die Ansprechschwelle von Optischen- und Ionisations-Rauchmeldern?
- Welche Unterschiede bestehen bezüglich Störungen und ungewollten Alarmen nach fünf und sieben Jahren?
- Welche Abweichung gegenüber der ursprünglichen Alarmschwelle darf bei Optischen- und Ionisations-Rauchmeldern toleriert werden?
- Welche Konsequenzen ergeben sich bezüglich der aktuellen Regelungen der periodisch verlangten Werkrevision von Rauchmeldern.

Das Projekt besteht aus vier Phasen

Erste Phase

Entnahme, Registrierung und Sichtkontrolle der Grenzwert-Rauchmelder aus etwa 20 verschiedenen Anlagen und Anwendungsbereichen (saubere wie auch kritische Räume), die zwischen fünf und sieben Jahren im Einsatz standen. Alle Rauchmelder werden dabei vorerst einem Funktionstest unterzogen und die Anzahl Störungs- und Alarmmeldungen der letzten zwei Jahre ermittelt.

Zweite Phase
Im Anschluss an die Entnahme werden die Ansprechschwellenwerte der Rauchmelder bei einer akkreditierten Prüfstelle ermittelt, registriert und mit jenen der seinerzeit durchgeführten Typenprüfung verglichen.

Dritte Phase
Auswertungen der Informationen aus der Anlage (Einsatzort, Verschmutzung, Funktionskontrolle, Störungs- und Alarmmeldungen), der Messung der Ansprechschwellenwerte sowie Vergleich mit den Werten der Typenprüfung.

Vierte Phase
Entscheid, welche Toleranzen zu akzeptieren sind. Allenfalls müssen noch Vergleichsversuche durchgeführt werden. Erstellen eines Berichtes als Entscheidungsgrundlage für zukünftige Regelungen.

5. Erwartungen

Von den Untersuchungen erwarten wir mindestens Trend-Aussagen über den Zustand von Optischen- wie auch Ionisations-Rauchmeldern (Grenzwertmelder), welche fünf und sieben Jahre im Einsatz waren. Dies insbesondere bezüglich der Abweichung von der ursprünglichen Ansprechschwelle, der Funktionsbereitschaft, Störungsanfälligkeit sowie ungewollter Alarme. Wir erwarten weiter, dass sich auch gewisse Erkenntnisse in Bezug auf die moderneren Rauchmelder ableiten lassen. Dadurch lässt sich beurteilen, inwiefern die aktuelle Regelung über Brandmeldeanlagen bezüglich des Intervalls von Werkrevisionen bestätigt wird oder ob Korrekturen vorgenommen werden müssen.

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Professionelle Funk-Gefahrenmeldeanlage im SRD-Band

Abstract

Radio engineering in our profession appears to have gained a foothold. This can be attributed to the release of the 868 to 870 MHz frequency band for Short Range Device applications and to technological advances. If applied correctly radio engineering can open up completely new chances. It is also quite possible to increase the level of security. Those using radio engineering must pay much attention to system performance. Especially at the beginning where the regulatory world has not caught up with current technology. Otherwise there is a danger of achieving inferior security.

Einführung

Prinzipbedingt bieten Funk-Gefahrenmeldeanlagen (Funk-GMA) eine Fülle von Vorteilen für den Anwender. Zu den wichtigsten zählen

schnelle Montage
nachträglich einfach zu installieren
keine Betriebsunterbrechung während der Installation
variabel bei Nutzungsänderung.

Angesichts dieser Liste fragt man sich, warum es die Funktechnologie bis heute nicht geschafft hat, das Gebiet der professionellen GMA zu erobern. Der vorliegende Aufsatz versucht die aktuelle Situation schlaglichtartig zu beleuchten, wobei er aus dem schier unerschöpflichen Gebiet folgende Themen behandelt:

1) Begriffsbestimmungen
2) Störbarkeit von Funkübertragungen
3) Betriebsverhalten
4) Normen und Vorschriften

1. Begriffsbestimmungen

Eine *Funk-GMA* nutzt drahtlose Verbindungen zur Übertragung von Meldungen und Befehlen. Funkmelder werden in diesem Zusammenhang nicht behandelt.

Für eine *professionelle Funk-Gefahrenmeldeanlage* gilt, daß

- sie fachkundig projektiert, installiert, in Betrieb genommen und gepflegt wird,
- bei Funktionsverlust mit erheblichen Konsequenzenen für den Betreiber oder Errichter zu rechnen ist.
  Beispiel: Viele japanische Reiseunternehmer erwarten in ihren Vertrags-Hotels eine Brandmelde-Anlage (BMA). Läßt sich der Hotelier eine Funk-BMA einbauen und wird sie durch einen anderen Funkdienst gestört, so sind seine Übernachtungszahlen in Frage gestellt (Bild 1).

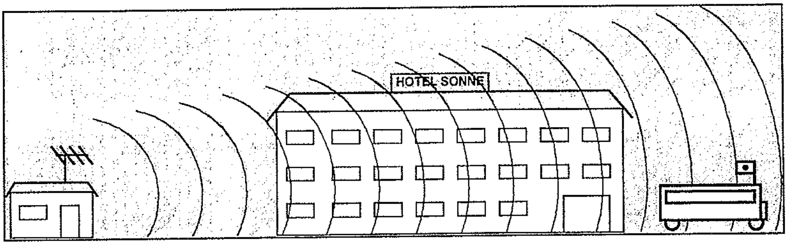


Bild 1

Der Pleitegeier bräuchte dann nur noch den Vertrag zwischen dem Hotel und dem Errichter zu studieren,um zu wissen, über wem er wann zu kreisen hat.

Die *Frequenzbänder* und die jeweiligen Zugangsbedingungen werden derzeit von nationalen Behörden verwaltet. In Deutschland ist das die Regulierungsbehörde für Telekommunikation und Post (Reg TP), in UK die Radio-communications Agency (RA) und in Frankreich die Agence National des Fréquences (ANF). Für unser Metier sind die sog. ISM-Bänder und das SRD-Band interessant.

ISM steht für „Industrial, Scientific and Medical“.

Aus dieser Gruppe ist für uns vor allem das Band um 433 MHz von Bedeutung.

SRD steht für „Short Range Device".
Der Name verrät bereits, daß in diesem Band mehrere Applikationen einträchtig nebeneinander arbeiten können.

Die Tabelle 1 vergleicht das SRD-Band mit dem ISM-Band bei 433 MHz.

Eigenschaft	ISM-Band 433 MHz	SRD-Band 870 MHz
Sendeleistung ohne Einzelgenehmigung z.B. für GMA mit Einzelgenehmigung z.B. für Funkamateure	max. 10 mW ERP > 1 kW ERP	5 mW, 10 mW, 25 mW, 500 mW ERP (frequenzabhängig) nicht vorgesehen
exkluslive Kanäle für Alarmanlagen	nein	ja
Inhalt der Übertragung	keine Einschränkung	nur Daten (nicht erlaubt sind z.B.: Musik, TV, Sprache)
Duty Cycle (Ein/Aus des Senders)	keine Einschränkung	frequenzabhängig: 100%; 10 %; 1%; 0,1% (z.B. Alarmkanäle)
Primärnutzer	Funkamateure	SRD
Reichweite in Gebäuden	besser	ausreichend

Tabelle 1

2. Störbarkeit von Funkübertragungen

Auch die glühenden Verfechter der Funkübertragung geben zu, daß drahtlose Verbindungen leichter störbar sind als drahtgebundene Übertragungen. Es muß deshalb untersucht werden, ob die auf Funk-GMA einwirkenden Störungen den Betrieb überhaupt beeinträchtigen. Dazu werden im Folgenden das Risikoprofil den zu erwartenden Einflüssen in den verschiedenen Bändern gegenübergestellt.

2.1 Das Risikoprofil bei Störbeeinflussungen.

Bild 2 zeigt, welche (funk)typischen Störungen auf die unterschiedlichen GMAs wirken können.

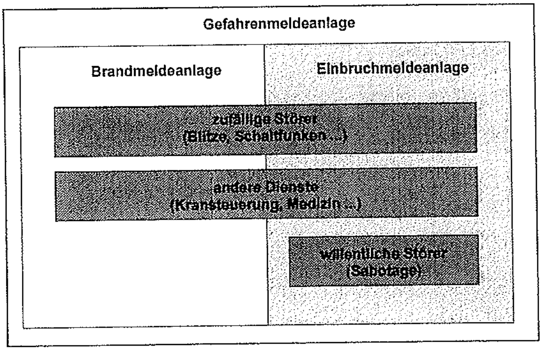


Bild 2

Alle GMA müssen sich mit zufälligen Störungen ihrer Übertragungswege auseinandersetzen. Solche Störungen entstehen bei Blitzen, Schaltfunken oder durch Strahlungen von defekten Geräten.

Abhängig vom gewählten Übertragungsmedium kann es zusätzlich zu Konflikten mit anderen Diensten kommen. Nicht nur bei der Benutzung von Funkfrequenzen sondern auch bei Bussystemen der Gebäudetechnik (EIB, LON .....) muß ein für alle Beteiligten akzeptables Zusammenleben gewährleistet sein. Sollte ein fremder Dienst den Kanal ausschließlich für sich belegen können, so ist dieses Übertragungsmedium für eine professionelle GMA ungeeignet.

Mit willentlichen Störern, d.h. mit Sabotage muß man nur bei Einbruchmeldeanlagen (EMA) und Überfallmeldeanlagen (ÜMA) rechnen. Dem Verfasserist kein Fall bekannt, in dem ein Brandstifter eine BMA ausgeschaltet hat. Diese Leute werfen lieber einen zweiten Brandsatz, als daß sie sich mit einer komplizierten Technik beschäftigen. Für EMA zum Schutz hoher Risiken erscheint die Funktechnologie dagegen ungeeignet.

Die drei genannten Störungsarten können, auch mit hohen Aufwendungen, nur zum Teil beherrscht werden (Bild 3).

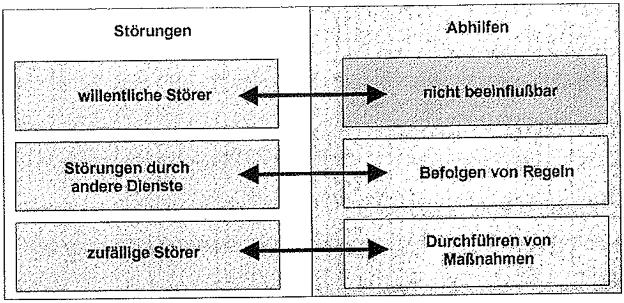


Bild 3

Gegen einen willentlichen Störer (Saboteur) einer Funkverbindung, der sich möglicherweise sogar Insiderwissen beschafft hat, ist kein Schutz möglich. Hohe Risikowerte, die das Ziel krimineller Energie sein könnten, sollten deshalb nicht mit einer reinen Funk-EMA überwacht werden.

Störungen durch andere Funkdienste sind vermeidbar, wenn für die benutzte Frequenz anerkannte Regeln bestehen, deren Einhaltung notfalls mit behördlicher Unterstützung durchgesetzt werden kann. Gerade hierin hat das ISM-Band für Sicherheitsanwendungen einen großen Nachteil. Andere Dienste dürfen beispielsweise sogar mit einer millionenfach höheren Leistung als Gefahrenmelder senden.

Die Beeinflussungen aus zufälligen Störquellen sind mit technischen Mitteln (Störunterdrückung) und ergänzenden Maßnahmen (Reparatur defekter Geräte) beherrschbar.

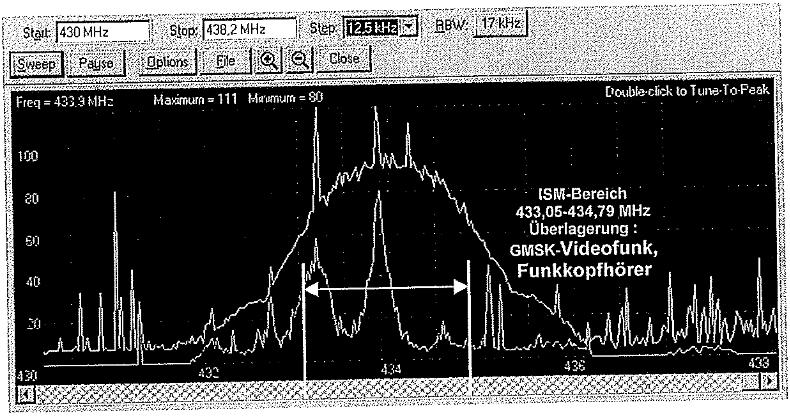
2.2. Wahrscheinlichkeit der Beeinflussung im ISM-Band (433 MHz) und SRD-Band (870 MHz).

Oben wurde gezeigt, daß professionelle GMA grundsätzlich über Funkverbindungen betrieben werden können. Voraussetzung dazu ist, daß

- willentliche Störer auszuschließen sind,
- die Komponenten selbst eine ausreichende Störunterdrückung besitzen,
- die Anlage gewartet wird und

- die GMA im Meldungsfall schnell genug zum Zuge kommt.

Gerade der letzte Punkt ist der Pferdefuß des ISM-Bandes. Weder Sendeleistung noch Sendedauer sind beschränkt. Bild 4 zeigt das Spektrum einer DATV-Übertragung, die mit ungefähr 2 kW ERP abgestrahlt wurde. Es istdavon auszugehen, daß diese Fernsehübertragungen bei Funkamateuren immer beliebter werden.



Start: 430 MHz Stop: 438,2 MHz Step: 12,5 kHz RBW: 17 kHz

Freq = 433,9 MHz Maximum = 111 Minimum = 80

Bild 4

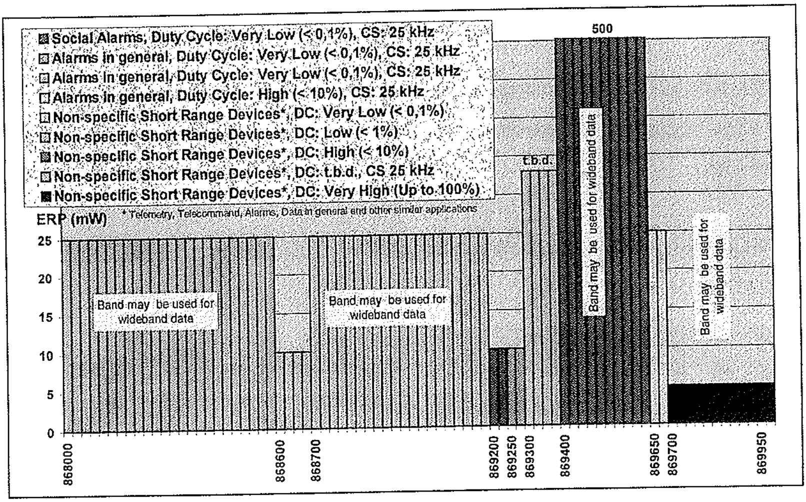


Bild 5

Die für das SRD-Band gültigen Regeln sind in der CEPT/REC 70/03 festgelegt und aus Bild 5 ersichtlich.

Exklusiv für Alarmsysteme sind sechs 25 KHz breite Kanäle reserviert. In ihnen ist ein Duty Cycle (Ein-Aus-Verhältnis) des Senders von <0,1 % einzuhalten. Auf den übrigen Frequenzen gelten ähnliche Restriktionen, wobei aber die Bandbreite größer sein darf und andere Nutzer zu finden sein werden.

Ein professionelles Funksystem arbeitet vorzugsweise auf diesen anderen Kanälen, um die Alarmfrequenzen für wirkliche Notfälle frei zu halten. Es schaltet nur in deren Belegtfall auf einen der Alarmkanäle. Wie häufig dies eintreten wird, ist schwer vorherzusagen. Man muß heute aber davon ausgehen, daß eine große Zahl der heutigen Nutzer der ISM-Bänder in die frei zugänglichen Kanäle des SRD-Bereiches drängen werden. Für Funk-GMA scheint es deshalb unabdingbar, in den Alarmkanälen arbeiten zu können. Im Gegensatz zu den allgemein zugänglichen Kanälen muß hier jedoch unbedingt schmalbandig übertragen werden. Die Schmalbandigkeit hat leider ihren Preis, ist aber für die Zukunftssicherung installierter Anlagen unabdingbar.

3. Das Betriebsverhalten

Ein Betreiber muß an eine Funk-GMA natürlich die gleichen Anforderungen stellen, wie an eine bedrahtete Anlage. Neben der Einhaltung der Vorschriften sind das vor allen Dingen :

-ein störungsfreier Betrieb,
-ein sicherer Betrieb und
-niedrige Betriebskosten

Zur Gewährleistung der Betriebssicherheit überprüfen die GMA regelmäßig ihre Systemintegrität, d.h. ihre Unversehrtheit. Das wird oft mit einer einfachen Fremdträgerüberwachung verwechselt (siehe 4.). Das bedeutet für die Belastung des Funkkanals, daß sich jeder Melder spätestens nach 100 Sekunden bei seiner

Masterstation melden muß. Um Kollisionen beim gleichzeitigen Senden mehrerer Teilnehmer zu vermeiden, empfiehlt sich ein geordneter Aufruf der Unterstationen. Dies erfordert eine bidirektionale Verbindung zu den Meldern, die die Kosten ebenfalls erhöht. Sie hilft jedoch auch noch ein anderes Problem zu lösen. Eine wirkliche sicherer Alarmübertragung läßt sich nämlich nur durch ein eindeutiges Quittungssignal garantieren. Unidirektionale Systeme versuchen diesen Nachteil durch blinde Mehrfachübertragungen auszugleichen.

Hochwertige Systeme bedienen sich zur Steigerung der Funktionssicherheit noch weiterer Mechanismen. Sie sollten bei der Initialisierung einer Funkzelle so lange das Frequenzband durchsuchen, bis ein freier Kanal gefunden wurde. Er wird dann für den weiteren Betrieb zum Basiskanal erklärt, da man auf ihm kaum mit Kollisionen mit anderen Funkdiensten zu rechnen hat. Zusätzlich kann vor jedem Datenaustausch, also vor jeder Routinemeldung und Alarmübertragung geprüft werden, ob der Kanal immer noch frei ist. Im Belegtfall kann auf Ausweichkanäle umgeschaltet werden. Erst am Ende der Ausweichliste sollten sich die Alarmkanäle befinden. Dadurch bleiben diese exklusiven Kanäle frei von unnötigen Meldungen. Echte Alarme finden so in jedem Fall zur Zentrale.

Die Betriebskosten spielen naturgemäß eine nicht zu unterschätzenden Rolle bei der Auswahl eines Systems. Der Energieverbrauch von modernen bidirektionalen Funkmeldern nach EN 54 kann so gering sein, daß sich die Melder bis zu 10 Jahre lang aus zwei Mignonzellen mit Energie versorgen können. Diese nicht zu unterschätzende Leistung ist nur durch die gleichzeitige Anwendung von drei verschiedenen Adressierverfahren beim Melderaufruf zu erreichen:

- Ein synchrones Verfahren sorgt für geringen Energieverbrauch.
- Ein Kollisionsverfahren sorgt für Reaktionszeiten von ca. einer Sekunde.
- Ein wahlfreier Aufruf erlaubt gezieltes Ansprechen einzelner Teilnehmer.

Dadurch können sich sogar die Master der Funkzellen direkt aus der Datenleitung des Melderloops mit Energie versorgen. Auf eine eigene Speiseleitung kann also verzichtet werden (Bild 6).

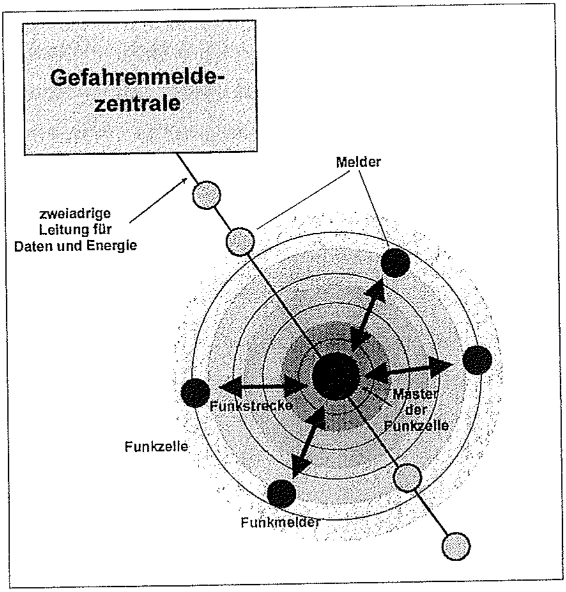


Bild 6

4. Einbettung der Funk-GMA in die bestehende Vorschriftenwelt

Die derzeit gültigen Normen und Vorschriften basieren auf den bedrahteten Anlagen. Daraus resultieren im wesentlichen zwei Schwierigkeiten. Zum einen beschreibt der Wortlaut nur das, was bei der Normung der bedrahteten Anlagen zur Diskussion stand. Dinge, die anders gar nicht gelöst werden konnten oder unabdingbare Konsequenz waren, wurden natürlich nicht angesprochen. Zum anderen wollten in dem jetzt teilweise vorhandenen vorschriftenfreien Raum vor allem die Firmen, die schon Produkte im Markt hatten, eine neue, technologiespezifische Norm.

Ein Beispiel soll die Problematik erhellen. Die EN 54 fordert im Teil 2 unter 8.1.3: "Die BMZ muß den Störungsmeldezustand ... innerhalb 100 s ... einnehmen." Durch die Funkbrille betrachtet hieße dies, daß die Empfänger der Masterstation lediglich alle 100 Sekunden kurz eingeschaltet werden müssen, um einen möglichen Fremdträger zu detektieren. Wird kein Signal erkannt, so ist der Funkkanal frei und die Forderung erfüllt. Bei genauerem Hinsehen erscheint diese Interpretation doch zu simpel. Selbst bei bedrahteten Anlagen in Gleichstromtechnik wird nämlich gleichzeitig mit der Überwachung des Übertragungsmediums Draht, auch die Unversehrtheit der Installation und die Energieversorgung des Melders verifiziert (Bild 7). Ein Handfeuermelder, der versehentlich von einem Gabelstapler von der Wand gerissen wurde, wird deshalb auch innerhalb von 100 Sekunden als gestört gemeldet.

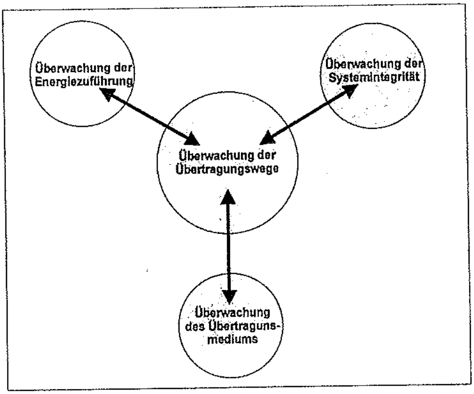


Bild 7

Es liegt auf der Hand, daß solche Zusammenhänge von den Mitarbeitern in den Normengremien erst erarbeitet werden müssen. Leider kostet dies viel Zeit. Trotzdem sollte der Prozeß so schnell wie möglich durchgeführt werden. Es kann nämlich nur technologieunabhängige Anforderungen an GMA geben (Bild 8). Die Prüfvorschriften jedoch können oder müssen sogar verschieden sein.

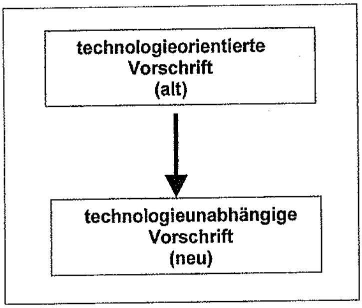


Bild 8

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Achieving optimum reliability in wireless alarm systems

Abstract

This paper deals with history, performance and state of the art in the field of radio security systems. It addresses the different steps through which security systems using radio frequency links have gone and brings details on the current state of the technology applied to this type of application. It also brings information on the limitations due to the regulatory environment along with perspectives for the future.

1 - History and definitions

About 20 years ago, the radio technology was very seldom seen in the field of security systems. Some application of it could be basically seen in Intrusion Systems in the low-end segment of residential burglar alarm systems.

Among the primary reasons for this situation was probably the fact that the electronic components were not mature enough along with electronics designers being not sufficiently skilled in radio technologies.

However, in this time period, some applications were developed primarily by start-up companies that understood the freedom brought by the usage of radio links in applications like residential alarm systems.

However to make understanding of the subsequent topics easier, it appears necessary at this stage to better define some of the words and terminology.

2 - Definitions

Security system : electronic system used in the field of security that mainly comprises intrusion, fire, access control, CCTV

Intrusion alarm system : electronic system used for intrusion detection purposes.

Radio alarm system : electronic alarm system using radio-frequency links instead of wired connections.

Tamper : deliberate action atempted by an intruder in order to decrease the integrity of the security system (e.g. opening of housing, removal from wall...)

3 - Radio link fundamentals

In a radio communications link, there are fundamentals items to be taken into account :

- radio transmitter aimed at radiating the electromagnetic energy characterized by its effective radiated power,
- radio receiver aimed at receiving the above energy characterized by its signal sensitivity,
- the transmission media which is the air itself,
- the passive environment that comprises all the physical environment excepted the media itself (i.e. walls, furnitures, trees,...)
- the electro-magnetic environment that comprises all radio transmissions generating energy in the area of the transmitter/receiver location.

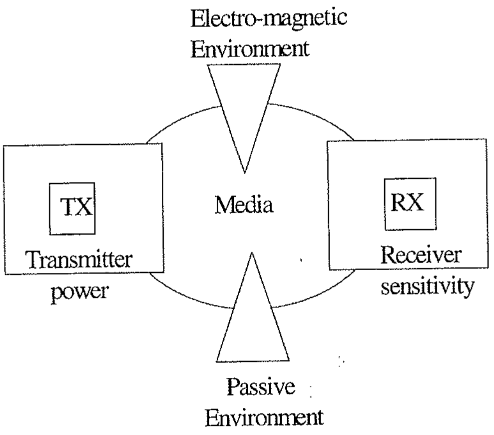

Table 1 : Radio link fundamentals

4 - RF spectrum considerations

Since the RF spectrum is by essence a shared media, it has to be ruled by some specialized bodies all over the earth.

When it comes to radio technology, there are two special parameters that appear to be of interest : frequency band allocation and power allowed in the band.

4.1 - Frequency band allocation

As far as security systems are concerned and due to available cost-effective radio technology components, we will concentrate on a spectrum range going from 0 to 3GHz. In this range, there are many different categories of applications competing to use part of this spectrum (among them we may mention broadcast radio, television, GSM phones, DECT phones and many others).

Probably because security systems (and primarily low-end residential alarm systems) compete with high-volume markets, they have not been allocated any particular spectrum bands dedicated to these applications. As a consequence, there are some bands of special interest within the above spectrum called ISM bands (for Industrial Scientific Medical).

The characteristics of these special bands are that their usage is allowed for Low Power Devices without licence fees. The drawback however is that they are shared with other transmitting devices without any warranty of protection and the devices operating in these bands have to deal with this situation.

The available ISM bands within the 0 to 3GHz spectrum are around :
- 27 MHz (better known as the CB band)
- 40 MHz (available but very narrow band)
- 433 MHz (shared by many applications like radio amateurs)
- 2.45 GHz (also used by high-power applications like microwaves ovens)

4.2 - Power allowed in the allocated band

Low Power Devices (or Short Range Devices as they are now called by ETSI) have a common feature which is they are not allowed to radiate more than 10mW within the allocated band. If they comply with this requirement there is no licence fees to be honored on a device-by-device basis. However, since the devices use the RF spectrum, a type-approval needs to be obtained from the national regulation body in each country.

With the above considerations in mind, and although some other non-harmonised nationally allocated bands were in use during th 80's and early 90's, it appeared that manufacturers of radio alarm systems have vastly migrated within the 433 MHz ISM band with the advantages and drawbacks of and harmonised and shared band.

5 - Performance parameters

In the field of intrusion (but this may also be true for other fields like access control or CCTV), there are 2 performance parameters of interest :

5.1 - Availability of the transmission link :

since radio is used as the basic means to convey data between devices, the availability of the media is to be monitored to make sure all data transmissions will be successful.

5.2 - Integrity of the system:

since alarm systems are aimed at protecting goods, some "intruders" may be searching how to decrease the integrity of the system. At the same time, radio systems use a shared and accessible media (the air) and as a consequence appropriate measures need to be taken in order to garranty system's integrity. In the case the system may not be certain its integrity cannot be garranteed, it shall be required that this information be reported to the appropriate person (owner or maintenance personnel).

6 - Causes of disturbances on radio links

The identified causes of disturbances on a radio link may be synthetised as follows :

- attenuation
- collision
- non-intentional emulation
- intentional emulation
- other generic interference

These disturbances and their effects are detailed in the table given below

Disturbances	**Potential Consequences**	**Equivalent OSI Level**	**System's impact**
Attenuation	Loss of message	1	Performance
Collision	Loss of message	2	Performance
Non-intentional Emulation	False message	2	Performance
Intentional Emulation	Modification of message	2	Integrity
Other Interference	Total obliteration	1	Integrity or Performance

Table 2 : Causes of Disturbances

To cope with the above disturbances the alarm systems need to be designed in such a way their performance still remain optimum and their integrity monitored at all times with the objective of reporting any problems.

The table below brings the answers to be dealt with according to the type of disturbances encountered by the system.

Disturbances	**Adequate System Requirements**
Attenuation	Transmission Margin
Collision	Transmission Protocol
Non-Intentional Emulation	Unique Identification
Intentional Emulation	Encryption
Other Interference	Receiver Processing and effective Spectrum usage

Table 3 : System requirements to avoid disturbances effects

7 - First generation of security radio systems

For the reasons already addressed above, the first generation of security radio systems were based on simple transmitters and receivers using a single frequency. The advantage of such a technology was obviously its low cost of implementation. However, since the electromagnetic environment has become more and more crowded, these single-frequency systems may suffer lack of availability of their radio links. Another major factor is that it is virtually impossible for their receivers to efficiently detect they may suddenly be unable to process any messages due to an intentional action. Since the media and the frequency channels are shared with other applications, the probability to find situations where transmissions may be interrupted is high. Unfortunately, there are no evident discriminating factors between intentional and non-intentional tampering actions.

8 - Second generation of security radio systems

For the above mentionned reasons, second generation systems have been developed. They use much more sophisticated technologies like redundant transmissions, dynamic frequency allocation or spread spectrum transmissions.

Single frequency	- single transmission
Multi-frequency	- fully redundant transmission - dynamic frequency allocation - spread spectrum frequency hopping - spread spectrum direct sequence

Table 4 : Major transmission technologies encountered in the security market

The table given below shows the classification of the transmission technologies in two categories : first and second generations.

Spectrum usage		Mono-directional communication protocol	Bi-directional communication protocol
Single frequency	One band	First generation	
Multi-frequency	One band	Second generation	Second generation
Multi-frequency	Two bands		

Table 5 : Radio Transmission Generations

The above transmissions technics labelled second generation all have their advantages and drawbacks but highly improve the quality of the links. In the arena of security systems, it should however be noticed that going from single to multi-frequency along with going from one band to two bands are the most significant advances that have been recently achieved.

On the other hand and although the air transmission protocol (level 2 of the OSI model) also brings some improvement, it can be considered less predominant as far as the intentional tampering of a radio link is concerned. This is a major comment since again, in the field of security, tampering is a real concern.

One band ↓ Two bands	- higher electro-magnetic immunity - tamper detection efficiency
Single frequency ↓ Double/Multi frequency	- higher availability - better tamper detection
Mono-directional ↓ Bi-directional	- better system monitoring - power consumption optimization

Table 6 : Advantages of technology improvements

9 - Electro-magnetic Compatibility (EMC) in Security Systems

One of the objective of the EMC Directive is to assure that a particuliar electronic equipment is capable of living with other equipment without modifing their expected behavior. There are two faces relating to EMC : emission and immunity.

The first one is correctly addressed by regulating bodies (formerly Post and Telecommunications administrations) that check specific equipment will not radiate more power than allowed as defined in the relevant technical documents. Since SRDs are not allowed radiating energy above 10mW, there are no major trouble to be expected in fulfilling this requirement.

It is a completely different problem when it comes to immunity. As a matter of fact, the generic standards claim for an immunity of 3V/m for all electronic equipment inside a frequency range of 0 to 3GHz. However, since radio equipment use electro-magnetic energy to convey information, if a high-energy field is applied right at its operating frequency, most equipment will not be able to remain fully functional anymore and reception will not occur anymore.

This is one of the reason for which the standardization body (ETSI) in charge of radio equipment had to issue specific standards to be used for CE marking compliance.

In these standards can be found the notion of "Exclusion Band". This latter defines a specific portion of the frequency range to be tested where the 3V/m field is not to be applied and no test to be performed on the equipment.

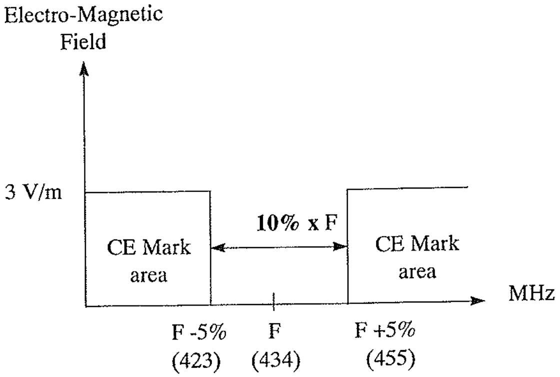

Table 7 : Exclusion band definition

Although this may sound reasonable for many type of radio equipment, it is totally unacceptable for security systems that cannot suffer a weak functionality particularly around their operating frequency. This also shows that the CE mark does not directly relates to a minimum quality level since a standard security equipment may bear the marking and however be really unsufficiently strong on its transmission backbone.

Here is the reason for which quality standards in the field of security have taken this fact into account. High-quality equipment has to cope with high energy field currently encountered in real life (e.g. GSM mobile phones may radiate fields higher than 10V/m) without suffering any performance degradation.

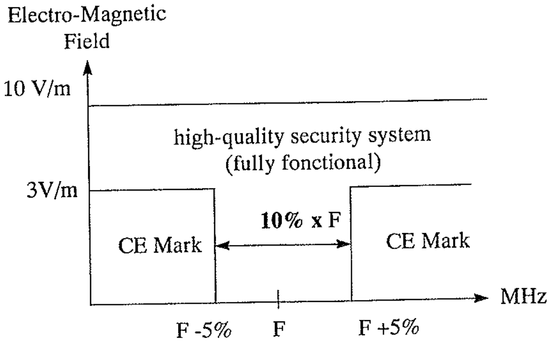

Table 8 : Requirements for high-quality security systems

10 - Conclusion

In the radio applications domain, there is now an active regulatory and normative environment in place.

ETSI is the standardization body in charge of radio applications. The standards generated by ETSI often become a base for technical regulations since the field of spectrum usage is highly regulated.

CENELEC is the standardization body in charge of the functional aspects of the electronic equipment. One of the technical committees deals specifically with alarm systems among which one of the working group is in charge of radio intrusion systems.

Market awareness and demand is moving towards a general use of radio applications that far exceed the domain of telephony.

Manufacturers are definitely switching to higher quality radio transmissions in the field of intrusion systems and at the same time, the standardazition bodies in this field are also emphazising good systems have to use improved radio transmissions by embedding in their standards or drafts the necessary functional and quality requirements.

Radio security systems are thus fully ready to enter both the next century and higher-risk applications in the security domain.

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Transmission of fire alarms in ISDN

Abstract

The fire alarms integrated in fire alarm or sprinkler systems must be transmitted direct to the public fire services communications centre. Under the fire protection regulations of the Swiss Fire Protection Authorities SFPA, this has been the case in Switzerland for more than 30 years, and today, more than 25,000 fire alarm systems are connected.

In the course of time and as a result of new technological developments, different transmission systems with new networks and components have been introduced. The latest innovation has been triggered by the introduction of ISDN.

In Switzerland, in accordance with the fire protection regulations of the SFPA, the fire alarms integrated in fire alarm and sprinkler systems must be transmitted to the public fire services communications centre by means of a constantly monitored transmission channel. The introduction of ISDN in the transmission network at Swisscom requires new technology in the field of alarm transmissions, since, for technical reasons, today's systems can no longer be applied. It is shown how the ISDN transmission systems satisfy these requirements.

The alarm transmission system is an important link in the chain between the detection of a fire by an automatic fire detector or sprinkler system and the mobilisation of the fire department. As such, it is of great significance from the point of view of both authorities and insurers.

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Übermittlung von Brandalarmen im ISDN

Zusammenfassung

Alarme von Brandmelde- und Sprinkleranlagen sind auf die öffentliche Feuermeldestelle zu übermitteln. Diese Auflage gilt in der Schweiz gemäss den Brandschutzvorschriften der Vereinigung Kantonaler Feuerversicherungen VKF seit über 30 Jahren. Heute sind mehr als 25'000 Brandmeldeanlagen aufgeschaltet.

Im Laufe der Zeit wurden aufgrund der technischen Entwicklung unterschiedliche Übermittlungssysteme mit neuen Netzen und Komponenten eingeführt. Der neuste Innovationsschub wurde ausgelöst durch die Einführung von ISDN.

Ebenfalls gemäss den Brandschutzvorschriften VKF müssen in der Schweiz Brandalarme von Brandmelde- und Sprinkleranlagen über einen kontinuierlich überwachten Übermittlungsweg auf die öffentliche Feuermeldestelle übertragen werden. Die Einführung von ISDN im Übertragungsnetz der Swisscom erfordert im Bereich der Alarmübermittlung neue Technologien - die heute bekannten Systeme können aus technischen Gründen nicht mehr eingesetzt werden. Es wird aufgezeigt, wie ISDN-Übermittlungssysteme diesen Anforderung genügen.

Das Alarmübermittlungssystem ist ein wichtiges Glied in der Kette von der Brandentdeckung durch eine automatische Brandmelde- oder Sprinkleranlage bis zur Mobilisation der Feuerwehr. Die Bedeutung aus der Sicht von Behörden und Versicherern ist sehr hoch.

1 Alarmübermittlung im Laufe der Zeit

1.1 Einleitung

Im Laufe der Jahre entstanden verschiedene Generationen von Systemen für die Übermittlung von Alarmen aus dezentralen Brandschutzanlagen (Brandmelde- und Sprinkleranlagen usw.) zur öffentlichen Feuermeldestelle. Über dieselben Systeme werden neben Brandalarmen auch Meldungen von anderen Sicherheitsanlagen übermittelt. Die Anforderungen sind vielfältig und stehen aufgrund der Wichtigkeit solcher Anlagen auf einem hohen Sicherheitsniveau. Nachstehend sind die wichtigsten heute in der Schweiz eingesetzten Alarmübermittlungssysteme aufgezählt und kurz beschrieben:

1.2 Mietleitungsanlagen dienten anfänglich für die sichere Alarmübermittlung zur öffentlichen Feuermeldestelle oder Polizei. Die hohen Leitungskosten und der zunehmende Bedarf liessen aber bald neue Systeme entstehen.

1.3 Telefonwählgeräte erreichen zwar nicht das Sicherheitsniveau von Mietleitungen oder modernen Alarmübermittlungssystemen, sind aber eine wesentliche Verbesserung im Vergleich zu einem blossen Aussenalarm. Telefonwählgeräte übermitteln Alarmmeldungen je nach System im Klartext oder digital kodifiziert. Die Meldungen laufen über das Sprachband des bestehenden Telefonwählnetzes. Durch die Verwendung einer eigenen Teilnehmer-Anschlussleitung kann das zufällige Belegen der Leitung und damit die Blockierung des Alarms von Aussen verhindert werden. Die Möglichkeit eine Verbindung zur öffentlichen Feuermeldestelle aufzubauen hängt jedoch von der Belastung des Telefonnetzes ab und ist nicht in jedem Fall gewährleistet.

1.4 TUS 35, das „Tonfrequente Übertragungssystem“, wurde Anfang der siebziger Jahre in vielen grösseren Städte und deren Vororte eingeführt. Das TUS nutzt bereits das Prinzip der Mehrfachnutzung der Teilnehmer-Anschlussleitung; Gesprächs- und Alarmübermittlung können gleichzeitig und ohne gegenseitige Beeinflussung erfolgen (Data-Over-Voice-Kanal, DOV). Dank kontinuierlicher Überwachung sämtlicher Alarmanschlüsse erreichte TUS ein hohes Sicherheitsniveau. Infolge der zentralen Netzstruktur entstanden aber hohe Kosten, die eine flächendeckende Ausbreitung dieses Systems verhinderten.

1.5 **INFRANET®** ist die sichere Infrastruktur der Swisscom für die Übertragung von Alarm- und Telemetriemeldungen in der ganzen Schweiz. Übertragen werden Kontaktzustände und Datenpakete . INFRANET® ist ausgelegt auf eine grosse Zahl von dezentralisierten Teilnehmern (Brandmelde-, Sprinkler- und andere Anlagen) und Leitstellen (öffentliche Feuermeldestelle oder Polizei) mit kleiner Informationsdichte. In den Telefonzentralen der Swisscom sind sogenannte Koppelfelder (KPF) installiert. Diese Koppelfelder sind untereinander mit Mietleitungen verbunden. Die Übermittlung der Fernwirkinformationen vom Teilnehmer zum Koppelfeld erfolgt wie beim TUS 35 mittels Mehrfachnutzung der Teilnehmer-Anschlussleitung (Data-Over-Voice-Kanal, DOV). Dank kontinuierlicher Überwachung sämtlicher Alarmanschlüsse in Kombination mit einer 24-Stunden-Stelle, die das Netz und die Anschlüsse überwacht und im Bedarfsfall die erforderliche Intervention einleitet, erreicht INFRANET® ein hohes Sicherheitsniveau. INFRANET® wird heute flächendeckend in der ganzen Schweiz als Dienstleistung unter der Bezeichnung ALARMNET von der IG TUS angeboten.

2 Anforderungen des Brandschutzes

2.1 Brandschutzvorschriften

Vorschriften ergeben sich aus einer Rechtsordnung. Das Brandschutzrecht obliegt grundsätzlich den Kantonen die dieses im Rahmen ihres Polzeirechts legiferieren. Anvisiert sind die polizeilichen Schutzgüter Leib, Leben und Gesundheit, aber auch Vermögen und Eigentum. Damit befassen sich die kantonale und kommunale Feuerpolizei. So bezwecken denn die Brandschutzvorschriften den Schutz von Personen und Sachen vor den Gefahren und Auswirkungen von Bränden.

Die Vereinigung Kantonaler Feuerversicherungen VKF setzt sich seit mehreren Jahrzehnten für die Vereinheitlichung der Brandschutzvorschriften in der Schweiz ein. Sie erarbeitet zu diesem Zweck Mustervorschriften in Zusammenarbeit mit den Brandschutzbehörden und weiteren interessierten Kreisen zuhanden der Kantone.

Die Brandschutzvorschriften der VKF sind dreigeteilt und bestehen aus der Brandschutznorm, Brandschutzrichtlinien und Prüfbestimmungen. Die **Brandschutznorm** ist als technische Verordnung ausgestaltet. In 154 Artikeln sind auf 39 Seiten die Grundsätze, Schutzziele und allgemeinen Anforderungen an den Brandschutz sowie die vorgeschriebenen Schutzmassnahmen unter Berücksichtigung der Nutzung gefasst. Ergänzend dazu bestehen für die wichtigsten Bereiche 16 **Brandschutzrichtlinien** (Ausführungsbestimmungen) mit Lösungsbeispielen und Lösungsskizzen.

2.2 Hohes Brandschutzniveau

Mit 5.5 Brandtoten pro Jahr und Million Einwohner nimmt die Schweiz bezüglich Brandsicherheit im internationalen Vergleich eine positive Spitzenposition ein. Diese Aussage wird durch die neusten vom World Fire Statistic Centre in London veröffentlichten Zahlen belegt. Der hohe Stellenwert, welcher dem Personenschutz bei den Brandschutzvorschriften beigemessen wird, schlägt sich in der Statistik positiv nieder.

Aber auch die Durchsetzung von brandschutztechnischen Massnahmen durch die Brandschutzbehörden hat in den letzten Jahrzehnten die Brandsicherheit verbessert. Solche Massnahmen sind:

- Einbau von Brandmauern und Brandabschlüssen zwecks Verhinderung der Feuer- und Rauchausbreitung.
- Vorsehen von Fluchtwegen, Notausgängen und Nottreppen sowie deren Kennzeichnung und Beleuchtung.

- Einbau von Brandschutzeinrichtungen wie Brandmelde- und Sprinkleranlagen zwecks rascher Branderkennung und Löschung.

2.3 Brandschutzeinrichtungen

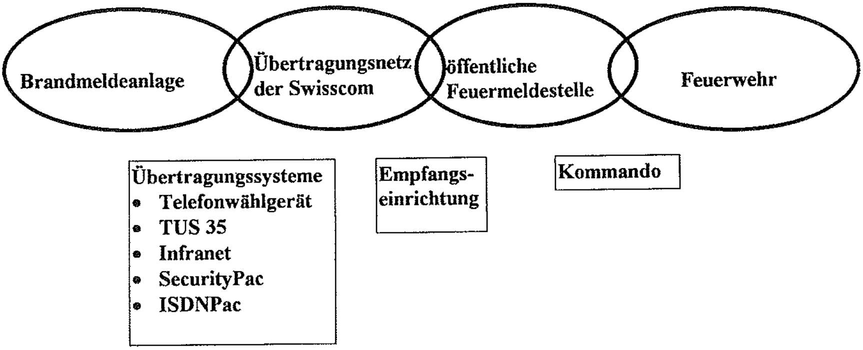
Die häufigsten in der Schweiz eingesetzten Brandschutzeinrichtungen sind Brandmelde- und Sprinkleranlagen. Beide Einrichtungen überwachen die entsprechenden Räume dauernd und sorgen für eine frühe Brandentdeckung und Alarmierung der gefährdeten Personen. In der Regel wird die Feuerwehr mittels der Fernalarmierung automatisch informiert. Je nach Gebäudenutzung entwickelt eine Brandmelde- oder Sprinkleranlage eine optimale Wirkung und wird entsprechend bevorzugt eingebaut. Von entscheidender Bedeutung für die Minimierung des Schadenausmasses, ist die möglichst frühzeitig einsetzende Löschung.

Gemäss den Brandschutzvorschriften der Vereinigung Kantonaler Feuerversicherungen VKF, müssen Brandschutzeinrichtungen wie Brandmelde- und Sprinkleranlagen in Gebäuden unter Berücksichtigung der Nutzung eingebaut werden. Jeder Brandalarm einer solchen Anlage ist auf die öffentliche Feuermeldestelle zu übermitteln. Im Lauf der Zeit wurden tausende Brandmelde- und Sprinkleranlagen aufgeschaltet. Heute stehen verschiedene Übermittlungssysteme unterschiedlicher Technologie für die Alamübermittlung zur Verfügung. Die Einführung einer weiteren Übermittlungstechnologie ist infolge der Verbreitung von ISDN erforderlich.

2.4 Nutzen von Brandmeldeanlagen mit Alarmübermittlungssystemen

Tagsüber brennt es häufiger als in der Nacht. Hingegen ist die Schadensumme bei einem nächtlichen Brand im Durchschnitt etwa drei mal höher als während dem Tag. Die Ursache liegt auf der Hand. Wo Bewohner schlafen und Fabrikationsgebäude leer stehen, wird ein Feuer in der Regel erst entdeckt, wenn die Flammen aus dem Dach schlagen. Zu diesem Zeitpunkt ist aber bereits ein grosser Schaden entstanden. Die Löscharbeiten der Feuerwehr gestalten sich schwierig und aufwendig. Viel einfacher ist demgegenüber die Löschung eines kleinen Entstehungsbrandes - hier genügt idealerweise ein Glas Wasser oder ein Handfeuerlöscher.

Typische Beispiele sind je ein Papierkorbbrand - einmal in einem besetzten und in einem leerstehenden Büro. Die selbe Brandursache hat wohl in beiden Beispielen eine höchst unterschiedliche Auswirkung. Es sei denn, dass auch im zweiten Fall für eine rasche, automatische Brandentdeckung gesorgt ist.



Übertragungskette Brandalarm

Alarmübermittlungssysteme leisten im Einsatz in Brandmelde- und Sprinkleranlagen besonders während der Nacht und über die Wochenenden einen wichtigen Beitrag zur Schadenverminderung. Sie sind ein entscheidend wichtiges Glied in der Kette von der Brandentdeckung durch einen automatischen Brandmelder oder Sprinkler bis zur Mobilisation der Feuerwehr. Die selbsttätige Alarmübermittlung zur öffentlichen Feuermeldestelle wertet die Wirksamkeit von Brandschutzeinrichtungen stark auf, insbesondere während der Abwesenheit von Personen. Die Höhe der Sachwerte, die vor den Flammen durch solche Anlagen jährlich gerettet werden, ist schwer abschätzbar, dürfte aber mehrere hundert Millionen Franken betragen. Unbekannt ist auch die Anzahl der dank dem Einsatz von Brandmeldeanlagen nicht verunglückten Personen.

2.5 Brandschutzanforderungen an Übermittlungssysteme im ISDN

Die zuständige Fachkommission Brandmeldetechnik der Vereinigung Kantonaler Feuerversicherungen VKF betrachtet das Überwachungsintervall von minimal 24 Stunden für Brandmelde- und Sprinkleranlagen als tolerierbar. Im Zusammenhang mit der Übermittlung von Brandalarmen zur öffentlichen Feuermeldestelle gilt folglich ein Übermittlungsweg im Sinne der VKF-Brandschutzrichtlinie Brandmeldeanlagen, Ziffer 1.4.1 als kontinuierlich überwacht, wenn spätestens nach 24 Stunden eine Abfrage zwecks Überprüfung der Funktionsbereitschaft erfolgt. Diese Regelung ist abgestimmt auf die Ziffer 3.2.1 der VKF-Brandschutzrichtlinie Zulassungsverfahren wonach eine Störungsbehebung an Brandmelde- oder Sprinkleranlagen ebenfalls innerhalb von 24 Stunden durchzuführen ist.

Bei speziell hohen Brandgefahren ist im Einzelfall auch im Bereich des Brandschutzes ein kürzeres Überwachungsintervall (zB. 5 Stunden oder gar nur alle 3 Minuten) sinnvoll. Dadurch wird verhindert, dass eine Störung des Übertragungssystems, beispielsweise verursacht durch Installationsarbeiten, während der nachfolgenden Nacht unbeachtet bleibt oder erst zu einer Unzeit entdeckt wird und entsprechend hohe Interventionskosten verursacht.

3 Übermittlungssysteme im ISDN-Umfeld

Mit der Einführung des ISDN stehen in Zukunft immer weniger analoge Telefonanschlüsse zur Verfügung. Dadurch kann die DOV-Technik nicht mehr angewendet werden. Damit die heute in der Schweiz verbreitete INFRANET® - Infrastruktur weiter genutzt werden kann, wurde diese mit einem Zugang für ISDN-Teilnehmer ergänzt.

Das Netz der Swisscom lässt mittlerweile die drei folgenden Möglichkeiten für die Alarmübermittlung im ISDN-Umfeld zu, welche unterschiedliche Sicherheitsanforderungen abdecken:

- **ISDN-Wählgerät im B-Kanal:** Untere Übermittlungssicherheit mit **indirektem Zugang** zum INFRANET® via Wählnetz (vergleichbar mit dem heute bekannten Wählgerät im analogen Netz);
- **ISDN-Wählgerät im D-Kanal:** Mittlere Übermittlungssicherheit mit **indirektem Zugang** zum INFRANET® über das ISDNPac (Paketdatenvermittlungsdienst, ITU-T-Norm X.31 CASE B);
- **SecurityPac:** Höchste Übermittlungssicherheit mit **direktem Zugang** zum INFRANET®. SecurityPac basiert auf dem ISDNPac der Swisscom. Die Leistungsmerkmale bezüglich Übertragungszeit, Verfügbarkeit und Störungsbehebung sind bei dieser Lösung vergleichbar mit denen des bisher bekannten INFRANET®. Bezüglich der Verbindungsüberwachung stehen verschiedene, auf die Sicherheitsansprüche abgestimmte, Überwachungsintervalle zur Auswahl.

Die beiden im D-Kanal des ISDN arbeitenden Systeme (Wählgerät und SecurityPac) übermitteln die Alarme unabhängig von der Belastung des Telefonnetzes.

Bezüglich Verbindungsüberwachung stehen nachstehende Intervalle wahlweise zur Verfügung:

- **Wählgeräte (B- und D-Kanal)**: Alle 23 Std. ein Kontrollanruf an die Leitstelle, initialisiert vom Wählgerät.
- **SecurityPac:** Automatisches Polling wahlweise alle 23h, 5h, 3 Minuten oder permanent.

Für die Kunden entstehen folgende Kosten:

- eine einmalige Gebühr für die Inbetriebsetzung
- eine monatliche Mietgebühr je nach Anschlusstyp (Intervall der Verbindungsüberwachung)

Begriffe

ISDN
Abkürzung für Integrated Services Digital Network (dienstintegrierendes digitales Netz) der Swisscom. Früher in der Schweiz als SwissNet bezeichnet.

Basisanschluss
Verfügt über zwei B-Kanäle à 64 kbit/s und einen D-Kanal à 16 kbit/s

kbit/s
In der Nachrichtentechnik benutzte Bezeichnung für die Übermittlungsgeschwindigkeit von Daten.

B-Kanal
Wird als Nutzkanal bezeichnet und dient der Übermittlung von Sprache beim Telefonieren, Zeichen bei Fax usw.
Übermittlungsgeschwindigkeit: 64 kbit/s

D-Kanal
Der Steuer- oder Signalisierkanal signalisiert und steuert die Verbindungen der B-Kanäle. Die frei verfügbare Kapazität im D-Kanal wird für die Übermittlung von Alarmen verwendet.

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The Construction Products Directive and the background to and principles of harmonisation

Abstract

The background and brief history of the Construction Products Directive are presented, as are the purpose and principles behind European standardisation being developed under the directive. Finally, the up to date picture of standards development in CEN is then presented, in relation to fixed fire fighting, fire alarm/detection, and other fire safety products.

Introduction

The Construction Products Directive (CPD) was adopted in 1989. Approaching its tenth anniversary, this paper looks briefly at the history of the directive, the process and implications of the mandating of harmonised standards within the European standards organisations CEN/Cenelec, and some of the principles which the CPD lays down. What is clear is that it will be standards under the CPD which will dominate standardisation work for the next several years and which will establish the marketing conditions for fire safety products for many years.

Although the directive has been in existence for some time now, some of its general principles and the requirements from and consequences of the standards produced in support of it are still not necessarily well known. Although there is a considerable body of information available, anyone not involved full time in standardisation should not be expected to know all the various aspects of it. This paper therefore tries to explain some of the essential aspects.

Although the CPD offers other routes to show conformity, this paper concentrates on standardisation only, because this is the route for the vast majority of fire safety products.

Background and general principles

It was back in 1985 that so-called New Approach directives (NADs) were first conceived as being the only practical way of achieving the Single European Market for goods, scheduled for completion in 1992. Although directives had existed long before this, they were often technically

complex and, consequently, took a very long time to produce. Some directives were almost as technically complex as product standards.
The main features of NADs is that they set out the essential safety requirements, in general terms, on products, allowing those products to be placed freely on the markets of all European Member States. The main aim is to remove technical barriers to trade on products caused by national differences in these requirements. Because the requirements are expressed in general terms, the directives foresee that the European standardisation bodies will, under mandate, produce standards defining the technical requirements on products, necessary to satisfy the essential requirements.

NADs generally state systems for attestation of conformity for products. This is "by whom" conformity is to be demonstrated (as opposed to "how", which is a technical matter, see below), i.e. by the manufacturer or by one or more different types of third party intervention. They all provide that conformity with the directive(s) shall be demonstrated by affixing the CE marking and, perhaps most importantly, they require that Member States shall presume that CE marked products are in conformity and that, therefore, their access to the market shall not be hindered.

Directives generally deal either with products (construction products, machinery, etc.) or with specific safety risks (electrical safety, gas safety, etc.). As a consequence, it is possible for a product to be covered by more than one directive. As far as standardisation is concerned, however, this should not make a significant difference; in producing standards for a product, the standardisation bodies should take account of all relevant directives, so that conformity with the standard leads generally to conformity with all relevant essential requirements.

The CPD as a New Approach directive

The CPD is aimed at opening up the single European market for construction products. It follows most of the provisions of other NADs but with some differences. It is worth examining these because they help explain why the CPD is not yet fully operational on the market.

Like other directives, the CPD sets out general essential requirements for health and safety but, unlike other directives, these requirements apply to the building or civil engineering works rather than to the construction products themselves. For fire safety the CPD requires that the construction works must be designed and built in such a way that in the event of a fire:

- the load bearing capacity of the construction can be assumed for a specific period,
- the generation and spread of fire and smoke within the works are limited,
- the spread of fire to neighbouring construction works is limited,
- occupants can leave the works or be rescued by other means,
- the safety of rescue teams is taken into account.

The CPD therefore foresaw the need for so-called Interpretative Documents (IDs), which would take fire safety and the other five essential requirements on works and, from them, identify the necessary characteristics of products. Here lay a major source of delay. In a directive such as for machines, a machine which is "safe" can generally be accepted as "safe" in all Member States. Under the CPD, however, whether a product is "safe" depends on how the works are designed and products installed; what one Member State considers "safe" will depend on its methods of building and design. Although the IDs went some way to making the link between works and products, they were not sufficiently precise as the basis for preparing standards.

Looking at ID2 "Safety in case of fire", and taking fire detectors as an example, the ID talks first about "actions" on fire detection installations (which are "parts of works", rather than individual products) and says that the actions may be characterised by the rate of heat release, flame height and amount of smoke generated, fire area and temperature level. The ID then develops the requirements on the installation further, requiring "ability to detect smoke, flames and/or heat automatically ... and transfer a signal to a central indication and control unit".

Finally, the ID talks about products, but saying no more than "The detection part of the installation consists of detectors connected to a control unit and one or more indication units with emergency power supplies". So it can be seen that nowhere in ID2 are there any indications of exactly which performance characteristics of an individual product are relevant. This lack of information made the production of complex mandates necessary (see below).

The CPD has one other difference compared with other NADs, in that it does not fix the system for attestation of conformity for products. Other directives give a choice of several systems involving different types of third party intervention, whereas the CPD requires a unique choice from four basic systems, to be made by Commission after consulting the Member States, and indicated in the mandates.

One last provision of the CPD and the IDs should also be mentioned here. "As far as is practicable the characteristics of products should be described in performance terms in the technical specifications ...". This is discussed further below.

The mandating process

Detailed mandates for product standards became necessary because of imprecisions in the IDs and because of the need to identify the system of attestation of conformity for each product. The IDs were agreed and published in 1994, but it took a further year before the first mandates were issued. The mandate for fire alarm, fixed fire fighting, fire and smoke control and explosion suppression products was received by CEN in August 1996. The process of drafting a mandate may take 18 months but the assumption is that, at the end, all those with an interest in the mandate should have been consulted, a process which has not always worked in practice.

The mandates call for harmonised European standards (see below), i.e. standards which support the essential requirements of the directive and the specific characteristics of products necessary for these requirements to be met. Following the example of detectors, the mandate identified the following essential characteristics:

- nominal activation conditions/sensitivity,
- response delay (response time),
- operational reliability,
- tolerance to supply voltage,
- self containment of radioactive sources
- durability and
- performance parameters under fire conditions,

these being the characteristics considered as essential for a fire detection system to meet the requirements on the installation given above.

The mandate also set the system of attestation of conformity for the products covered by the mandate. Because most fire safety products are safety critical, there was unanimous agreement within the Standing Committee for Construction for CPD system 1, i.e. third party product certification, based on the manufacturer operating a factory production control (FPC) system and undertaking further product testing at the factory in accordance with a prescribed test plan, and the third party undertaking initial type testing of the product, initial inspection of the factory and FPC system, and continuous surveillance, assessment and approval of FPC.

The mandate covered both individual products (detectors, sprinklers, water motor alarms, etc.) and also “kits” of components. In the wording of the CPD, a "kit" is the equivalent of a "construction product". A construction product is a "kit" when it is a set of at least two separate components that need to be put together to be installed permanently in the works. For a "kit" to come within the scope of the CPD, the following conditions must be satisfied :

i) the "kit" must be placed on the market, allowing a purchaser to buy it in one transaction from a single supplier,

ii) the "kit" must have characteristics that allow the works in which it is incorporated to satisfy the Essential Requirements, when the works are subject to regulations containing such requirements.

The concept of “kits” is offered to standarisers as a possibility, based on the stated position from the fire safety industry and other experts that some fire safety products are sold as kits. It does not mean, however, that standards must be produced for kits if such kits do not currently exist on the market or if CEN/Cenelec do not wish to produce such standards.

CEN/Cenelec are required by the mandate to put forward a Work Programme. In responding to the mandate, the Technical Committees (in this case mainly CEN TC72 and TC191) need to identify the products in the mandate for which they propose standards, giving target dates, and how they intend to deal with the characteristics given in the mandate. This latter is open to some modification, depending on the particular nature of certain products. For example (using the characteristics listed above), TC72 considered that “self containment of radioactive sources” was not relevant to detectors not containing radioactive components. The term “durability” also required development, because the directive requires durability of the relevant essential characteristic(s), rather than of the product itself. It was agreed with the TCs that “operational reliability” would mean the ability to operate once, while “durability” would mean the ability to operate over time or following repeated actions. So in the case of detectors, parameters under “durability” include such as:

- durability of response delay, temperature resistance,
- durability of operational reliability, vibration resistance,
- durability of operation reliability, corrosion resistance, etc.

The Work Programme in response to the fire safety products mandate was submitted to and accepted by the European Commission in mid-1998. This means that the CEN Technical Committees now have a green light to produced the necessary harmonised standards.

The nature of harmonised product standards

General

The CPD requires the production of harmonised product standards (hENs) covering the characteristics given in the mandate and necessary to support the essential requirements of the directive. Note here that the term "harmonised" means specifically "produced under mandate in support of an EC directive" and not any other meaning.

Once an hEN is adopted, compliance become effectively compulsory for those products within the scope of the standard, so the standard itself becomes effectively compulsory. Because the CPD aims at removing technical barriers to trade, standards in support of the CPD cannot, therefore, re-introduce existing or create new barriers by their provisions. This means, in general, that each standard or group of standards should cover all products which are currently legally placed on the European market (taking due account of specific national requirements arising from differences in geographical or climatic conditions or in ways of life as well as different levels of protection). All such products should be able to benefit from the free circulation benefits offered by CE marking at more or less the same time. Standards should in general deal only with technical aspects of products and their evaluation of conformity, and should not be re-writing national regulations nor introducing contractual terms (such as involvement of third parties), except where required by the CPD.

Normal European standards (ENs, i.e. those usually being developed by Technical Committees (TCs)) generally cover more aspects of a product than the essential characteristics. Examples may be colour, standard sizes and performance levels which go beyond what are necessary to define a product as "safe". Because of this, it is necessary to distinguish between the harmonised and the voluntary (but normative in usual standardisation language) parts (see below). Conformity with the harmonised part is all that is necessary for conformity with the directive and subsequent CE marking. If an EN covers all the harmonised requirements as well as some voluntary ones, then conformity with the whole EN would also mean conformity with the CPD requirements.

In the case of fire safety products, most if not all of the content of the standard is likely to be harmonised. The CE marking applies to the product at the time that products are first placed on the European market, and demonstrates that the product either meets or has the capability to meet the directive. This means that where, for example, the stated performance of a product depends on it being correctly installed, the standard may require that the CE marking be accompanied by instructions for installation. Note, though, that the CE marking requirement is that instructions be given; it is not the product manufacturer's responsibility if the product is not subsequently correctly installed, nor does the CE marking guarantee this.

Performance based standards

As stated above, the CPD requires, in general, that standards be written in performance based, rather than prescriptive, terms. In principle it means that standards should not contain prescriptive requirements on raw materials, should not include "pass/fail" tests, and should not be introducing levels of performance whose effect is to remove some products from the market. In general, for CE marking purposes, standards should be saying only "assess the characteristic and state the resulting performance".

Having said that, it seems that an element of pragmatism is being permitted, at least in the "first generation" of harmonised standards. This recognises that, for example, prescriptive material requirements are an indirect way of considering durability, and that pass/fail tests (especially in the case of fire safety products) have a long history of demonstrating the safety of the product. It is also expected that as standards are updated and revised through the normal process of five-yearly reviews, they will evolve more towards a performance based approach.

Evaluation of conformity

All product standards should contain a clause entitled "Evaluation of conformity", i.e. how it will be shown that the product conforms to the standard. This clause will contain two sections: initial type testing identifying which tests or assessments (usually all) have to be performed (and possibly details of sampling and number of products to be tested), and factory production control (FPC).

It is for the TC to decide how much to include for FPC. The minimum is to state the requirement that the manufacturer operates an FPC system. Over and above this, it is possible to give more details, such as which characteristics have to be tested as part of FPC, which can be controlled indirectly (e.g. by controlling raw material, design, manufacturing process, etc.), and which do not change over time and therefore do not need repeat control under FPC. Frequencies for FPC testing or assessment may also be given, together with details of other aspects of FPC, such as defective products, calibration of test equipment, control of incoming raw materials/components, etc.

“Evaluation of conformity” requirements should be written without identifying who will perform the evaluation (which is specified in Annex ZA, see below) e.g. "initial type testing shall be carried out", not "the third party test lab shall perform type testing" (although it is possible to require that "The manufacturer shall operate an FPC system").

There are different consequences depending on how much detail on evaluation is given in the standard. If there are very detailed and thorough provisions, the role of a third party becomes limited to ensuring that the manufacturer follows these provisions. If there are only general provisions, it will up to the third party(ies) to decide how to implement them (although there will, at European level, be meetings of notified bodies to decide, between them, how to implement attestation of conformity in the absence of details in the standard).

Annex ZA

Recognising that most ENs would contain both harmonised and voluntary aspects with a need to differentiate between them, and also recognising the need to state the system of attestation of conformity in the standard but that standards are not normally permitted to do this, the concept of the “informative/normative” Annex ZA was developed. This is informative to avoid problems with CEN/Cenelec Rules and voting, but normative in that it must be complied with fully in order to comply with the CPD. Although the concept of Annex ZA is now well known, what is not so well known is its required content.

Annex ZA consists of three separate clauses. ZA.1 identifies those clauses (requirements rather than test methods) of the body of the standard which cover mandated characteristics. ZA.2 repeats the attestation of conformity system which must be followed for CE marking and may give more details on attestation, such as where the mandate identifies that some characteristics require initial type testing by a third party, while others are performed by the manufacturer. Where this is the case, the “Evaluation of conformity” (see above) clause should allow Annex ZA to refer separately to these.

Annex ZA.3 must, importantly, state the information which must accompany the CE marking, either placed on the product itself, on a label attached to the product, on the packaging or on accompanying commercial documents (for the standard to decide which, and a combination may be used, e.g. the CE symbol on the product, with further details on the commercial documents). Because in general standards should not contain minimum levels or "pass/fail" requirements, citing only the number of the standard will not be sufficient. For a detector, as an example, the CE marking could be expected to be accompanied by information on the activation conditions/sensitivity, the response time and the sensitivity to supply voltage. Given that most of the durability requirements are pass/fail, citing the EN number might be taken to mean passing all such tests, but the standard should make this clear.

Some or all of the information given with the CE marking will, of course, be of use to the purchaser and not just the market regulator. But the purchaser will still have to ensure that the product he buys (of maybe several products of similar type on offer) has the necessary performance for the end use in mind, and he may well require other characteristics of the products not linked to health and safety and therefore included in the voluntary part of the EN.

Progress on standardisation of fire safety products

The various CEN TCs dealing with these products have been working steadily to develop a whole series of both product and design/installation standards. With some 15 standards due to be voted next year, covering a range of products such as: control and indicating equipment, fire alarm devices, heat, smoke and flame detectors, hose reels and components for sprinkler systems, these are likely to be among the first products to receive CE marking under the CPD.

A few of the standards already exist as (non-harmonised) ENs with which manufacturers have been gaining experience. Some aspects need to be checked as the standards develop, for example that they do not exclude currently accepted products from the market (either directly or by market forces) nor prevent the development of new products and technologies, that the various design standards do not prevent alternative technical solutions or technical developments, and that the standards permit all specifiers to continue to choose and use appropriate products and systems. But by and large the harmonisation process will not lead to significant changes either to existing ENs or to the way in which other ENs are developing.

Conclusions

Standardisation work in CEN/Cenelec is the dominant activity, at least as far as Europe and trade with Europe is concerned. With the requirement for Member States to withdraw their own national standards on publication of European ones, it is the CEN/Cenelec activity which will set the scene for many years to come.

The necessary decisions have been taken at regulatory/political level in the Commission and the SCC so that the was forward is now shaped and it just remains for those in CEN/Cenelec to produce the standards necessary to provide the benefits offered by the CPD and CE marking. All concerned should therefore be concentrating on becoming fully aware of the way things are progressing, on helping to make it work properly and smoothly, and on ensuring that they are ready for the new European standards when they arrive in a year or two's time.

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The interpretation of the European Standards for control and indicating equipment (EN54-2) and power supplies (EN54-4)

Abstract

The European Standards for control and indicating equipment (EN54-2) and power supplies (EN54-4) are now published in all CEN countries. The application of these standards has shown that many clauses can be interpreted in different ways, in particular by manufacturers and test houses. This can lead to misunderstandings during testing and certification. WG7 and WG8 of CEN/TC72 were therefore given the task to produce an interpretative document, to clarify various points, and reach a common understanding of what was meant when the standard was drafted. The interpretation document will also form the basis of amendments to improve the documents and bring them up to date, without changing the spirit, or fundamental technical content. This paper gives an overview of the work, and the first results.

Introduction

The European Standards EN54-2 for control and indicating equipment (c.i.e.) and EN54-4 for power supply equipment (p.s.e.) were a long time in preparation. WG7 of CEN/TC72 started work on part 2 in the early 1970s. The first draft attracted widespread comment, not only for its functional deficiencies, but also a failure to reflect addressable systems. A revised draft in 1989 again attracted much comment, and the full WG7 met a further 12 times before the document was finally completed in 1992. EN54 parts 2 and 4 were formally accepted by a positive vote with a great majority. Although the standards were not published until 1997, they had already been widely implemented by manufacturers and test houses across Europe. This working experience brought to light various errors and ambiguities. The UK triggered the interpretative and amendment process, and provided most of the comments. This was mainly because EN54-2 is so similar to the DIN standard in style and content, and whereas existing equipment from Germany and other countries more or less complied already, UK manufacturers had to design new equipment and have this approved. EN54-2 is a large document, with many detailed requirements. The aim was to make the wording precise and minimise ambiguities, but this was not always possible, especially where there were still underlying disagreements. Part of the problem of interpretation is that different nationalities read the standards differently. Certain words and concepts taken for granted in one country may be unknown or differently understood elsewhere. Different perceptions in the UK may be explained by the difference in the Anglo Saxon and Napoleonic legal traditions, which is summed up by the adage: in Britain anything not explicitly forbidden is permitted, whereas in continental Europe anything not explicitly permitted is forbidden.

WG7 an WG8 were given the following tasks by CEN/TC72:

- to prepare the standards for harmonisation under the EU Construction Products Directive;
- to review the national comments, and categorise them into those to be dealt with by interpretation, and those requiring amendment or revision;
- to prepare an interpretative document, reaching a common understanding of what was meant when the standard was drafted;
- to correct errors and make the standards more readable;
- to propose amendments, where requirements have been overtaken by new technology, standards, or changes in practice.

This paper does not deal with subject of harmonisation, although this process does make the present work particularly urgent. In some CEN countries, third party certification has hitherto not been required by law, and only a small proportion of the equipment sold in those countries is approved. This may remain so in future for the free market. However, with the introduction of the CPD this practice becomes illegal for the regulatory market. It is vital that equipment can comply with the standards, and this is currently difficult in some respects. The main emphasis is on EN54-2, which is really the master document for achieving harmonisation of fire detection and fire alarm systems in Europe. Rather than attempting to cover all of the detail, several topics are discussed, each of which highlights one aspect of the work.

Indications and displays

The requirements for indications and displays is a good example of where alternative technologies are specified which implicate on the application of equipment. For most indications, either light emitting indicators or an alphanumeric display may be used, but EN54-2 imposes different requirements for each. This is one aspect where it may have been preferable to specify the information which shall be displayed, rather than exactly how it is to be displayed. The two means of display are not really equivalent, and this can lead to some anomalies. The concept of 'functional condition' was introduced in this standard. The functional condition (e.g. the fire alarm condition) is characterised by its indication at the c.i.e.. This is logically consistent, but has led to confusion. Some manufacturers did not fully grasp that all functional conditions had to be simultaneously indicated, by general light emitting indicators. It is not uncommon to suppress the indication of faults and disablements during fire, in order to help avoid a 'Christmas tree effect' (too many lights to confuse a user in an emergency). In the case of alphanumeric displays, suppression of indications was anticipated because of the known capacity limitations, and detailed requirements were included so that suppressed indications could be revealed in a orderly manner. However, in the case of light emitting indicators, similar requirements were not included.

EN54-2 reinforced the concept of zonal indications, and requires that a c.i.e. shall be capable of grouping detectors to provide a single indication for each zone. Parts of market have still not grasped that this remains important even for alphanumeric displays in addressable systems. Other points which have been misunderstood are the distinction between fields (each of which displays an indication) and windows (a group of fields all relating to the same functional condition), and also that window boundaries may be created in software.

Delays to outputs and coincidence detection

Delays to outputs, and coincidence detection were each included as an optional function with requirements. The role of the options in the structure of EN54-2 is not widely understood. There are really two classes of options. For functions which are genuine additions, for example the standardised input/output interface (7.13), the manufacturer is free to provide a similar feature which does not fully comply (although he may not then claim compliance with the option). However there are also options which permit a mandatory requirement to be modified, and here the manufacturer has no choice; if a relevant feature is included, it must fully comply with the requirements. Delays to outputs (7.11) and coincidence detection (7.12) fall into the latter category, because in each case they permit the c.i.e. not to immediately fulfil the requirements in the fire alarm condition on receipt of a fire signal. These options are essential, but were difficult to draft because of wide differences in custom and practice, and the absence of common European installation guidelines or system rules.

There are two main reasons for delaying output signals, which have quite different implications:

- so that a person may verify that there really is a fire following an alarm, before ordering an evacuation of the premises, calling out the fire brigade, or carrying out other potentially costly or disruptive actions;
- to make it possible to achieve a more orderly evacuation of the premises, hence reducing the risk to the occupants.

An attempt was made to explain the spirit of clause 7.11 (delays to outputs) in annex E of EN54-2. However, this may not be sufficient to answer all of the questions. One has to accept that EN54-2 is a compromise reached after long discussions within WG7 and finally approved by the majority of the CEN members. Due to this compromise, important features commonly employed in parts of Europe, are no longer permitted where EN54-2 is applied, for example delays to outputs to fire alarm routing equipment (E) following a signal from a manual call point, and delays to outputs to fire protection equipment (G). There has also been confusion concerning the control functions associated with delays, i.e. the distinction between:

- configuration of delay structures and times (at access level 3);
- disablement and enablement of delays (at access level 2);
- controls to override a delay in progress (at access level 1).

Coincidence detection was included to permit alarms from fire detectors to be inhibited until more information on the fire is received. This is becoming increasingly common as a means of reducing unwanted alarms, and not only in conjunction with automatic extinguishing systems. There has been some confusion relating the permissible coincidence criteria. The first alarm must be from a fire detector, but the second alarm may be from any point: a manual call point, a different fire detector, or a second alarm from the same fire detector based on the same or different fire detection criteria. It is not clear whether it is permissible to combine alarms from different zones, or whether it is required to individually select the outputs which are inhibited. An additional annex on this subject may be helpful. There are also points for amendment or revision. It is permitted that the c.i.e. does not enter the fire alarm condition following a first alarm, but there is no requirement for this to be indicated. Perhaps there is a need for a 'pre-fire condition' or 'warning condition'. Also, if a second alarm does not occur, should the first alarm be reset manually, or automatically after a delay, and if so for how long may a first alarm remain latched?

Software controlled systems

Some early software controlled equipment gained a poor reputation for reliability, and there was still widespread suspicion when EN54-2 was being drafted. A complete clause (13, the unlucky number for some) was devoted to special requirements. Much of these concerned documentation and good design practice, and here EN54-2 broke new ground in recognising that modern equipment includes complicated technology, and that certain requirements could only be verified by inspection of the accompanying design documentation. However, clause 13 also included design requirements, concerning program storage and monitoring, special indications, and certain restrictions. Some WG7 members viewed this as a dangerous precedent; while it is a tradition for standards to impose restrictions on the use of new technology, it is not always done in so determined a manner. A good general rule is that standards should deal only with the fundamentals of function and reliability and should not attempt to specify which technologies are acceptable, otherwise reality soon overtakes the standard and renders it obsolete. Technology moves particularly quickly in the field of microprocessors and software, and clause 13 now needs amending, not just interpreting.

One potential problem area concerns acceptable methods of memory storage. EN54-2 effectively forbids the storage of the program in memory with moving parts. Yet there is nothing fundamentally unreliable about mechanical mechanisms. The reliability of such memories has increased enormously in recent years. We now tend to trust the hard disc on a modern PC (even if we are not completely at ease with the operating system it stores).

Another example relates to the monitoring of memory contents. It was assumed that the program would usually be stored in programmable memory (EPROM), and that this was inherently unreliable. The memory contents therefore had to be monitored, using a checksum procedure. This did not anticipate the growth in the use of low cost microcontrollers which have invaded all sorts of products and subsystems, including the liquid crystal display modules now built into many c.i.e.. Most modules do not implement memory monitoring. Often the microcontrollers employ masked ROM, and with some types it is not even possible to perform a ROM checksum. If we are to avoid falling into the technology trap again, a solution is to delete the specific requirement, and rely on more general requirements that the execution of essential parts of the program shall be satisfactorily monitored.

One of the more contentious requirements concerned 'emergency operation', which was felt by some to have no sound justification in terms of reliability theory. A fire alarm system above a certain size shall still be able to detect and indicate a fire, even if microprocessors or software in the c.i.e. have failed (defined as the presence of a system fault). This also applies to indication and control at a common point where the c.i.e. is distributed on a network. During emergency operation there is no requirement to identify the location of the alarm, warn the occupants of the building, or carry out other actions. A modern approach, which can improve on the minimum requirement, is to employ a network of processors, having built in redundancy to cope with any single failure. However, the requirements for program monitoring did not really anticipate processors which monitored each other. It was assumed that each processor in the system would have its own hardware watchdog circuit.

Power supply equipment

EN54-4 contains fewer functional requirements than EN54-2, and most of the problems concern the clause on tests. However, there has been confusion over functional requirements, for example as to what the stand by source actually comprises, and also whether the float charging voltage for batteries must be temperature compensated. There are also technology restrictions, for example at least one stand by source must be a rechargeable battery 'suitable to be maintained in a fully charged state'. This would appear to rule out multiple battery banks, deep discharged in turn, and the high performance fuel cells which may soon reach the market. A surprising omission is any requirement for a minimum stand by period after the mains has failed.

The biggest problem with part 4 results from its being separate from part 2. In an important sense this is correct, since the intention is to cover p.s.e. for all system components, not just c.i.e.. However, in a great deal of equipment now the p.s.e. is integrated with the c.i.e.. The degree of integration varies, from separate modules in a single enclosure to seamless designs with control and monitoring carried out by a common processor. EN54-4 assumes that the p.s.e. has a defined DC output voltage, which may not be the case. It may not be easy to recognise the boundary between the functions of the p.s.e. and the c.i.e. There may be a number of power supply sub-modules, including switching converters to provide voltages for all sorts of functions. It is not always obvious which functions have to monitored, and how some of the required tests are to be applied. Because there are problems in common, WG7 and WG8 are co-operating closely in addressing these issues.

Environmental tests

Each standard includes a detailed clause on tests. Some of the required tests are specific to the application, especially in EN54-4. However, electrical and electromagnetic compatibility tests are also included, the latter being an area subject to rapid technological change. The growth in mobile phone use over the last 10 years has resulted in a widening of the electromagnetic spectrum and an increase in the field strength to which equipment is subject. In consequence, methods of test have become more sophisticated. A relatively recent product family standard (EN50130-4) deals with the subject of electromagnetic compatibility, and from 01/01/2001 this becomes mandatory for alarm systems covered by the EMC Directive. In practice, the most significant technical change is the replacement of radiated susceptibility tests at frequencies below 80MHz by a test for conductive disturbances, in which AC voltages in the frequency range 100kHz to 100MHz are injected into the circuits connected to the equipment. EN54 parts 2 and 4 must be amended to delete certain tests, and call up EN50130-4 instead. This is not as simple as it appears. The requirements in EN50130-4 are generic. We need to sufficiently define the test methods such that each manufacturer and test house applies equivalent rules. This has not always been the case, and this has led to confusion and argument. This is an opportunity not to be missed to get things right in a technical, but very important field.

The future for EN54-2 and EN54-4

The published standards are not perfect; how could they be? Nevertheless, members of the working groups need not be too defensive about this. That workable standards emerged at all was a considerable tribute to the skill and patience of the convenors, and to the willingness of experts to compromise on entrenched national positions and argue for common solutions, even against their own national committees. The results are a great improvement over the previous national standards. The present process of interpretation and amendment will not lead to major changes in the functional requirements; this would be too disruptive at the present time. At its meeting in October 1998, CEN/TC72 decided to issue the interpretations of EN54 parts 2 and 4 officially, as CEN Reports. This will allow publication in the shortest possible time, because no translations are needed. Although they are not normative, the reports may become de facto standards and will be seen as important documents in discussions between manufacturers and test houses.

Looking forward to revision, the basic shape and core content is likely to be carried forward, although there will inevitably have to be changes, and material to add. In this context it is important to mention that the revision of EN54 parts 2 and 4 will be carried out in co-operation with ISO/TC21/SC3/WG4. This means that input from non-European countries will be considered. Important aspects are the integration of evacuation and smoke control. In the revisions, WG7 and WG8 must have the vision to as far as possible future proof the standards against the march of technology and evolution in custom and practice. Hopefully, this will result in clearer documents, with a strong emphasis on fundamental requirements, and more of the detail incorporated into annexes as statements of good design practice.

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STANDARDISATION IN FIRE DETECTION AND FIRE ALARM SYSTEM

ABSTRACT

Since the beginning of the CEN TC72/WG9 on standardization of the fire detection and fire alarm system in 1988 ,the need for standardizing the system was confirmed but it remains a lot of problems to solve before achieveing the task.

My lecture will give you the status of the standardization process and on the methodology which is used by the experts to garantee the correct functioning of the installations of fire detection and fire alarm system.

In a second step,I will deal with fire detection system included in building management system .These systems are more complexes and group several applications such as access control, intruder alarm system, CCTV.. but may not be always fully compatible and will lead to specific case to case answer.

1- INTRODUCTION

Depuis plusieurs années, le CENTC72/WG9 travaille sur la définition des exigences à appliquer pour la conception de système de détection d'incendie (voir conférence de AUBE 1995).Il y a eu jusqu'à aujourd'hui un gros investissement en temps des professionnels : le résultat est toujours attendu et il doit satisfaire les attentes de tous. C'est pourquoi, de nouvelles orientations ont été prises au sein du groupe de travail qu'il ait eu connaissance des commentaires de la première enquête CEN.

Simultanément, un groupe de travail du CENELEC TC79/WG13. a développé une démarche normative pour les systèmes combinés ou intégrés.

Je vais donc vous tenir informés de ces évolutions qui orientent fortement les travaux et qui ont des conséquences sur la réglementation dans les différents pays d'Europe.

2- COMMENTAIRES DE L'ENQUETE CEN SUR LE PROJET EN54-13

Le projet de norme concernant les systèmes de détection incendie PrEN54-13 a été mis en enquête de 6 mois en Août 1996. Après réception des commentaires en Avril 1997, les experts ont repris leurs travaux afin d'intégrer les besoins exprimés lors de l' enquête CEN.

Le contenu des commentaires montre que:

Le document était trop compliqué à exploiter car en fonction des situations, la logique à suivre n'était pas naturelle.

Le document cherchait à trouver un consensus sur les principes génériques à suivre pour concevoir un système. Cependant il faut tenir compte que la conception est aussi liée à sa mise en oeuvre et de ce fait la finalisation des exigences s'effectue également sur le site d'application en fonction des règlementations locales.

3- NOUVELLE METHODOLOGIE DEVELOPPEE DANS LE PrEN54-13

Suite aux commentaires, les travaux se sont engagés sur la terminologie, les catégories et les principes des liaisons entre systèmes. Il en ressort les principales évolutions suivantes:

3.1 Terminologie :

Les dispositifs constitutifs d'un système de détection et d'alarme incendie sont décrits sous deux termes :

- les **composants** : dispositifs essentiels du système couverte par la EN54.
- les **éléments** : dispositifs additionnels non couverts par une partie de la EN54 (la subdivision des éléments en type 1 et type 2 est abandonnée)

La classification des systèmes en catégories est également abandonnée, mais il subsiste la classification des systèmes en réseaux et en systèmes hiérarchisés.

3.2 Les principes de base

Les voies de transmission sont considérées comme indépendantes (c'est à dire qu'un défaut sur l'une d'entre elles n'affecte pas les autres).

Tout type de dispositifs (composant ou élément) est connectable sur n'importe quelles voies de transmission dans la mesure où il respecte la fonctionnalité du système, et où il ne perturbe pas son fonctionnement. (exception faite de la voie de transmission du transmetteur d'alarme incendie).

Afin de s'adapter à toutes les exigences règlementaires nationales et également à celles du client ou du prescripteur , il est demandé que chaque système, présenté dans une ou plusieurs configurations, possède des dispositifs d'isolation permettant de séparer fonctionnellement les produits sur un même circuit de détection.

3.3 Liaison avec les systèmes de protection incendie

Les interfaces entre les systèmes n'étant pas standardisées, il convient de se préoccuper de définir clairement la répartition des fonctions nécessaires à l'accomplissement de la mission globale de mise en sécurité.

Pour cela il faut absolument définir les systèmes sous une approche fonctionnelle et non pas sous une approche matérielle, afin de laisser au concepteur toute liberté d'action sans lui imposer un moyen qui pourra n'être valable que dans des situations particulières.

Afin de permettre cette approche le schéma de principe de la détection d'incendie que l'on trouve dans la partie EN54-1, sous forme d'exemple de réalisation de système à partir de produit, a été reconsidéré sous une approche de fonctions. Un exemple est donné pour un système de détection incendie et un système d'extinction automatique (annexe1).

On peut clairement identifier les fonctions à assurer. Par exemple, le concepteur peut mettre les fonctions de traitement et de commande

- ↳ soit dans des équipements différents,
- ↳ soit dans un même équipement assurant le traitement des fonctions CIE et ECD par exemple.

Cette approche a le mérite:

- ↳ de laisser la liberté de conception pourvu que l'objectif soit atteint,
- ↳ de clairement identifier les exigences normatives à appliquer,
- ↳ de permettre l'évolution et la création de nouveau produit plus intégré sans perdre en fiabilité,
- ↳ de répondre de façon adaptée à toutes les configurations nécessaires sur le marché.

Elle est plus difficile à exploiter par :

- ↳ les concepteurs qui doivent bien séparer les fonctions et éviter les contradictions et les doublons.
- ↳ les laboratoires qui doivent faire les « interprétations » adéquates pour valider un produit et de ce fait renforce la compétence des équipes d'essais.
- ↳ les prescripteurs qui devront spécifier leur besoin en terme d'objectifs fonctionnels et non pas de moyens (règles d'installation) .Il devrait par contre définir les moyens des vérifications d'obtention de ces objectifs.

Elle facilite l'usage :

- ↳ des utilisateurs qui trouveront sur le marché des produits mieux adaptés à leur besoin,(cohérence d'exploitation, homogénéité, convivialité...)
- ↳ des utilisateurs dans la définition des cahiers des charges de sécurité et notamment dans l'analyse des fonctions essentielles et des fonctions additionnelles et des mesures compensatoires à prendre en cas de dysfonctionnement (redondance, limitations...).
- ↳ des prescripteurs qui n'auront pas à se soucier de la façon de faire mais uniquement de l'objectif à atteindre

Cette approche fonctionnelle guide la rédaction du texte et doit s'étendre à tous les systèmes entrant en communication avec le Système de Détection Incendie : en effet c'est la seule qui permette une vision normative non limitée aux techniques d'aujourd'hui mais laisse possible une évolution technologique sans remettre en question les textes de normes qui, comme chacun sait, mettent du temps à être conçus et autant de temps à être révisés. C'est le seul salut pour la normalisation en incendie : faire de la normalisation fonctionnelle.

Cette approche présente à priori un inconvenient : elle demande que la réalisation et le suivi des installations soient réalisés par des experts capables « d'interpréter » correctement les objectifs à atteindre. Mais c'est peut être finalement un avantage pour certains métiers !

3.3 Liaison avec les autres systèmes de sécurité

La norme « exigences pour les systèmes de détection incendie » PrEN54-13 ne traitera pas directement la liaison ou l'intimité du système de détection avec les autres systèmes d'alarme: cela est du ressort de la normalisation des systèmes combinés ou intégrés qui sont traités par le CLC TC 79/WG13.

Il est d'ores et déjà envisagé d'avoir plusieurs types de configuration permettant

- soit de partager certains moyens communs aux applications,
- soit de les garder de façon dédiée en partageant uniquement une liaison additionnelle vers un équipement central de commande .

Le principe de base retenu dans ce texte est : tout système doit d'abord répondre aux exigences des normes qui lui sont applicables et en particulier les moyens communs doivent répondre aux différents textes couvrant les applications communes.

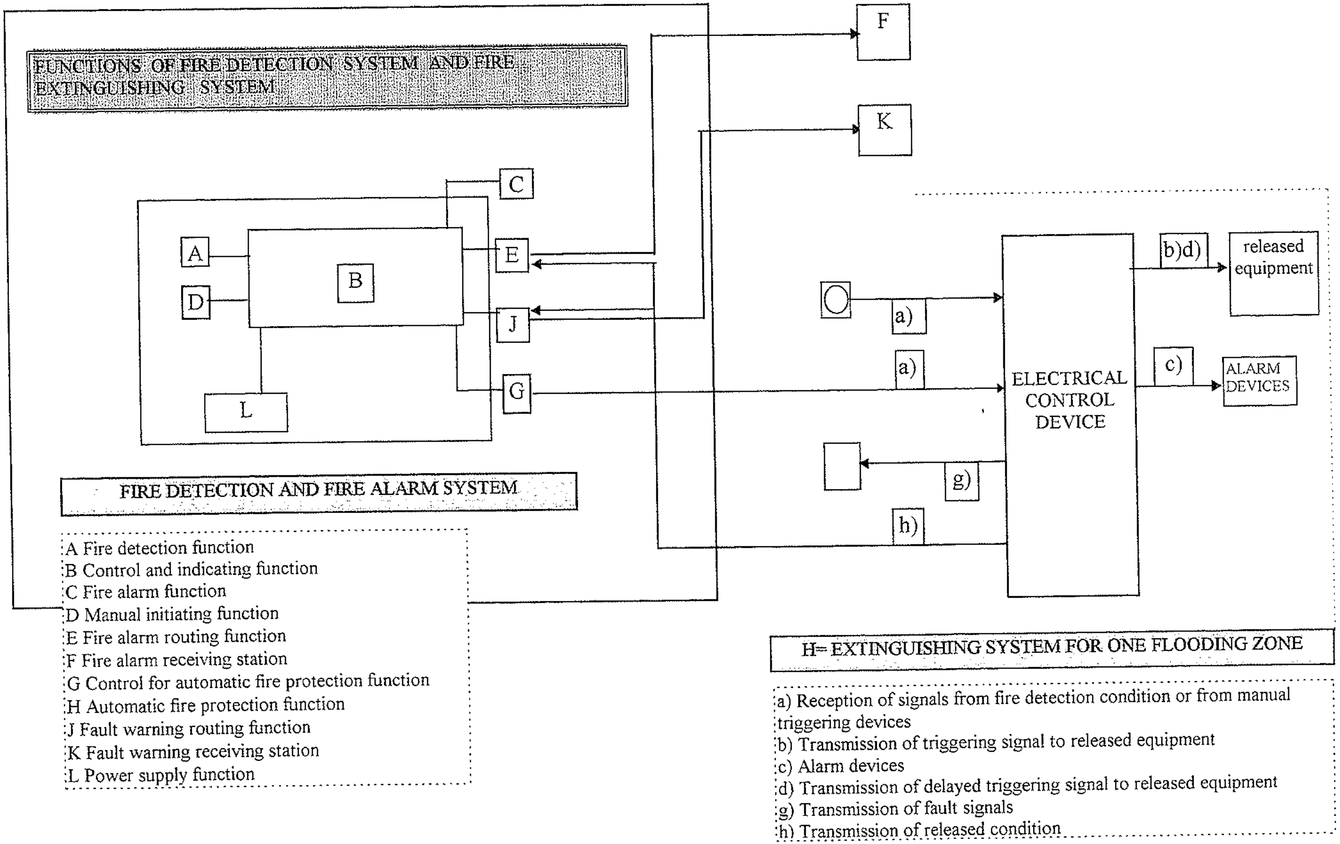
Toute les situations pouvant existées (annexe 2) , il convient que l'utilisateur ou le prescripteur de tel système soit bien au fait des conséquences d'un dysfonctionnement sur la sûreté de fonctionnement des applications. L'approche fonctionnelle décrite plus haut pour la détection lui permettra de faire son analyse de façon plus aisée et de choisir la configuration la plus adaptée à son besoin (qualité-coût).

4- CONCLUSION

Les travaux du WG9 sont longs car il faut établir de nouvelles règles pour l'Europe dans un contexte de marché unique (directive DPC) et en partant d'usage très différent et de technologie en perpétuelle évolution.

Le travail, que les experts du CEN TC72/WG9 ont effectué, doit être considéré comme un exemple pour les autres groupes de normalisation fonctionnelle de système.

J'espère que lors de la prochaine conférence AUBE , j'aurai le plaisir de vous dire que cette tâche est enfin accomplie.



FUNCTIONS OF FIRE DETECTION SYSTEM AND FIRE EXTINGUISHING SYSTEM

FIRE DETECTION AND FIRE ALARM SYSTEM

A Fire detection function
B Control and indicating function
C Fire alarm function
D Manual initiating function
E Fire alarm routing function
F Fire alarm receiving station
G Control for automatic fire protection function
H Automatic fire protection function
J Fault warning routing function
K Fault warning receiving station
L Power supply function

H= EXTINGUISHING SYSTEM FOR ONE FLOODING ZONE

a) Reception of signals from fire detection condition or from manual triggering devices
b) Transmission of triggering signal to released equipment
c) Alarm devices
d) Transmission of delayed triggering signal to released equipment
g) Transmission of fault signals
h) Transmission of released condition

ANNEXE 2 EXEMPLE DE SYSTEME COMBINEE

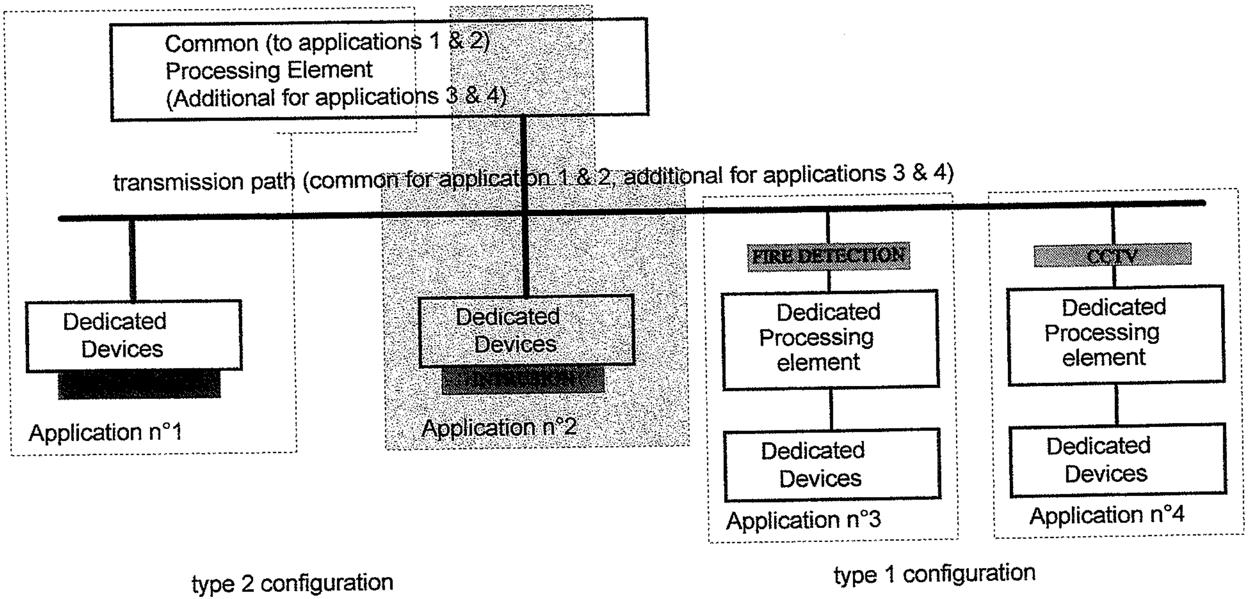


Figure 9 : A combination of type 1 and type 2 configurations

Colin F Reynolds

Euralarm - The Association of European Manufacturers of Fire and Intruder Alarm Systems

Euralarm – Its Role in Standards, Testing and Certification

Who or what is **EURALARM?**

It's the association of European manufacturers of Fire and Intruder Alarm Systems and was founded in 1970. Like many of the 300 European trade associations/federations within Europe they have been granted liaison status with the European Standards body – **CEN. (Comitè Europèen De Normalisation / Europaisches Komitee Fur Normung)**

EURALARM members consist of the National Associations of 13 European countries and have both Fire section and Intruder sections. Where no national association exists, country membership is allowed through the representation of an individual firm. (See Table 1). The countries involved represent around 650 companies having a turnover, which approximates to 70% of the total market volume.

The purpose of EURALARM is to represent on an international level, the interests of European manufactures and installers of products and/or systems which are spread across the disciplines of: - Fire Detection and Fire Alarm, Intrusion Alarm, Access Control for Security Applications, CCTV Systems for Security Applications, Alarm Transmission and Alarm Receiving Centres.

If we look at the standards organisations that are involved in the development of European standards, we can see that the responsibility falls to 2 major organisations. **CEN - the European committee for standardisation (Comitè Europèen De Normalisation) and CENELEC - the European Committee for Electro Technical Standardisation.** The technical committees involved are **CEN/TC72-Fire Detection**

and Fire Alarm Systems and CLC/TC79-Alarm Systems. In addition to these standards bodies, other organisations are developing and publishing technical requirements specific to their needs or complimenting European standards and regulations. The main body responsible for this within the industries EURALARM represent, is the European Insurance Body – the **CEA (Comitè Europèen Des Assùrance.)**

We can see therefore the importance of a European involvement through EURALARM with these bodies, in the development of standards and technical requirements against which products and services that their members manufacture and sell, and the systems incorporating these products that are installed. Standards are accepted as a technical and performance requirement against which products and services can be tested in order that a **"quality level"** can be conveyed to the market for use by legislators, specifiers, users and others, where function, performance and reliability is paramount. By using independent third party testing and certification bodies, a common level of quality and performance can be achieved which is essential for the Fire and Security Industry.

So what is the role of EURALARM in all these activities of standards development, testing and certification?

The simple mission statement of Euralarm states: -

As the European representative of national trade associations involved in Fire Safety and Intrusion Security, the EURALARM mission is to influence the positive growth of the market and the added value of the companies serving the market.

To do this a number of objectives have been developed which are specific to those areas already mentioned.

It is an objective of EURALARM to improve the recognition of the member companies of the associations represented, by providing solutions to the needs of Fire Safety, Intrusion and Security across Europe. A major thrust is to avoid the banalisation of products and the associated service to ensure the necessary quality requirements are met.

Standards and Certification must be kept at a high level in relation to the market and the concept of **"system"** must be promoted using appropriate specialised communication and training education programmes.

In the case for recognition, this can only be increased by regular contact with those organisations from whom recognition is sought. This is a role that EURALARM is continuing to improve and develop by direct contact and liaison with specifiers, insurers, legislators, regulators (fire authorities, police authorities) and standards bodies committees. Harmonised European Standards and their use for Third Party Certification need to be accepted by specialists, general installers and specifiers of those products.

The objective of achieving agreed single harmonised standards across Europe for publication by the standards bodies previously mentioned, is effected by the very slow progress of the development of these standards and the reluctance in the acceptance of "one stop" testing and certification. There is a need to break down barriers of national prejudice for globalised markets. EURALARM is striving for - one standard quality and specification of a product and system able to satisfy all markets, both regulatory and non-regulatory. In this instance the role of EURALARM through it's member association's active involvement with the National, European and International standards bodies, the Test and Certification laboratories and the Insurers, is to influence, drive and exercise some control on their work, as well as maintaining a close relationship with the regulators.

The elimination of barriers by encouraging *Mutual Recognition*, and the development of acceptable *Testing and Certification Schemes* is another area in which the role of Euralarm plays an important part. The discussions with the leading Certification Bodies have led to some encouraging developments in the acceptance of the principles of Mutual Acceptance, promoted by Euralarm. The initiative taken by LPCB and VdS in the signing of a *Memorandum of Understanding* recently, is a first step to Mutual recognition across Europe.

EURALARM has a role to play in the education and communication of its policies and informing on progress and developments in the activities in which it is involved. The education role in this instance is both internal for it's own membership and external for those other trade associations with which it has an involvement as well as the standards and certification community and most importantly the end user. This is being addressed through the circulation of newsletters and brochures, workshops and seminars, and more recently the setting up of a web site. In addition, presentations for example **AUBE 99** are being used to inform those who are just joining the industry or undergoing education and will become the engineers, marketing or even legislators of tomorrow. If I can register the name of Euralarm and what it stands for with 20% of the visitors to AUBE, who never heard of it before, then I would be satisfied.

A further objective of EURALARM and a role to play, is that of establishing relationships based on confidence and co-operation with organisations prescribing the related products and services of members. By representing them and retaining a level of independence, proactive and reactive relationships will continue to be developed, ensuring that balanced views and requirements of the users regulatory authorities, insurers, test laboratories and certification bodies are taken into account.

European Activities over the Last 5 Years

With the introduction of a number of European Directives, which had a direct impact on the Fire and Intrusion Security industry, manufacturers and suppliers of equipment have spent considerable time and money in ensuring that these directives which ultimately become European law, are met. The EMC Directive and the Low Voltage Directive are examples and to which the equipment manufacturers now comply. The development of the EMC Product Family Standard within CENELEC received input from Euralarm members within the committees and working groups involved. The use of this standard for EMC compliance is being built into the European Norms under review and development against which Fire and Intrusion Detection products are tested and approved.

The next directive to have an impact on Euralarm members, is the Construction Products Directive (CPD). However this will only apply to Fire related products in relation to one of the six essential requirements – Safety in case of fire.

In keeping with its role as previously stated in the earlier part of this presentation, Euralarm made representations to the bodies involved in determining how the Directive could be met has contributed to: - On-going development of *Harmonised European Standards*, mandated by the commission to CEN.

Harmonised Product Standards are an essential part of Attesting conformity to allow the display of the CE mark, allowing products to cross boarders and give confidence to the customer and user that the product is safe.

Euralarm in its commitment for ensuring products were not only safe, but meet recognised acceptable standards, set up within its structure, committees and task groups to work with other organisations and the Commission, to provide an agreed *Method of Attestation of Conformity*, selected from the options within the directive's guidelines. The CEN technical committee responsible, accepted that Voluntary *Self-Certification* adopted by other sectors falling under the CPD, was not conducive with promoting quality levels required within the industry.

Examples of the contribution that Euralarm has made in support of it's policy to develop standards and specifications, is the publication of a number of Euralarm Documents.e.g

Quality Management for Fire and in Intrusion Protection the Security Industry. EUR(SC6).Doc1/96

A guide for companies in the application of International Standard ISO9000.

Code of Practice for Alarm Central Stations. EUR(SC7).01/96

A Euralarm Position Paper.

Combined /Integrated Alarm Systems. EUR(SC5).21/95

A Euralarm position paper.
There is the role of *Reward* that Euralarm sees as a means of bestowing Recognition for significant initiatives in the fields of Fire and Intrusion Protection. With an objective of reducing the risk and costs of fire-related losses and the cost of crime associated with Intrusions, National Associations nominate candidates who they believe have contributed to this aim. Euralarm Medals are presented yearly to individuals as a recognition of their achievements by the Industry. Since 1993 awards have been made in a different country each year.

In closing, it can be seen that Euralarm has many roles to play in its representation of the Fire Detection and Intrusion Protection Industry. It takes on Leadership, Advisor, Facilitator of all activities and issues in the Regulatory and Non-regulatory markets affecting the Industry and User. It is the provider of information and when identified, the rewarder of achievement. Euralarm can only exist through the involvement of it's members and recognises that it has a duty and service to perform along side all those involved in making the world a **Safer Place.**

CFR/EUR/AUBE99.doc 9/11/98

Name: Colin F Reynolds
Euralarm.

Euralarm its Role in Standards, Testing and Certification.

TABLE 1 MEMBERSHIP OF EURALARM.

Fire Section.

Country	**National Association**
Austria	-VBo
Belgium	-CPDI
France	-GESI
Germany	-ZVEI
Italy	-ANIE
Luxemburg	- *
The Netherlands	-NVOB
Norway	-NORALARM
Portugal	- *
Spain	-TECNIFUEGO
Sweden	-SWELARM
Switzerland	-VSHSA
United Kingdom	-BFPSA

Intruder Section

Austria	-Vso
Belgium	-AIA
France	-CIFRE
Germany	-ZVEI
Italy	-ANIE
Luxemburg	- *
The Netherlands	-NVOB

Portugal	- *

Table 1 continued.

Spain	-FADES-AES
Sweden	-LIF
Switzerland	-VSHSA
United Kingdom	-BSIA

Note :- * Membership by individual firm.

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Environmental Test Requirements for Fire Alarm Equipment Used for Marine Applications Compared to Test Requirements for Industrial Applications

Abstract

Type approval testing of fire alarm equipment varies depending upon the environment where the equipment is to be used. The Marine Equipment Directive takes effect as from 1st January 1999, which may motivate some fire alarm manufacturers to consider expanding their market. In the present paper, the differences between the environmental test requirements for a smoke detector intended for industrial applications compared to marine applications are pointed out.

Introduction

To ensure safety both in the industry ashore as well as at sea, fire alarm equipment has to comply with certain standard requirements. These requirements include different environmental tests to make sure that the equipment is fit for ensuring the life and property saving function it was designed to perform.

If the fire alarm equipment is intended for industrial use the EN54 series of standards are relevant. The Marine Equipment Directive takes effect as from 1st January 1999. With the directive comes new environmental test requirements according to IEC945, which are also used as test requirements for fire alarm equipment. The marine authorities have test requirements according to IACS E10; however, the requirements of the IEC945 are different from the E10 requirements.

In the following, test of a smoke detector will be used as an example of the difference between environmental test requirements for industrial applications compared to marine applications.

Example

A smoke detector intended for industrial applications has to comply with the EN54-7 standard. In this example the prEN54-7: Draft A3 is used as reference, since the standard is expected to replace the former editions in the near future. Environmental tests are generally categorised in climatic, mechanical and electromagnetic compatibility (EMC) tests.

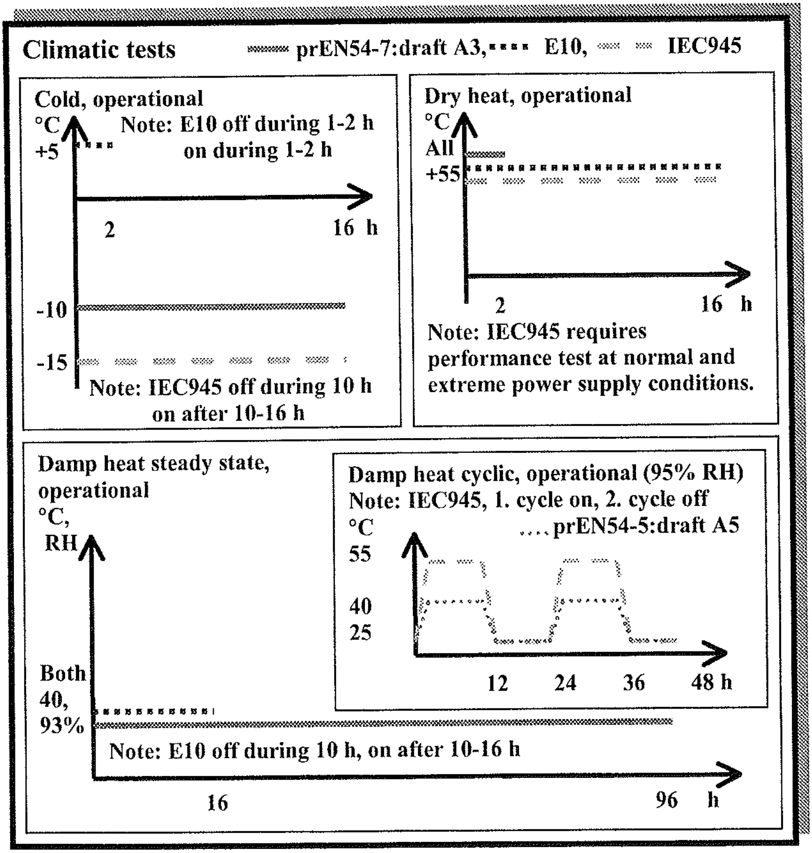

Fig. 1, Climatic test examples

In figure 1 climatic test examples are given. The examples show that the tests are different in duration and severity. For instance the cold, operational test requirements varies from +5°C to –15°C and from 2 to 16 hours for a smoke detector installed in a protected location. Further more the test requirements are different with regard to the smoke detector's power supply conditions (i.e. ON or OFF), and therefore also different with regard to when the functional test of the smoke detector should be carried out during the test. The same issues comply to the dry heat, operational test, though the required test temperature is the same for all the industrial and marine standards, which have been compared. Damp heat, steady state operational can only be found in the prEN54-7 (draft A3) and the E10 standards – IEC945 requires damp heat, cyclic operational test. The damp heat, cyclic operational test is required in the industrial prEN54-5 (draft A5) standard for heat detectors, but the test was included in the smoke detector standard though there were intense discussions in the revision work group. The severity of the IEC945 damp heat cyclic operational test exceeds the requirements found in the prEN54-5 (draft A5).

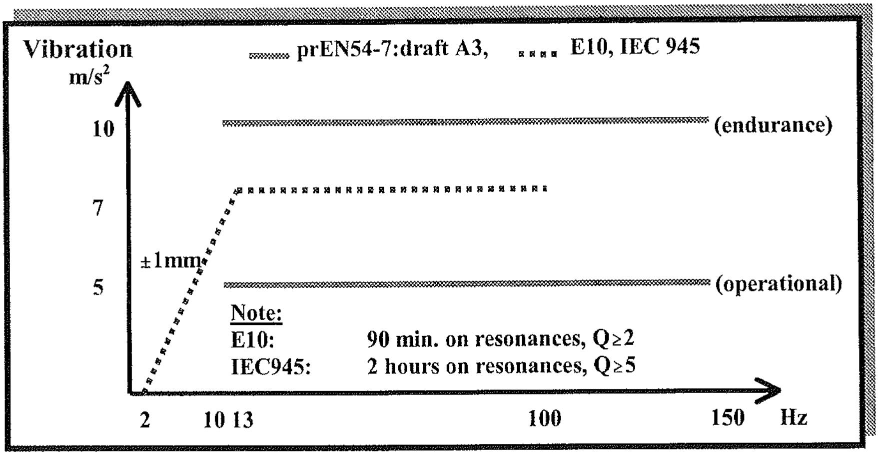

Fig. 2, Mechanical test example

In figure 2 a mechanical test example is given. The example shows that the tests are different in duration and severity. The industrial test requirements are separated into an operational test and an endurance test where the power of the smoke detector is switched ON and OFF respectively. The marine test requirements are based on a different principle. First, the equipment is examined for resonances. If there are resonances with a high amplification factor, also called Q, the equipment is exposed at each resonance for a period of time. However, the exposed resonances and the duration of the vibration vary for IEC945 and E10. With the marine vibration method, it is difficult to determine the actual test time, and therefore also the cost of the test because the number of resonances to be exposed are not known until the resonance search has been performed. In some cases the marine authorities accept random vibration, which is strongly recommended to use. With this vibration type, all the resonances are exposed at the same time, and the cost and test time are reduced.

In figure 3 examples are given for electromagnetic compatibility (EMC) tests. For electrostatic discharges, the requirements are the same. For the fast transient bursts, the duration of the exposure varies from 1 min. per polarity for industrial application to 5 min. per polarity for marine application, though IEC945 is not quite as specific in the duration requirements as E10. For slow high energy voltage surges, the marine standards only require test on the power supply lines. However, this causes confusion since the marine authorities sometimes require the typically defined signal lines tested as power lines. The industrial standard has separate requirements for the power lines and the signal lines. Furthermore, the performance criteria A and B are not applied in the marine standards as they are normally seen in EMC-standards. (A: The apparatus shall continue to operate as intented; B: During the test, degradation of performance is however allowed and no change of actual operating state or stored data is allowed.)

Radiated electromagnetic fields test has both amplitude and pulse modulation requirements for industrial application. Marine application requires amplitude modulation, however, the modulation frequency is not the same for both marine standards. Conducted disturbances induced by electromagnetic fields have both amplitude and pulse modulation requirements for industrial application. Marine application requires amplitude modulation, however, the modulation frequency is not the same for both marine standards. Furthermore, the severity varies from 3 to 10 Vrms for the marine standards.

EMC-tests

Electrostatic discharges:
prEN54-7:draft A3, E10 and IEC945 all have the same requirements:
6 kV contact, 8kV air, 10 pulses per polarity.

Fast transient bursts:
prEN54-7:draft A3, E10 and IEC945 only the duration is different respectively:
5 min., 3-5 min. and 1 min. per polarity;
2kV on power lines, 1kV on signal lines.

Slow high energy voltage surges:
prEN54-7:draft A3:
2 kV on power lines (line-to-earth), 1 kV on power lines (line-to-line), 20 pulses per polarity (5 pulses at each zero-crossing point, min. and max. point on the mains voltage wave)
1 kV on signal lines (line-to-earth), 5 pulses per polarity, ≥1 pulse/min.
E10:
2 kV on power lines (line-to-earth), 1 kV on power lines (line-to-line), 5 pulses per polarity, ≥1 pulse/min.
IEC945:
1 kV on power lines (line-to-earth), 0.5 kV on power lines (line-to-line), 5 pulses per polarity, ≥1 pulse/min.

Radiated electromagnetic fields:
prEN54-7:draft A3:
80-1000 MHz, 10 V/m, AM 80% at 1 kHz, PM (0.5 s on: 0.5 s off).
E10:
80-1000 MHz, 10 V/m, AM 80% at 1 kHz.
IEC945:
80-1000 MHz, 10 V/m, AM 80% at 400 Hz

Conducted disturbances induced by electromagnetic fields:
prEN54-7:draft A3:
0.15-100 MHz, 10 Vrms, AM 80% at 1 kHz, PM (0.5 s on: 0.5 s off).
E10:
0.01-80 MHz, 10 Vrms, AM 80% at 1 kHz.
IEC945:
0.01-80 MHz, 3 Vrms, 10 Vrms at spot frequencies 2-25 MHz, AM 80% at 400 Hz.

Fig. 3, EMC test examples

Though electromagnetic emission is not part of the prEN54-7:draft A3, a few considerations have to be mentioned here. When smoke detectors are tested for industrial application, they often have been tested to comply with the EMC-directive. When the radiated and conducted emmision requirements of the industrial standard EN55022:1994 class B are compared with the radiated and conducted emission requirements of IEC945, it is found that the marine emission requirements are more severe than the industrial requirements both in frequency range and field strength. This is illustrated in figure 4.

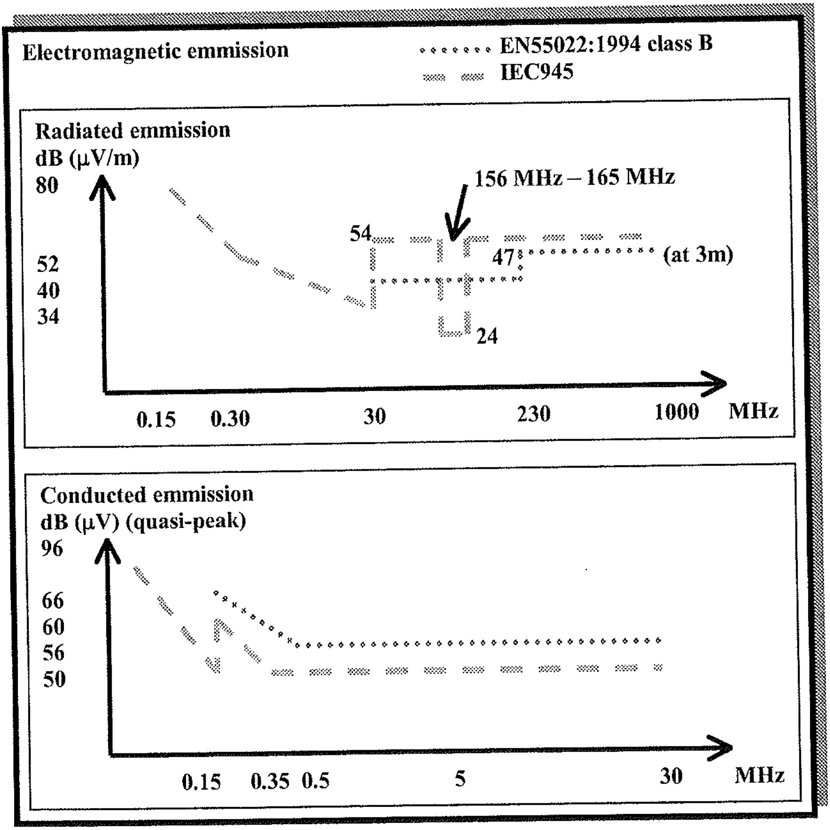

Fig. 4, Electromagnetic emmission

Aditional test requirements

prEN54-7:draft A3	E10	IEC945
RTV-measurements: repeatability, directional dependence, reproducibility, air movement, dazzling, variations in supply parameters (i.e. voltage)		
Impact, operational		
Shock, operational		
Damp heat steady state, endurance		
SO_2 corrosion		
Fire sensitivity		
	Power supply failure	Power supply failure
	Power supply variations permanent	Power supply variations permanent
	Power supply variations short-term	Power supply variations short-term
	Insulation resistance	
	High voltage	
	Salt mist cyclic	Salt mist cyclic
	Inclination	
	Flame retardent	
		Acoustic noise & signal
		Compass safe distance
		Enclosure protection

Fig. 5, Aditional test requirements

Since industrial and marine environment are very different, this is also reflected in the test requirements. The differences excists partly because the environments are different and partly because the standards are created by different groups with different traditions. In figure 5, some examples of tests which point out the differences are listed.

One of the most significant differences between test of a smoke detector for industrial application compared to test for marine application is that the functional tests are very different. In the marine standards, the concept functional test is referred to, however, when compared to the industrial functional test, the marine functional test is quite limited. This is because the marine standards cover a large number of different types of equipment – unlike the prEN54-7 (draft A3), which only covers one specific type of equipment. In the industrial standard the Response Threshold Values are used as a reference to determine whether the smoke sensitivity of the detectors varies as a result of the test exposures. Specific tests are performed to ensure that the smoke detection principle used is performing as intended. This includes tests to ensure that the optical smoke detectors do not react to dazzling light and that the ionisation detectors are not disturbed by sudden air movements, which could disturb the detection current by blowing away the ion cloud in the ionisation chamber.

Conclusion

As the above test examples show, it is difficult to compare the requirements of the industrial environment to the marine environment. This is one of the most important issues to point out since manufacturers have to consider the requirements already where the equipment is developed. Furthermore, the marine requirements are in general more severe than the industrial requirements. The difference in the marine standards IEC945 and E10 are still an issue to be solved. The E10 standard was issued as a minimum test guideline for a number of marine authorities and classification societies, however, the classification societies still have individual additional test requirements. Therefore, when equipment has to be used both for industrial and marine applications, DELTA Electronics Testing recommends to first negotiate the marine test programme, based on a combination of the IEC945 and E10 standards, with the relevant marine authorities and classification societies. When the marine test programme is determined, it is coordinated with the test schedule of the industrial test programme as well. In this way, the duration of the entire test period and the cost are reduced to a minimum, since the industrial and marine tests can be performed in blocks to reduce the handling time.

In the future, work has to be performed to solve the issue of the different test methods for marine application and industrial application, so that more tests could be uniform with regard to severity, duration, power supply conditions (i.e. ON or OFF), and therefore also be uniform with regard to when the functional test of the smoke detector should be carried out during the test.

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PRACTICAL COMPARISON OF DOMESTIC SMOKE ALARM SENSITIVITY STANDARDS

ABSTRACT

In 1995 it was proposed that the British Standard for domestic smoke alarms be revised in order to bring the fire sensitivity tests established in the British Standard, BS 5446 : Part 1 : 1990, into line with those in the British/European standard for commercial point-type smoke sensors, BS 5445/EN 54 : Part 9 : 1984 and to reduce nuisance alarms which smoke detector manufacturers considered to be a problem. The UK Home Office wished to be reassured that a reduction in the sensitivity would not constitute a significant reduction in the level of life safety provided by the devices.

A series of eleven tests were conducted to examine the performance of a range of smoke detectors. The fires were selected to closely match the fire sensitivity tests specified in the BS/EN/ISO stand-ards or as representative of realistic fire scenarios. The tests were conducted in a detached three-bedroom dwelling of typical 1970's UK design and construction. Optical and ionisation domestic smoke alarms and commercial analogue addressable smoke sensors, complying with UK and US standards, were installed in four locations within the dwelling; in the lounge, in the hall, on the landing and in a bedroom. The optical density of smoke close to the detectors was also measured.

In each location, the times to alarm for each detector and the time at which the density of the smoke reached a hazardous level were recorded. The time between an alarm and the onset of the smoke density hazard was calculated for each smoke detector. These data were analysed by com-paring the performance of individual smoke detectors, by using standard statistical methods for groups of detectors and by ranking the relative performance of each smoke detector across a range of tests.

For detectors complying with the UK domestic and commercial standards, analogue sensors responded as well as or, in some cases, better than the domestic smoke alarms depending on the type of fire. The overall performance of the analogue and domestic detectors were statistically similar. The ranking analysis indicated that the analogue optical sensors performed better than the domestic optical smoke alarms whereas the ionisation detectors exhibited a similar performance. Therefore, revising the domestic smoke alarm requirements to match the commercial smoke sensor standard would not reduce the life safety effectiveness of domestic smoke alarms.

Analysis of the performance of the detectors complying with the US standards found that the

domestic ionisation smoke alarm and the analogue ionisation smoke sensor showed a statistically significant variability. The ranking analysis indicated that the domestic ionisation smoke alarm detected smoke earlier than the analogue ionisation smoke sensor. In the case of the optical devices, the overall performance of the two types was statistically similar. However, the ranking analysis indicated that the analogue optical sensor performed better in some types of fire scenario.

Background

Several different test fires have been used to calibrate domestic (or residential) smoke alarms and commercial smoke detectors. In 1995 it was proposed that the British Standard for domestic smoke alarms BS 5446 : Part 1 : 1990 [1], be revised in order to reduce nuisance alarms, which the smoke detector manufacturers considered to be a problem, and to bring the fire sensitivity tests established in the British Standard into line with those in the European standard for commercial smoke detectors, BS 5445 / EN 54 : Part 9 : 1984 [2]. However, the extent of nuisance alarms had not been adequately established in the United Kingdom (UK) and the Home Office wished to be reassured that a reduction in the sensitivity of domestic smoke alarms would not constitute a significant reduction in the level of life safety provided by the smoke alarms.

A series of fire tests were conducted by the Fire Research Station (FRS), on behalf of the Home Office Fire Research and Development Group (FRDG) to examine the performance of smoke detectors complying with UK and United States (US) standards. This paper summarises the study and a full report of the work has been published by the Home Office [Spearpoint, **M. J. & Smithies, J.** N.: Practical comparison of domestic smoke alarm sensi-tivity standards. FRDG 4/97, Home Office Fire Research and Development Group, 1997.].

Smoke detector standards

At the time of this study, there were separate British Standards that covered the performance of domestic smoke alarms and commercial fire detectors. BS 5446 : Part 1 : 1990 covered the requirements for domestic self-contained smoke alarms and point-type smoke detectors for dwellings. BS 5445, covered the requirements for fire detectors for commercial fire detection and alarm systems.

The two standards had differing requirements for the fire tests used to assess the sensitivity of the two types of smoke detector. BS 5446 : Part 1 : 1990 described four test fires; slow burning wood fire, fast burning wood fire, liquid hydrocarbon fire and polyurethane foam fire. BS 5445 / EN 54 : Part 9 : 1984 described six test fires (designated TF 1 to TF 6); open cellulosic (wood), smouldering pyrolysis (wood), glowing smouldering (cotton), open plastics (polyurethane), liquid (*n*-heptane) and liquid (methylated spirits). At the same time a revised version of BS 5446 : Part 1 [4] had been proposed in which the fire sensitivity tests were the same as some of those tests (TF 2-5) specified in BS 5445/EN54 : Part 9 : 1984.

In the US, UL 217 [5] covered the requirements for domestic smoke alarms and UL 268 [6] covered the requirements for smoke detectors for commercial fire detection and alarm systems. In both of these standards, the fire tests used to measure the performance and sensitivity of the smoke detectors are exactly the same. Six tests are specified; paper, wood, gasoline, polystyrene, smoldering (wood) smoke and (smoldering) cotton wick.

In addition, there was a draft ISO/EN standard [7] being developed under the Vienna agreement. The sensitivity tests TF 2-5 were the same as those specified in EN 54 : Part 9 : 1984 with the addition of test TF 7 which was the same as the smouldering smoke test specified in UL 217/268.

Previous work

A theoretical study to compare the sensitivity standards for smoke detectors [8] was completed. The study compared four standards: Draft ISO/DIS 12239 [7], BS 5446: Part 1 [1], UL 217 [5] and the proposed revision of BS 5446: Part 1 [4] to decide whether the proposed revision of BS 5446 could be accepted in place of the existing BS 5446. The study also reviewed the similarities between the fire test specifications for the existing and revised BS 5446 and also the existing European standard for commercial detectors (EN 54). The study concluded that BS 5445 and BS 5446 (revised) had effectively the same requirements on fire sensitivity. Furthermore, it appeared that BS 5446 (original) required a greater fire sensitivity when compared to BS 5446 (revised). It further concluded that BS 5446 (original) and BS 5446 (revised) could not be directly compared as they used different sets of fire tests and different pass/fail parameters.

EXPERIMENTAL SETUP

The fire tests were selected so as to closely match the fire sensitivity specified in BS 5445 : Part 9 : 1984 [2] (TF 2-5) or the draft ISO standard [7] (TF 7). In addition, two non-standard tests were conducted as representative of realistic fire scenarios that occur in dwellings (Table 1). The fire tests that matched the sensitivity tests are referred to as the 'standard' tests and the two realistic fires are referred to as the 'ad-hoc' tests. The downstairs dining room (at the rear) and the upstairs bathroom were both sealed. The doors to the other two first floor bedrooms were kept closed for all of the tests. The kitchen door was closed for all tests apart from Test 10. The fire tests were terminated once all detectors had gone into alarm or when it was considered that no more detectors would raise an alarm.

Test number	*Description*	*Location*
1	Smouldering pine	Lounge
2	Flaming polyurethane foam mat	Lounge
3	Smouldering cotton wick	Lounge
4	Flaming heptane	Lounge
5	Smouldering pine	Bedroom
6	Smouldering beech	Bedroom
7	Smouldering cotton wick	Bedroom
8	Flaming polyurethane foam mat	Bedroom
9	Flaming heptane	Bedroom
10	Flaming cooking oil	Kitchen
11	Smouldering/flaming armchair	Lounge

Table 1. Summary of fire test scenarios.

Smoke detectors

The analogue addressable smoke sensors were installed as supplied but minor modifications were made to the domestic smoke alarms. For practical and economic reasons, the smoke detectors were not replaced between each test. This may have resulted in some contamination of the sensing elements but it should be noted that in BS 5445 : Part 7 : 1984 [9] the same set of four detectors are used throughout the procedure of test fires TF 2, TF 3, TF 4 and TF 5. Smoke detectors were located in four areas in the dwelling; the lounge, the downstairs hall, the upstairs landing and the front bedroom. As far as practicable, the devices were mounted in the centre of the ceiling, away from obstructions. Four pairs of smoke detectors were located in the four areas, each pair consisting of an optical and ionisation device (Table 2).

Type	*Sensor*	*Manufacturer*	*Model*	*Standard*
Analogue	Ionisation & optical	Apollo Fire Detectors Ltd	XP95	BS 5445
Analogue	Ionisation & optical	Apollo Fire Detectors Ltd	XP95A	UL 268
Domestic	Ionisation	E.I. Company Ltd	EI 105C	BS 5446
Domestic	Optical	E.I. Company Ltd	EI 100C	BS 5446
Domestic	Ionisation	Dicon Safety Products Inc.	Micro 300	UL 217
Domestic	Optical	Dicon Safety Products Inc.	440	UL 217

Table 2. Smoke detector types installed in test series.

Optical density measurements

Optical density meters were installed in each of the rooms containing the smoke detectors. The optical density meters used a white light tungsten halogen lamp with a broad spectrum. The path length and position below the ceiling was chosen with reference to the BS, UL and Australian [Automatic fire detection and alarm systems - methods of test for actuating devices, Method 17: Sensitivity test. Draft Australian Standard DR 92114. Standards Australia, 1992.] standards. The path length was set to a nominal distance of 1.0 m and the transmission and receiver units were located such that their centres were nominally 100 mm below the ceiling. Each optical density meter was located below and central to the installed smoke detectors subject to practical limitations and accessibility. The optical density meters were calibrated using neutral density filters of 0.3 OD and 1.0 OD; in addition, the outputs at full and no obscuration were measured.

ANALYSIS

A comparison of the times to the individual alarms triggering was a logical starting point for the comparison of the different smoke detector types within each room. However, it is not necessarily the time to alarm that is critical but the time between an alarm being raised and the onset of a hazard that is of particular concern.

A study into smoke detection in domestic buildings [**Ghosh, B. K.:** Smoke detection in domestic buildings. *BRE CR34/87*. Borehamwood, 1988.] suggests that an optical density in the range of 0.07 per metre to 0.1 per metre can make escape very difficult. An empirical relationship between visibility and optical density [12] shows that 0.1 OD/m is approximately equivalent to a 10 m visibility. However, if the smoke causes eye irritation, the effective visibility may be significantly reduced. A study of the behaviour of people in fires [13] has shown that smoke density does affect whether or not people move into smoke and once visibility falls below 10 yards (9.14 m) persons moving through smoke will tend to turn back. Furthermore, the (then draft) British Standard for fire safety engineering in buildings [14] suggested that it is unlikely that the tenability limits for mixed toxic products will be exceeded providing the optical density of the irritant smoke does not exceed 0.1 OD/m. Therefore it is appropriate to consider the smoke density in this study as being representative of the principle hazard and an optical density of 0.1 OD/m was chosen as the limiting condition for the analysis.

The theoretical study [8] concluded that BS 5445 and BS 5446 (revised) had the same sensitivity requirements. It is therefore appropriate to assume that the times to alarm from the BS analogue smoke sensors are equivalent to those that would be given by domestic smoke alarms complying to BS 5446 (revised). The relative response of the two was investigated by subtracting the alarm time of each BS domestic smoke alarm from the equivalent BS analogue smoke sensor in each room.

Smouldering pine in lounge, Test 1

It is not possible to present the data for each of the 11 fire tests in this paper. Instead, details are given for a representative smouldering fire test. This test was similar to the TF 7, Smouldering pyrolysis fire (wood) as specified in the draft ISO standard [7]. Nine pieces of pine (75 mm x 25 mm x 20 mm) were arranged on the surface of a hot-plate in a radial star shape. Figure 1 shows the optical density at the lounge, hall and landing locations (the bedroom optical density was not recorded).

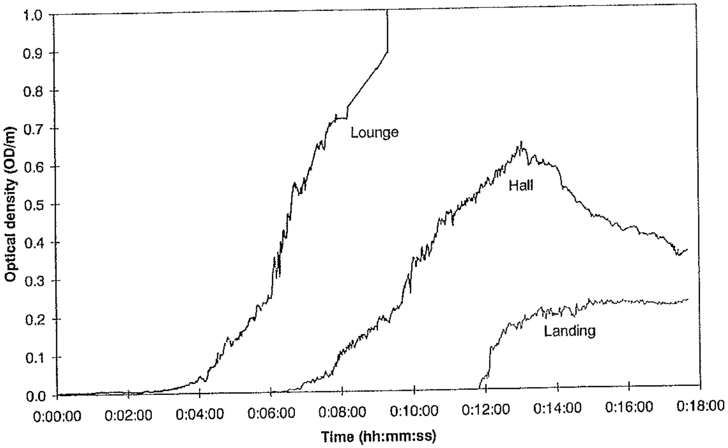

Figure 1. Optical density of smoke in lounge, hall and landing, Test 1.

Table **3** shows the detection-to-hazard times for each detector. It was noted that UL analogue optical sensor gave the greatest time in the lounge whereas it gave the least time in the hall. In general, optical detectors gave better detection-to-hazard times than ionisation detectors.

Location	Time to 0.1 OD/m (h:mm:ss)	Detector type	Domestic smoke alarm detection-to-hazard time (h:mm:ss)	Analogue smoke sensor detection-to-hazard time (h:mm:ss)
Lounge	0:04:32	Ionisation BS	-0:01:26	-0:01:59
		Optical BS	-0:03:29	0:00:42
		Ionisation UL	-0:00:48	-0:01:08
		Optical UL	0:00:20	0:00:53
Hall	0:07:57	Ionisation BS	-0:01:52	-0:01:04
		Optical BS	0:00:09	-0:01:30
		Ionisation UL	-0:00:13	-0:02:53
		Optical UL	-0:00:44	-0:04:17
Landing	0:12:09	Ionisation BS	-0:01:28	-0:01:07
		Optical BS	0:00:28	-0:00:43
		Ionisation UL	0:00:43	-0:01:21
		Optical UL	-0:00:41	-0:01:09

Table 3. Detection-to-hazard times, Test 1.

Alarm sequence and detection-to-hazard times

The alarm sequences showed the analogue smoke sensors responded quicker as a group compared to the domestic smoke alarms in the same room particularly in the standard flaming and ad-hoc fire scenarios. In these tests it was found that the last analogue sensor to respond was always ahead of the of the last domestic smoke alarm.

The detection-to-hazard times showed the difference in performance of the two types of smoke detector in different types of fire. For the standard smouldering fire tests, in general optical detectors gave higher detection-to-hazard times than ionisation detectors. In the standard flaming fires, ionisation detectors provided the longer detection-to-hazard times. The results from the two ad-hoc fire tests did not demonstrate any particular performance differences from the two types of smoke detector.

Comparison of BS 5445 / BS 5446 (revised)

In the standard smouldering fire tests the performance of the BS detectors was mixed. There were cases of a domestic smoke alarm raising the alarm before its equivalent analogue smoke sensor in one test and yet in another the response was reversed. The response of pairs of equivalent BS detectors also varied by location. For example, in Test 3 the lounge the BS domestic optical smoke alarm raised the alarm before the BS analogue optical smoke sensor whereas in the bedroom the response was reversed.

In the standard flaming fire tests, it was found that the time differences between the response of any pair of equivalent BS domestic smoke alarm and BS analogue smoke sensor was small. However, it was generally found that the BS analogue smoke sensor, particularly the optical type, would give an alarm before the equivalent BS domestic smoke sensor. In the two ad-hoc fire tests, the BS analogue sensors generally raised an alarm before the equivalent BS domestic smoke alarm.

A standard set of statistical analyses of the detection-to-hazard times for all 11 test fires was conducted. The analysis compared the variances and means of the detection-to-hazard times from the pair of BS ionisation detectors and the pair of BS optical detectors in all rooms. The comparison of the variances was carried out by using the *F-Test* with a 95% confidence limit. The comparison of the means was conducted using the *t-Test* also with a 95% confidence limit. The *F-Test* comparison of each BS detector pair found that their variances were common. The *t-Test* analyses for the detector pairs found that the mean detection-to-hazard times were not statistically different. Thus, the performances of equivalent BS domestic and analogue detectors in the 11 test fires were similar.

It was found that the BS analogue smoke sensors tested to EN54 gave detection-to-hazard times similar to or better than the BS domestic smoke alarms tested to BS 5446. Thus, domestic smoke alarms that are be tested to the revised version of BS 5446 would perform as well as the domestic smoke alarms tested to the earlier standard.

Comparison of UL detector responses

In the standard smouldering fires it was found that the UL domestic smoke alarms generally responded earlier than the equivalent UL analogue smoke sensor. However, there were cases, such as in Test 7, where there were significant variations in favour of the UL analogue smoke sensors. In the standard flaming fires the difference in response between equivalent detector pairs was small. The UL analogue optical smoke sensors were found to be marginally more responsive than their equivalent UL domestic optical smoke alarm. In the ad-hoc fire tests, it was found that with the exception of a number of isolated cases, the response times of UL detector pairs were close together.

As for the BS detectors, a statistical analysis of the performance of the pairs of UL ionisation detectors and UL optical detectors was performed using the *F-Test* and the *t-Test*. The variances for the UL analogue and domestic ionisation detectors indicated that the performance of the UL domestic ionisation smoke alarm and UL analogue ionisation smoke sensor was not similar. However, the mean detection-to-hazard times for the UL optical detector pair were statistically similar.

Ranking analysis

The initial analyses of the results calculated and compared the average hazard-to-detection times for each smoke detector type in each room. However, when a detector failed to raise an alarm in a test in which the optical density reached 0.1 OD/m it was not possible to assign a detection-to-hazard time. Omitting such detectors from the overall analysis may have skewed the conclusions away from those detector types that did not give an appropriate alarm. Therefore, an additional method of ranking was developed to ascertain the relative performance of the different types of smoke detector.

Each individual detector was ranked in decreasing order of detection-to-hazard times. Detectors that raised an alarm where the optical density never reached 0.1 OD/m were ranked equal top. Thereafter a detector with the highest detection-to-hazard time was ranked next and detectors with equal detect-ion-to-hazard times were given an equal ranking. Where the optical density in a room reached 0.1 OD/m and the detector failed to raise an alarm the detector was ranked last. However, where a detector did not raise an alarm and the optical density did not reach 0.1 OD/m, the detector was omitted from the ranking since was not possible to infer the performance level from such a circumstance. For each test, an average rank for each detector type, regardless of location, was calculated and these averages ranked. Thus, the eight detector types were ranked in order of performance for each test fire and these rankings were used as a basis of further analysis.

Clearly, unlike the analysis of the actual detection-to-hazard times, the ranking analysis does not account for the time differences that will exist between ranking levels. A detector in a specific test will be ranked higher than another whether it gave alarm several minutes or merely seconds before. The ranking analysis also does not differentiate between cases where the detection-to-hazard was a positive time and where it was a negative time. However, the technique does allow a method of reducing the test data into a format that aids the overall analysis.

Standard smouldering fires

Figure 2 shows the spread of rankings for each detector type in the standard smouldering fire tests. It is clear that there was a considerable amount of variability between tests as shown by the wide spread in rankings for most of the smoke detector types.

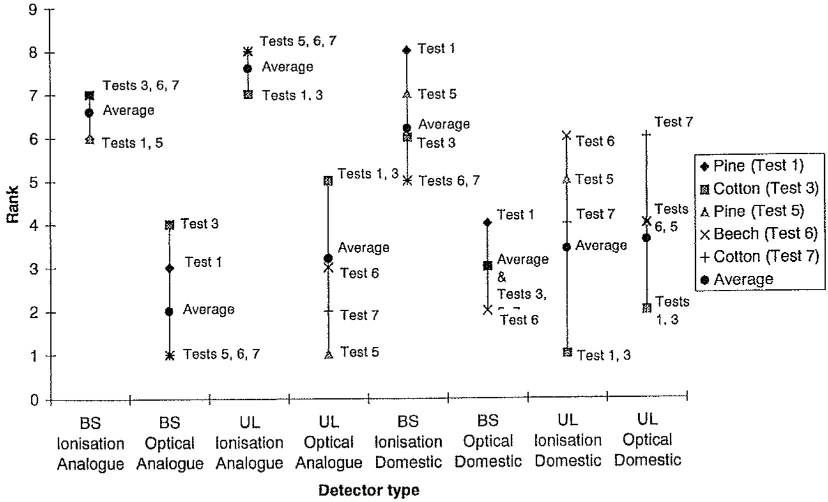

Figure 2. Ranking analysis for the standard smouldering fires.

Comparing the BS domestic and BS analogue detectors it is found that there are three cases of the BS analogue optical smoke sensor ranked 1 and three cases of the BS domestic optical smoke alarm ranked 3 thus suggesting a better performance from the analogue optical smoke sensor. For the ionisation smoke detectors, three cases were at ranks 5 and 6 for the BS domestic ionisation smoke alarm and three cases at rank 7 for the BS analogue ionisation smoke sensor. However, the BS domestic ionisation smoke alarm shows a wider spread.

The rankings of the UL domestic and UL analogue detectors were also compared. The ranking patterns of the UL domestic ionisation and UL domestic optical smoke alarms are similar, both exhibiting a wide spread between ranks 1 and 6. However, the UL analogue ionisation and UL analogue optical smoke sensors show a distinct difference. The UL analogue ionisation smoke sensor cases are all clustered in the ranks 7 and 8 whereas the UL analogue optical smoke sensor is spread between ranks 1 and 5. The UL analogue optical smoke sensor and UL domestic optical smoke alarm ranking spreads are similar whereas the UL domestic ionisation smoke alarm always ranks better than the UL analogue ionisation smoke sensor.

Standard flaming fires

Figure 3 shows the spread of rankings for each detector type in the standard flaming fire tests.

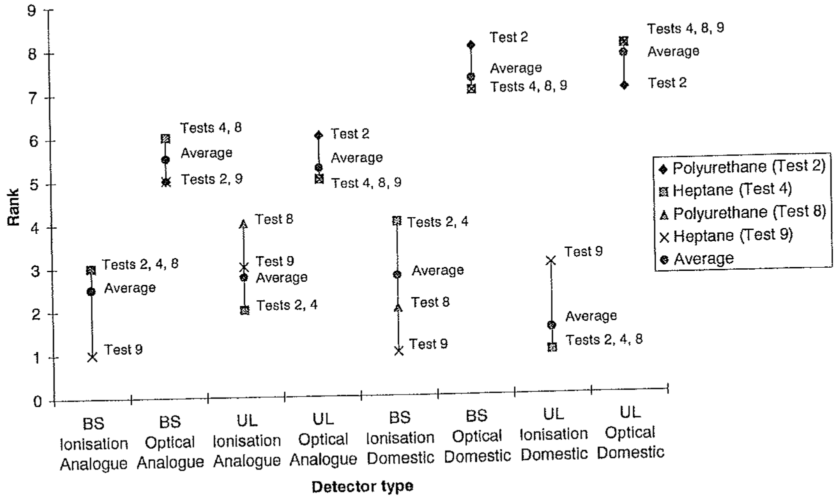

Figure 3. Ranking analysis for the standard flaming fires.

There is less variability in these tests when compared with the standard smouldering fires. Comparison of the BS domestic smoke alarms and BS analogue smoke sensors rankings revealed a similar result as for the standard smouldering fires. The analogue optical sensors performed better than the domestic optical smoke alarms whilst the analogue ionisation smoke sensors and domestic ionisation smoke alarms showed a similar performance. The ranking of the UL smoke detectors indicates that UL domestic ionisation smoke alarm performed more effectively than the UL analogue ionisation smoke sensor. However, the analogue optical smoke sensor performed better than the domestic optical smoke alarm.

Examination of the rankings of equivalent sensor types indicated that the BS and UL analogue optical smoke sensors are very similar as are the BS and UL domestic optical smoke alarms. The ionisation smoke detectors show a wider variability in rankings but again are relatively similar across the four types with the UL domestic smoke alarms being the most effective.

Ad-hoc fires

For the two ad-hoc fires the rankings matched closely with all four optical detectors achieving the same rank in every test. Examination of the BS analogue and BS optical smoke detect-ors again showed a significantly improved detection performance from the BS analogue optical device over the BS domestic optical device. The BS analogue ionisation sensor showed a greater variability when compared with the BS domestic device but on average it performed marginally better. Comparison of the UL smoke detector rankings showed that the UL analogue optical smoke sensor was more effective than the UL domestic optical smoke alarm whilst the UL analogue and UL domestic ionisation detectors were similar.

Effect on life safety

The analysis of the fire tests demonstrated that the proposed revision to BS 5446 : Part 1 would not lower the life safety potential of domestic smoke alarms. This conclusion was based on the comparison of the hazard-to-detection times obtained by the BS detectors and the ranking analysis. It was shown by interpretation and statistical analysis that the detection-to-hazard times from analogue smoke sensors tested to EN 54 were similar to domestic smoke alarms tested to BS 5446. Furthermore, the ranking analysis suggested that analogue optical sensors tested to EN 54 perform generally better than domestic optical smoke alarms tested to BS 5446 and analogue ionisation sensors tested to EN 54 perform as well as domestic ionisation smoke alarms tested to BS 5446.

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Standards and Certification for Fire Detection and Alarm Equipment in P.R.C

Abstract

In this paper, standard classification in China, standard-related organizations and Chinese Standards for fire detection and alarm equipment are introduced. The harmonization of these standards with EN standards and other national standards are explained. On the base of explaining the need for new standards, the standards under preparing are discussed. Furthermore, procedures of China certification for fire detection and alarm equipment are introduced.

1. Introduction

Nowadays fire detection and alarm systems are widely used in China. The related laws, governmental documents and national standards stipulate that many kinds of buildings shall have fire detection and alarm systems as well as other related fire prevention systems installed. China market of fire detection and alarm equipment has developed rapidly and become one of the largest markets in the world. In this development standards have played important roles in the improvement of product quality and developments of product technology. Up to now seventeen national standards for fire detection and alarm equipment have been issued. China also introduced its certification for fire detection and alarm equipment for domestic products in 1993 and for foreign products in 1996.

2. Standard classification and related organizations

In China, four kinds of standards are legal. They are National Standard (GB) issued by China State Bureau of Technology Supervision (CSBTS), Profession Standard (GA) issued by the ministry of public security, local standards issued by local bureaus of technology supervision and manufacturer's standards which must be registered in local bureaus. The national committee for standards is CSBTS. Under CSBTS there are many technical committees (TC). TC113 is National Technical Committee for Fire Standardization.

The sub-committee 6 of TC113, which was set up in 1986, is in charge of the preparation of standards for fire detection and alarm equipment (both GB and GA standards). Secretariat of CSBTS/TC113/SC6 is in Shenyang Fire Research Institute. National Supervision and Test Center for Fire Electronic

Product Quality, which was set up in 1985, has carried out tests according to four kinds of standards and taken most tasks of writing draft GB and GA.

3. GB and GA standards for fire detection and alarm equipment

The first three national standards were issued in 1984. Since then, other fourteen GB and GA standards for fire detection and alarm equipment have been issued. They are the following:

(1). GB 4715 Technical requirements and test methods for point type smoke detector

(2). GB 4716 Technical requirements and test methods for point type heat detector

(3). GB 4717 General technical conditions for fire alarm control units (control and indicating equipment)

(4). GB 4718 Terms for fire detection and alarm equipment

(5). GB 12978 Rules for product test of fire detection and alarm equipment

(6). GB 12791 Performance requirements and test methods for point ultraviolet flame detectors

(7). GB 14003 Technical requirements and test methods for optical beam smoke detectors

(8). GB 15322 Technical requirements and test methods for point combustible gas detectors

(9). GB 15631 Performance requirements and test methods for point infrared flame detectors

(10). GB 16280 Technical requirements and test methods for line type heat detectors

(11). GB 16806 General technical conditions for controls of automatic fire protection equipment

(12). GB 16808 Technical requirements and test methods for control panels of combustible gas detection

(13). GB 16838 Environmental test methods and severities for fire electronic products

(14). GA5 Technical requirements and test methods for manual call points

(15). GA127 Technical requirements and test methods for household combustible gas alarm unit

(16). GBJ116 Code for design of automatic fire detection and alarm systems in buildings

(17). GBJ50166 Code for installation and commission of automatic fire detection and alarm systems in buildings

Among these standards GB4715, GB4716, GB4717, GB12791, GB14003 are very similar to related EN standards or British standards and GB 16838 is similar to ISO/TC21/SC3 document --Environmental test. For GB12978 and GB 16806 further explanation is needed. GB12978 specifies the rules for tests of fire detection and alarm equipment. The rules include classification of test (including approval test, audit test, supervision test, mandated test and arbitration test) , procedures of going through these tests, document requirements for related tests, definitions of main type products and sub-type products, criteria of test results, rules for retesting when a product is failed in some test, number of samples for each kind of tests and so on. GB16806 specifies the function requirements and test methods for integrated controls of automatic fire protection equipment, including classification of products, kinds of fire protection equipment that integrated controls shall be capable of controlling, control logic, state displays of controlled equipment and so on. This standard was issued in 1997 and now is an important standard because many large-scale buildings are under construction and more and more integrated controls are needed and will be installed in buildings in China.

3. Standards under preparing

In China market more than one hundred manufacturers or companies sell fire detection and alarm equipment now. Most of them have developed new products and sold them in market in a large number. In order to control the quality of this kind of products and meet the need for national standards four standards are under preparing or planning and related research is being carried. The four standards under preparing or planning are:

(1). Performance requirements and test methods for fire sound and light alarms

(2). Technical requirement and test method for aspirating high sensitive smoke detection system

(3). Communications and interface protocol for municipal net of fire detection and alarm systems

(4). Technical requirements and test methods for point multi-sensor detectors

4. Procedures of China certification

China carries out its certification for foreign fire detection and alarm equipment according to ISO 9001. The organization that is in charge of this certification is China Fire Fighting Products Quality Certification Committee. The procedures for getting China certification are:

(1). To apply for the approval test in National Supervision and Test Center for Fire Electronic Product Quality and get the report of approval test.

(2). To apply for certification in China Fire Fighting Products Quality Certification Committee, fill in application forms and submit application forms together with documents required to Secretariat of the certification committee.

(3). Secretariat exanimate documents submitted. When documents are up to requirements Secretariat will send a document to inform the acceptance of application and ask the applicant to send it an official invitation for audit visiting and pay charges for application acceptance and quality system audit.

(4). Auditors visit the manufacture to audit quality system and sample product for audit test.

(5). China Fire Fighting Products Quality Certification Committee issues Certificate of Conformity of Product Quality.

5. Summary

In this paper, standard classification in China, related organizations, Chinese Standards for fire detection and alarm equipment and Chinese certification procedures for fire detection and alarm equipment are introduced. They can be written in short words as following:

(1) There are four level standards in China, and GB and GA are national level standards.

(2) CSBTS/TC113/SC6 is in charge of preparing of standards on fire detection and alarm equipment.

(3) There are seventeen national standards for fire detection and alarm equipment issued in China. Some of them are very similar to related EN standards.

(4) China carries out mandatory product certification when there is National Standard of this product in existence.

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Melder für den privaten Haushalt

Abstract

- Due to the large number of fire deaths the use of smoke alarms is essential.
- Photoelektric smoke alarms are best suited to detecte fires. The development of gas detector remains to be seen.
- The end user needs reliable support concerning the quality of smoke alarms.
- The standards, guidelines and laws to be expected in the future will clarify the use of smoke alarms.
- In the future will focus more attention on the surveillance and protection of people. It is high time, that the little life safers are installed in our houses and protect what is valuable to us.

Warum brauchen wir Rauchmelder in privaten Haushalten?

Dem baulichen Brandschutz kommt traditionell in Deutschland ein hoher Stellenwert zu, er kann jedoch nur begrenzt Personen im Falle eines Brandausbruches schützen.
Bei genemigungspflichtigen Neu- und Umbauten müssen, wie gesetzlich vorgeschrieben, vor Baubeginn die Planungsunterlagen durch die Bauordnungsämter und zum Teil von den Brandschutzdienststellen genehmigt werden. Mängel werden aufgedeckt und entsprechende Korrekturen vorgenommen.

Die Anforderungen für kleinere Wohngebäude und Einfamilienhäuser ist bewußt niedrig, da sonst in diesem Bereich kaum eine Finanzierung möglich wäre. Die Bauordnungen lassen viel mehr Spielräume zu. Zum Beispiel beim vermehrten Einsatz von Holz als Baustoff, beim Verzicht auf Flucht- und Rettungswege, bei platzsparenden offenen Treppen zwischen Etagen und Wohnungen, etc. Hier bleibt es den Bewohnern in Deutschland, wie auch in den meisten anderen Ländern dieser Welt selbst überlassen, wie sie sich schützen.

Tabelle 1.:

Brandtote, Brandschäden in Deutschland in 1997 (gilt trendmäßig weltweit)

	Industrie	**private Haushalte**	**gesamt**
Brandtote (1)	117	497	614
Brandschäden lt. GDV (8)	4,9 Mrd. DM	1,6 Mrd. DM	6,5 Mrd. DM
Brandschäden geschätzt (2)	5-7 Mrd. DM	3-4 Mrd. DM	ca. 11 Mrd. DM
Brandorte (1)	23%	77%	100%

Die Unternehmen sind fast alle gegen Feuer- (ca. 90%) und Betriebsunterbrechungen (ca. 50%) versichert. Im privaten Bereich sind 74,3% **(8)** mit Gebäude und Hausrat feuerversichert. Viele sind jedoch unterversichert gerade im Hausratbereich. Wie im industrieellen Bereich konzentrieren sich auch im privaten Bereich die Werte auf engstem Raum. PC, Einbauküchen, Hi Fi- Geräte, Kleidung, Sportartikel, ...,(zudem noch immer mehr Single Haushalte). Die Versicherer rechnen mit ca. 1.200 DM **(13)** pro m^2 Wohnfläche. Deshalb werden die Schäden viel höher, insgesamt auf über 11 Mrd. DM pro Jahr geschätzt.

Die Statistiken zeigen eindeutig: In den Wohnbereichen besteht großer Handlungsbedarf. So makaber es klingt, bis jetzt hat uns der humanitäre Aspekt, Leben zu schützen, nicht überzeugt. Vielleicht führt der wirtschaftliche Aspekt zum Handeln. Denn die Brandschäden in privaten Haushalten sind erschreckend hoch und die Tendenz ist ständig steigend.

Die meisten Personen- und Sachschäden werden durch den Brandrauch hervorgerufen. Fast alle Brände gehen in der Entstehungsphase (Schwelbrandphase) mit der Entwicklung von Brandrauch einher.

Räume und Gebäude sind oft innerhalb kürzester Zeit mit lebensgefährlichem Brandrauch aufgefüllt. Laut Statistiken der Feuerwehren verbleiben durchschnittlich nur 4 Minuten zur Flucht. Eine schnelle Feuerwehr ist nach 8 Minuten am Brandgeschehen. Eine Rauchvergiftung tötet aber, bereits nach 2 bis 3 Minuten. Siehe Diagramm 1.: Nur 100 g Schaumgummi oder Heizöl füllen beim Verschwelen eine Wohnfläche von 100 m^2 bei einer Raumhöhe von 2,5 m mit Rauch. Ein schwelendes Bügeleisen oder ein Radio können eine ganze Wohnungseinrichtung zerstören. Versicherungen zahlen dagegen nur bei offenem Feuer!

Diagramm 1. **(14)**:

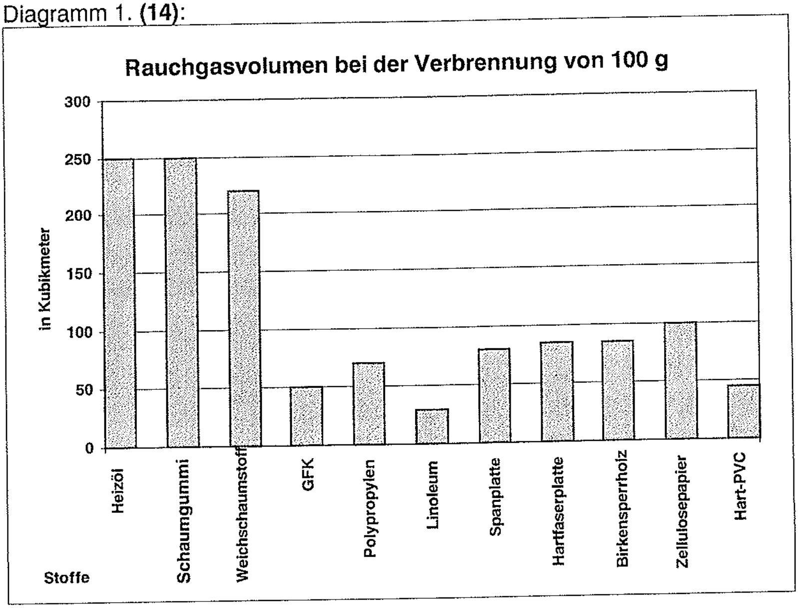

Tabelle 2.:

Brandrauch ist immer giftig, er enthält exemplarisch:

Blausäure entsteht beim Verbrennen von Polyurethan Schaumstoffmatratzen Polstermöbeln Wolle, Seide, Daunen **verschiedene andere Säuren** (z. B. Salzsäure, Phosphorsäure, ...)	**Kohlenmonoxid** entsteht beim Verschwelen fast aller Produkte	**Ammoniak** entsteht beim Verschwelen von Kunststofffasern, Wolle, Seide, Nylon
	Kohlendioxid entsteht ebenfalls beim Verschwelen	**Schwefeldioxid** entsteht ebenfalls beim Verschwelen
↓	↓	↓
Atemgifte mit Wirkung auf Blut und Nerven	Atemgifte mit erstickender Wirkung	Atemgifte mit Reiz- und Ätzwirkung

Im Brandrauch befinden sich toxische und korrosive Bestandteile, die je nach Konzentration innerhalb kurzer Zeit zum Tode führen.

Schon das Einatmen einer Lungenfüllung mit Brandrauch ist tödlich.

Im wachen Zustand besteht eine Chance, einige Gifte der Brandgase durch ihren Geruch, Reizwirkung und Farbe zu erkennen. Im Schlaf haben wir keine Chance. Geruch weckt die Menschen nicht, sie sterben still an Rauchgasvergiftung. Untersuchungen der Feuerwehr Frankfurt ergaben, daß diese Menschen durch Heimrauchmelder hätten gerettet werden können. Die Brände zwischen 23 Uhr nachts und 7 Uhr morgens verursachen 70% der Brandtoten.

Das Molekül des **farb-, geschmack-, geruchlosen Kohlenmonoxid (CO)** verbindet sich 100mal schneller mit dem Hämmoglobin des menschlichen Blutes als das Sauerstoffmolekül aus der Luft (O_2). Es gibt keine Möglichkeit, dies im Körper zu unterbinden oder schnell rückgängig zu machen. Nur geringe Mengen von Kohlenmonoxid können über den normalen langsamen Regenerationsprozess des Körpers ausgeschieden werden. Enthält die Atemluft nur 0,5% Vol/Luft kommt es zu einer Bewußtlosigkeit mit tödlichen Folgen.

Kohlendioxid (CO_2), ebenfalls farb-, und geruchlos wirkt unmittelar auf das Atemzentrum im Gehirn. Bei einer Konzentration von 12% Vol/Luft entsteht nach 2 bis 3 Minuten eine Bewußtseinstrübung, steigt die Konzentration auf 15% Vol/Luft tritt der sofortige Tod ein.

Hier gilt es entsprechende Sicherheitskonzepte umzusetzen.

Die USA, Kanada, Großbritanien, Australien und die Skandinavischen Länder sind in diesem Bereich wesentlich weiter.

Tabelle 3.:		* nur für Neubauten und sarnierte Altbauten	
Der Einsatz Rauchmelder in privaten Haushalten			
Land	**Anteil der Melder in privaten Haushalten**	**gesetzlich vorgeschrieben**	**ergibt in % weniger Brandtote**
Großbritanien	75%	ja*	40%
Schweden	70%	nein	50%
Deutschland	7%	nein	?
USA	90%	ja	40%
Niederlande	?	ab 1999*	?
Österreich	ca. 5 bis 7%	nein	?

Unbestritten ist, daß durch die Rauchentwicklung eines Schadensfeuers die meisten Todesfälle (80 %) zu beklagen sind.

Lebensgefährliche Schwelbrände entstehen letztendlich, unabhängig von der Bauweise des Hauses, im norwegischen Holzhaus wie im englischen Steinhaus, durch defekte Haushaltsgeräte oder durch Unachtsamkeit beim Rauchen, Bügeln oder durch nicht abgeschaltete Herdplatten. Deshalb sind Heimrauchmelder überall erforderlich.

Wie sind die Rauchmelder aufgebaut und wie funktionieren sie?
Heimrauchmelder arbeiten nach dem Ionisationskammer- oder nach dem Streulicht-Prinzip.

Aufgrund der Auflagen des Strahlenschutzgesetzes in Deutschland und dem damit verbundenen staatlich kontrollierten und genehmigungspflichtigen Umgang mit Ionisationskammmer-Meldern, ist der Einsatz dieser Melder im privaten Haushalt nicht möglich. Es gibt auch keine Akzeptanz im privaten Bereich für solche **„I-Melder“**.
Aus diesem Grund und schließlich auch wegen der besseren Detektionseigenschaften bei Schwelbränden, hat sich das optische Streulicht-Prinzip (**„O-Melder“**) durchgesetzt.

Eine neue Technologie der Branderkennung wird in den nächsten Jahren verstärkt in den Vordergrund rücken. Die Detektion von Gasen durch Halbleiter. Hier werden interessante Ergebnisse erwartet, was die sehr frühe Detektion von Brandgasen anbetrifft.

Tabelle 4.:			
Mögliche Funktionsprinzipien für Gas-Sensoren			
→ Halbleiter Metalloxid	**→ Halbleiter Polymer**	**→ IR-optisch**	**→ el. chemisch**
Folgendes kann detektiert werden:			
Rauch: → Wasserstoff (H_2) → Kohlenmomoxid (CO) **Schwelbrand:** → Kohlenmonoxide → auch Wasserstoff (H_2)		**Flamme:** → Stickoxyde (NO_X) → Kohlendioxid(CO_2) **Meßkombinationen:** → CO/H_2 → CO/CO_2 (wenig sinnvoll) → CO/NO_X	

Neben den Stand-alone-Heimrauchmeldern, die nur Personen in ihrem direkten Überwachungsbereich warnen, befaßt man sich im zunehmenden Maße mit sinnvollen Ergänzungen der Alarmweitermeldung.
Einige Heimrauchmelder lassen sich heute schon durch Verdrahtung vernetzen und können damit die Alarmierung auch in anderen Bereichen realisieren. Ein

Heimrauchmelder, beispielsweise im Heizungskeller, aktiviert auch das akustische Signal des Heimrauchmelders im Schlafzimmer.

Neue Übertragungstechniken ermöglichen weitere sinnvolle Konzepte, z.B. der EIB-Bus. Er realisiert sinnvolle Alarmkonzepte und Funktionen nicht nur im eigentlichen Wohnbereich, sondern auch darüber hinaus, wie z.B. die Aufschaltung auf vorhandene Alarmsysteme, Telefonwähl-und/oder Ansage-Geräte. Nachbarschafts-Alarmierung sind Konzepte, die schon heute technisch umgesetzt werden könnten.
Auch der Funkübertragung kommt immer mehr Aufmerksamkeit zu.

Wie verhalten sich die Verbraucher?
Die Mehrzahl der Verbraucher verhält sich nach dem Floriansprinzip: „Lieber heiliger Florian, beschütz mein Haus, zünd Andere an“.
Man verdrängt die Situation. Hat der Verbraucher sich für den Kauf eines Heimrauchmelders entschieden, wählt er das Produkt nach Preis und Design aus.
Technische Vergleiche kann der Privatverbraucher nicht anstellen. Alle Hersteller loben selbstverständlich ihre Erzeugnisse.
Hier muß dem Verbraucher eine seriöse Entscheidungshilfe geboten werden, denn eine Nichtfunktion im Schadensfalle wird der Einsatzbereitschaft von Heimrauchmeldern sicher schaden.

Tabelle 5.:

Wenn nachts in Ihrer Wohnung ein Feuer ausbricht? 2.000 Bundesbürger antworteten im Jahre 1997: (9) Doppelantworten möglich!

55 %	glauben von Mitbewohnern oder Nachbarn alarmiert zu werden
25 %	verlassen sich auf ein wachsames Haustier
20 %	meinen die Feuerwehr weckt sie
38 %	sind sicher in weniger als zwei Minuten Ihre Wohnung verlassen zu können
10 %	würden einem Frühwarnsystem z. B. einem Rauchmelder vertrauen
7 %	besitzen mindestens einen Rauchmelder (3% mehr! 1994 besaßen nur 4% einen Rauchmelder)
66 %	befürworten eine gesetzliche Vorschrift zur Installation von Rauchwächtern

Ausnahmen bilden, nach Aussagen der Gebäudeversicherer, die Verbraucher, die durch Brände an Haus und Leib geschädigt wurden. Hier ist man sofort bereit Heimrauchmelder zu installieren.

Welche Normen, Richtlinien, Gesetze und Auflagen gibt es?

Tabelle 6.:

Auszug der weltweit vorhandenen Kennzeichnungen für Heimrauchmelder

Richtlinie, Norm, Spezifikation	Schwerpunkte, Prüfungen

prEN ISO 12239, Norm	• ISO Norm gilt weltweit, soll vereinheitlichen
	• genormt ist die Funktion des Melders
	  • Raucheintritt
	  • elektrische, konstruktive Daten

VdS, Prüfrichtlinien	• prüfen nach prEN ISO 12239

BS 5446, Spezifikation	• die EN ISO 12239 lößt den BS 5446 ab
	• genormt ist die Funktion des Melders
	  • Raucheintritt
	  • elektrische, konstruktive Daten

UL 217, Spezifikation	• die Funktion des Melders wird vorausgesetzt • allgemeine Sicherheitsdaten

EN 54, Teil 7, Norm	• genormt ist die Funktion des Melders
	  • Raucheintritt
	  • elektrische, konstruktive Daten

Was bedeutet British Standard BS 5446?

Die Spezifikation für Heimrauchmelder erschien 1977 und hat Anforderungen an Konstruktion, Ansprechverhalten und Prüfverfahren. Diese wurde auch sukkzessive angepasst. Jedoch entsprechen oftmals die Melder die mit BS gekennzeichnet sind den aktuellen Anforderungen des BS 5446. Einige Produkte wurden von unserer Entwicklung untersucht und im Brandversuchsraum getestet:

Keiner der Melder entsprach in allen Punkten den Anforderungen des BS 5446. Zwei Meldertypen erwiesen sich als regelrechte Todesfallen. Sie sprachen erst bei einer Rauchkonzentration an, bei der bereits ein Drittel der Konzentration zum sicheren Tode geführt hätte. Dies gilt eben so für einige Melder die das UL 217 Prüfzertifikat tragen.

Was ist das wesentliche an der neuen prEN ISO Norm 12239?

Diese Norm ist leider schon lange im Entwurfstadium. Wird sie gültig, gilt sie weltweit?

Die Europäische Kommission hat durch das Mandat M 109 den Antrag gestellt, daß die ISO die Arbeiten an dem Normenentwurf prEN 12239 bis Oktober 1998 weiterführen muß.

Werden die Arbeiten nicht weitergeführt, ist DEN durch das Mandat M109 der Europäischen Kommission gehalten, den Normenentwurf bis Ende 1999 fertigzustellen. Dann wird aus dem ursprünglich weltweit geltenden ISO Normentwurf 1999 eine Europäische Norm. Nach Inkrafttreten dieser Norm dürfen in Europa nur noch Heimrauchmelder verkauft werden, die dieser Norm entsprechen. In Deutschland wird zukünftig die Fachkommission „Bauaufsicht“ die für das Bau-, Wohnungs- und Siedlungswesen zuständigen Minister der Länder (ARGEBAU) in Ihren Baurichtlinien auf Heimrauchmelder verweisen, die nach dieser Europäischen Norm geprüft sind .

An die Technik und Zuverlässigkeit der Heimrauchmelder stellt die EN 12239 sehr hohe Anforderungen. In den meisten Punkten sind die Forderungen, als sie für Industrie Rauchmelder gelten, die zusammen mit Brandmelderzentralen eingesetzt werden.

Besonders hohe Anforderungen der prEN ISO12239 werden gestellt bei:

➔ EMV Festigkeit
➔ Batterie (Funktionskontrolle, Einsatz)
➔ Festigkeit gegen Elektrostatische Entladungen
➔ Ansprechempfindlichkeit
➔ Korrosionsfestigkeit
➔ Stoß- und Schwingungsfestigkeit
➔ Gegendruck

Momentan würde keiner der auf dem Markt befindlichen Heimrauchmeldern den prEN ISO 12239 Normanforderungen entsprechen.

Wie wird der VdS prüfen?
Die VdS Prüfrichtlinien für Heimrauchmelder entsprechen in fast allen Punkten der prEN ISO12239.
Das Prüfverfahren selbst wird z. Zt. vom VdS festgelegt.

Welche Gesetze/Auflagen sind in Deutschland angedacht und in Vorbereitung?

Nur in Hessen können die Baugenemigungsbehörden und die Feuerwehr mit dem Erlaß vom 13.02.1996 batteriebetriebene Rauchmelder fordern:
Sind Aufenthaltsräume nur über eine Maisionettetreppe nach § 34 Abs. 1 Satz 3 Hessische Bauordnung (HBO) zugängig, können im Einzelfall an geeigneten Stellen batteriebetriebene Rauchmelder gefordert werden. Sonst gibt es in Deutschland keine gesetzliche Vorschriften, die Heimrauchmelder fordern.

Der Verein Childrens Health Support **(10)** hat in einer Petition an den deutschen Bundestag ein Gesetz gefordert, dass Heimrauchmelder im privaten Wohnbereich vorschreibt. Die Petition mit der Gesetzesforderung ging an alle Regierungen der Bundesländer. Fast alle Regierungen der Bundesländer haben abgelehnt. Childrens Health Support ist ein Verein mit über 200 Mitgliedern. Sie akzeptieren es nicht, dass jährlich allein In Deutschland hunderte von Kindern getötet und noch mehr ihr Leben lang mit schrecklichen Folgeschäden kämpfen müssen.

Bevor in den USA Heimrauchmelder gesetzlich vorgeschrieben wurden, hatten nur ca. 5% bis 7% der Bevölkerung Rauchmelder in ihren Wohnungen installiert. Aufklärungsaktionen durch Feuerwehren, Hersteller, Behörden, etc. blieben vor allem in den unteren Bevölkerungsschichten erfolglos. Einen flächendeckenden Einsatz und damit ein nachvollziehbarer Erfolg durch weniger Brände und damit weniger Tote und Verletzte kam erst mit der gesetzlichen Vorschrift.
Eine Gewährleistung für sicheren Schutz bringt ein Gesetz, daß den Einsatz von Heimrauchmeldern vorschreibt zusammen mit einer kontiunierlichen Überwachung der Produktequalität der Melder.

Unbestritten ist, daß die Brände im privaten Wohnbereich die meisten Toten, Verletzten und verhältnismäßig hohe Sachschäden verursachen. Heimrauchmelder erkennen Brände in der Entstehungsphase und warnen die Menschen bevor eine Rauchvergiftung überhaupt entstehen kann. Weltweit ist dies von den Menschen begriffen worden, letztlich durch die Summe aller Aktivitäten, wie verschärfte Vorschriften, Prüfverfahren, Gesetze und viele Aufklärungsaktionen.

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Lautsprecher-Alarm-Systeme; Stand der Technik und Entwicklungs-Konzepte

Abstract

Part 1 shows the basic function and architecture of voice alarm systems, and also their positioning in the market. Part 2 gives more detail on the size and functionality of such systems as part of a complete danger management system, and on the different requirements in the various markets. Part 3 treats the architecture and structure of todays designs and of possible new solutions. Part 4 gives an overview of standards and regulations in effect or in preparation. Part 5 draws conclusions on the further positioning and possible wider use of these systems.

1. Einführung

Lautsprecher-Alarm-Systeme sind vor allem in Amerika schon seit mehreren Jahrzehnten ein integrierender Bestandteil der Brandmelde-Einrichtung. Sie sind oft vorgeschrieben von den lokalen, für den Feuerschutz verantwortlichen Stellen. Sie dienen dazu, den Insassen im Alarmfall Anweisungen zum geordneten Verlassen des Gebäudes zu geben. Sie sind deshalb auch bekannt unter den Bezeichnungen Evakuations-System, Not-Durchsage-System, Not-Warnungs-System, Not- Kommunikations-System, „Umplazierungs-Anweisungs“-System (relocation system).

In den Amerikas wurden solche Anlagen populär wegen der dortigen Gebäude-Architektur (Hochhäuser), und auch wegen der weiten Verbreitung von Holz als rasch brennendem Baustoff, was beides zu Evakuations-Problemen führen kann.
Die entsprechenden Feuerschutz-Vorschriften wurden durch die Feuerwehren gemacht, zum Personenschutz.
In Europa andrerseits sind solche Systeme noch relativ wenig verbreitet, da es viel weniger Hochhäuser gibt, und vielleicht auch weil die Brandschutz-Vorschriften eher von den Gebäude-Versicherern gemacht wurden.

So sind denn auch in der entsprechenden Norm EN 54 für die Alarmgabe nur die Signalgeräte (Sirenen Hörner, Glocken) als Bestandteil einer Brandmelde-Anlage vorgesehen (Teil C), und das Gerät zur Übermittlung des Alarms an eine zentrale Empfangsstelle wie z.B. die Feuerwehr (Teil E).

Die Hauptfunktion der Lautsprecher-Systeme ist also die Warnung und Anweisung der Gebäudeinsassen. Im einfachsten Fall werden dazu auch wirklich nur speziell definierte Töne, Signale oder Tonfolgen verwendet. Dazu braucht es nicht unbedingt Lautsprecher.
Es hat sich aber gezeigt, dass diese Töne oft nicht bekannt sind, weil sie ausser im Brandfall nie gehört werden. Das gleiche gilt auch zum Beispiel in Hotels mit ortsfremder Kundschaft. Anweisungen in Klartext werden sehr viel besser verstanden und befolgt.
Weiter hat die verfügbare Technik es ermöglicht, die spezifizierten Töne preisgünstig auch mit Lautsprechern als Signalgebern zu erzeugen.
Und Lautsprecher-Systeme sind auch für andere betriebliche Durchsagen nutzbar.

2. **Heutige Systemtechnik**

Ein Standard Alarmierungs-System funktioniert auch heute noch so, dass im Alarmfall ein vordefiniertes Tonsignal im ganzen Gebäude ausgegeben wird, über Lautsprecher. Diese Lautsprecher werden dann von dem auf dem Platz erschienen Feuerwehr-Kommandanten, oder von einem eigenen Sicherheit-Beauftragten benutzt, um über ein zentral gelegenes Mikrofon weitere differenzierte, gesprochene Anweisungen zu geben.
Vor allem in Hochhäusern oder verzweigten Gebäudestrukturen ist es aber notwendig, die Insassen in differenzierter. geordneter Reihenfolge zu evakuieren. Dazu müssen verschiedene Teile des Gebäudes mit verschiedenen Informationen und Anweisungen versehen werden.
Vom Feuer weiter entfernte Lokalitäten erhalten gar keine oder nur Warnungs-Information, direkt betroffene erhalten Alarm- und Räumungs-Anweisungen.
Die verschiedenen Mitteilungen entsprechend den Informations-Stufen werden vor Eintreffen der Feuerwehr aus gespeicherten Sprachkonserven automatisch abgerufen und ausgegeben, je nachdem wo das Feuer festgestellt wurde. In einem Hochhaus ist es das Stockwerk mit der Feuermeldung, und dasjenige direkt unter und über dem Feuer, welches normalerweise Evakuations-Anweisung erhält. Weitere Stockwerke werden nur gewarnt, andere werden gar nicht informiert. Vom zentralen Mikrofon kann dann gleichzeitig ein ganz bestimmter Gebäudeteil mit speziellen Anweisungen versehen werden.
Diese Funktionalität bedingt ein sogenanntes „Mehrkanal-System“, das heisst mehrere Signalarten können an verschiedenen Stellen des Gebäudes gleichzeitig ausgegeben werden. Im weltweiten Markt wird diese Funktion heute verlangt, sobald es sich um ein grösseres Objekt, insbesondere ein Hochhaus handelt.

Die Forderungen an die technische Auslegung solcher System werden ebenfalls anspruchsvoller. Nachdem in der eigentliche Brandmelde-Anlage eine fast vollständige Redundanz oder Notlauf-Eigenschaften verlangt werden, wird auch für die Alarmierungs-Anlagen ähnliche Funktionssicherheit gewünscht. Das heisst redundante Verdrahtungs-Techniken, Reserve-Verstärker-Einheiten, vollständige Leitungs-Überwachungen sind schon zum Teil verwirklicht.

3. **Heutige und kommende Systemkonzepte**

Bis vor kurzem waren die im Markt erhältlichen Lautsprecher Alarm Systeme so aufgebaut, wie es ganz allgemein in der Technik von Lautsprecher-Durchsage- und Hintergrund-Musik-Anlagen üblich ist. Nur in Amerika waren es insofern eigene Techniken der Brandmelde-Firmen, weil dort die Integration in die Brandmelde-Anlage praktisch vorgeschrieben ist, respektive die Alarmierungs-Funktion als Teil der BM-Zentrale in der UL-Norm enthalten ist. Aber auch da waren und sind meist noch Konzepte im Einsatz, in denen zentrale und abgesetzte Vertärker-Banken über so viele Audio-Leitungen verbunden sind, wie „Kanäle“ notwendig sind.
Zusätzlich weisen sie eine gemeinsame Steuer-Linie auf, welche die Verstärker auf diese Kanäle und die Lautsprecher-Zonen-Linien auf die Verstärker umschaltet.
Alle Tonleitungen sind noch in analoger, und die Verstärker in linearer Technik ausgeführt.

Mit der heute sich rasant entwickelnden „Multi Media“ Technologie ergeben sich nun aber ganz andere Möglichkeiten, solche Anlagen zu bauen. Die Digitaltechnik im speziellen hat ganz generell die Methoden von Tonübertragung und Signalverarbeitung revolutioniert. Das ist uns allen bekannt von der Telephonie und den Compact Disk Tonträgern.

Diese Techniken haben zum Teil schon Einzug gehalten auch in der Realisierung von Lautsprecher Alarmierungs-Systemen, und es ergeben sich damit eine ganze Anzahl von Vorteilen:

- Die vielen „Kanäle" werden nicht mehr analog, sondern digital übertragen, und zwar gleichzeitig mehrere auf einer 2-draht Leitung.
- Dies wird möglich mit relativ kleinen Datenraten, unter Benützung von Kompressions-Algorithmen, und somit auch auf rel. kostengünstigen Kabeln
- Die verschiedenen Kanal-Signale oder gesprochenen Mitteilungen werden digital gespeichert, kostengünstig und flexibel anpassbar
- Die Audio Verstärker werden in digital geschalteter Technik realisiert, was Verlustleistung, Volumen und Kosten reduziert
- Dezentrale Verteilung von (kleinen) Verstärkern erlaubt kostengünstigere Leitungen zu den Lautsprechern
- Die digital gespeicherten Meldungen und Signale können in den verteilten Verstärkereinheiten lokal abgelegt und abgerufen werde werden, was die mögliche Anzahl „Kanäle" stark erhöht.

Es ist abzusehen, dass mit dem Einsatz der neuen Techniken eine Verbesserung sowohl der Funktionalitäten, Spezifikationen als auch des Kosten/Leistungs-Verhältnisses stattfinden wird. Ebenso sind Erweiterungen der damit möglichen Dienstleistungen voraussehbar. So ist zum Beispiel die Kommunikation mittels Mehrkanal Lautsprecher-Systemen erst ein Anfang, welcher mit bi-direktionaler Sprach-Kommunikation, auch vom Brandort zurück zur Brandmelde-Zentrale, zur zentralen Leitstelle, fortgesetzt werden kann. Solche **Feuerwehr-Telephonsysteme** sind oft schon heute in USA neben dem Lautsprecher-Alarm-System gefordert. Auch dafür sind die digitalen Übertragungstechniken heute voll vorhanden, werden aber noch kaum eingesetzt. Die gleichen Techniken könnten dann auch für die Übertragung von Bild-Information aus dem Brand-Ort im Gebäude Verwendung finden. In der Einbruch-Meldetechnik sind solche Konzepte unter der Bezeichnung „Hinein-Hören/Hinein-Sehen" schon bekannt.

Und mit der digitalen Telephonie kommt dann, im Zeitalter der Mobil-Telephonie, sehr rasch auch die drahtlose Übermittlung all dieser Information ins Gespräch. Dies nicht nur zur Brandmelde-Zentrale im Gebäude, sondern auch gleich zur Feuerwehr, und dort auch zum Einsatz-Fahrzeug, während der Fahrt zum Brandort. Ein bi-direktionaler Kommunikations-Pfad würde dann der Feuerwehr erlauben, schon vom Standplatz und vom Fahrzeug aus auch aktiv in die Brandfall-Steuerung und Evakuations-Leitung einzugreifen.

4. **Normen und Vorschriften**

Lautsprecher Alarm Systeme waren schon seit den siebziger Jahren Bestandteil der Vorschriften für Brandmeldeanlagen in den USA und Canada. Auch in andern Ländern wurden damals schon Lautsprecher-Systeme für die Alarmierung im Brandfall verwendet, aber nur sehr vereinzelt. Es bestanden dort dafür bis vor kurzem keine Vorschriften oder Richtlinien.
Erst in den letzten Jahren hat sich nun die Aktivität in dieser Richtung auch in einer Reihe anderer Länder stark vergrössert. Es sind zur Zeit folgende Dokumente bekannt:

UL 864 Zentralen für Brandmelde-Anlagen
CAN/ULC-S525, -S527 Akustische Alarmgeräte, Brandmelde-Zentralen
NFPA 72 Brandmelde Anlagen
Diverse Staats-/Stadt-Richtlinien in USA (California, NewYork, Chicago, etc.)
BS 5839 part 8 Brandmelde- und Alarm-System für Gebäude; Richtlinie für Lautsprecher-Alarm-Systeme
NEN 2575 Brandschutz von Gebäuden; Räumungsalarm-Systeme (Entwurf)
SFB Richtlinie 1998 Evakuationsalarm
AS/NZS 4428 Brandmeldezentralen; Not-Warn-System (Entwurf)
AS/NZS 1670 Brandmeldezentralen; Not-Kommunikations-System (Entwurf)
EN 60849 Audio Systeme für Notfälle (Entwurf)

Daneben gibt es noch eine Reihe von mindestens teilweise relevanten Vorschriften, in Kraft oder als Entwürfe, wie zum Beispiel prEN 54-3 „(Hörbare) Brandalarmierungs-Geräte“ (Entwurf) für Europa, oder ähnliche Dokumente in den einzelnen Ländern, welche z.B. standardisierte Alarmtöne definieren.

Es besteht also heute eine rege Aktivität sowohl in der Normierung von Lautsprecher-Alarmierungs-Systemen, als auch in der technischen Evolution bei der Bereitstellung solcher Systeme. In den Normen-Gremien sind meist die Hersteller von Geräten und Systemen massgebend beteiligt. Dies führt etwa dazu, dass der Stand einer bestimmten Technik in eine Norm einfliesst, nicht zuletzt auch als Versuch, dieser Technik einen marktpolitischen Vorteil zu verschaffen. Es bleibt zu hoffen, dass in der Standardisierung der Lautsprecher-Alarm-Systeme nicht Lösungen spezifiziert werden, sondern Leistungs-Merkmale und Funktionen. Nur so kann der sich rasch entwickelnden Technologie bei der Geräte-Bereitstellung gefolgt werden, und können die neuen technischen Errungenschaften innert nützlicher Frist dem Kunden zur Verfügung gestellt werden.

5. **Schlussfolgerungen, Ausblick**

Die Technik erlaubt laufend neue Lösungen für die bekannten Funktionalitäten von Lautsprecher Alarm Systemen. Gleichzeitig kommen solche Systeme vermehrt in das „Gesichtsfeld“ von Verantwortlichen für Brandschutz-Massnahmen, bei Feuerwehren, Versicherungen und Gebäude-Besitzern. Das heisst der Markt für solche Systeme wird sich vergrössern, dort, wo er nicht schon etabliert ist, das heisst weltweit, ausser Nordamerika. Sollte der Einsatz solcher System dort den gleichen Anteil im Verhältnis zu Brandmelde-Anlagen erreichen wie in den USA, dann sprechen wir von vielleicht 20'000 Systemen jährlich.

Diese Situation führt zu einer Beschleunigung der Aktivitäten auf dem Gebiet der Bereitstellung solcher Geräte und Systeme, als auch von Richtlinien für deren Anwendung, und Normen für deren Ausführung. Gerade da sind aber zur Zeit nur landesspezifische Richtlinien in Arbeit.

Es ist somit sicher notwendig, dass sich die gesamt-europäischen, besser noch weltweiten Brandschutz-Normengremien dem Thema „Alarmierung", sowohl lokal im Brandfall-Gebäude, als auch durch Fernübertragung zur Feuerwehr, vermehrt annehmen.

Die Norm prEN54-3 für Alarmierungsgeräte ist da eigentlich, im Blick auf die hier beschriebenen Alarmierungs-Techniken, schon „veraltet". Die vorliegenden Landes-Richtlinien oder -Normen für Lautsprecher Alarm Systeme sind aber durchaus eine Basis, um daraus ein europäisches oder weltweites Werk zu gestalten.

Eine EN für den Teil E eines Brandmeldesystems nach EN54, Übertragungsgeräte, gibt es gar nicht. Wenn das nicht im CEN/TC72 vorangetrieben wird, kann man vielleicht die Arbeiten in CENELEC/TC79 über „Alarm Transmission Systems" in Betracht ziehen, respektive dort mitarbeiten.

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Anwendungen des BACnet Standards in der Gefahrenmeldetechnik

Application of the BACnet Standards in danger management technology

Abstract

For years the autonomy of danger management systems has been defended as a strategic position. Use of infrastructures by different disciplines, whether for communication, or as a platform for the realization of management station functions, has repeatedly given rise to debate.

However, the trend towards open systems cannot be overlooked. A joint solution for fire and intrusion at detector bus and control unit level is being clearly promoted by individual manufacturers. The fusion of the disciplines intrusion and access control seems to be the next logical step. The integration process of danger management technology and building technology must be in line with the existing regulations and manufacturers must actively participate in shaping it. Siemens Cerberus promotes to open the danger management system for others by using the BACnet Standard in the new generation products. And while this communication standard is strongly influenced by the discipline HVAC (heating, ventilation, air conditioning) it maintains that it will cover the entire building technology aspect in the foreseeable future. The application of the BACnet Standard for danger management technology is proving to be a special challenge because the manufacturer of such systems continues to bear responsibility of his market services. At the same time he has to comply with a standard which can hardly be influenced.

Standardisierte Kommunikation

Im Bereich der Gefahrenmeldetechnik sind verschiedene Aspekte nutzbringend standardisierbar, so zum Beispiel die Leistungseigenschaften, bestimmte Funktionen, Komponenten oder Schnittstellen. Je nach Disziplin führen die Zulassungsvorschriften zu mehr oder weniger ausgeprägten, landesspezifischen Standards, die jedoch unmittelbar im Zusammenhang mit der sicherheitstechnischen Aufgabe des Gefahrenmeldesystems stehen. Darüber hinaus liegt ein grosses Standardisierungspotential im Bereich der Kommunikation. Hier steht nicht die sicherheitstechnische Aufgabe, sondern der Austausch und die Nutzung von Informationen zwischen verschiedenen Systemkomponenten im Vordergrund. Falls ein Hersteller die verwendeten Standards und deren Anwendungsweise offenlegt, ist auch der Austausch und die Nutzung von Informationen zwischen verschiedenen Herstellern möglich. Standardisierungs-Institutionen dienen gelegentlich als unabhängige Plattform für die Umsetzung solcher Interessen. Der Begriff „Interoperabilität„ hat sich für diese Art der offenen Kommunikation mittlerweile eingebürgert.

Standardisierung: Pro und Kontras

Für den Kunden oder Betreiber eines autarken Gefahrenmeldesystems steht die Frage nach der Verwendung von Standards eher im Hintergrund. Ein bestimmter Kunde beansprucht für seine spezifische Anlage eine in sich geschlossene Lösung. Die Kompatibilität zu weiteren Herstellern und Produkten sowie Vorgaben bezüglich der Verwendung bestimmter Standards treten dann als direkte Marktanforderung auf, wenn ein heterogener Verbund von Teilsystemen oder Lösungen mit Leitstellen vorgegeben ist. In diesem Segment profitiert der Kunde gravierend von Standards. Die Integration von Produkten unterschiedlicher Hersteller wird erheblich vereinfacht und die Abhängigkeit vom Hersteller vermindert. In absehbarer Zukunft könnte die interdisziplinäre Nutzung von Infrastrukturen auch den Installations- und Wartungsaufwand reduzieren. Ein Problem ist allerdings noch nicht gelöst: Die Abgrenzung der Verantwortlichkeiten zwischen den einzelnen Disziplinen muss sich hieb- und stichfest regeln lassen.

Aus Herstellersicht führen Standards zum Verlust an Kundenbindung und zum Abbau der Eintrittsbarriere für Konkurrenten. Die Produktedifferenzierung wird schwieriger, d.h. die Differenzierung verlagert sich eher auf die Ebene der gesamten Marktleistung. Aus technischer Sicht reduzieren sich der Aufwand und das Risiko bei der Produkteentwicklung, da man üblicherweise eine solide technologische Basis und käufliche Komponenten voraussetzen kann. Standards wirken stabilisierend, behindern jedoch punktuelle Optimierungen und behindern innovative Lösungsansätze.

Standardisierung hat ihren Preis, auch hier zählt das Verhältnis von Nutzen zu Kosten.

Die Auswahl eines Standards

Im Umfeld der Kommunikation gibt es eine Vielzahl von Standards, die sich zum Teil konkurrenzieren. Es ist schwer voraussehbar welcher Standard sich durchsetzen wird und so die oben erwähnten Vorteile zum tragen bringt. Ein Hersteller kann bei rechtzeitigem Engagement den Standard selbst beeinflussen, allerdings besteht das Risiko, dass schliesslich ein anderes Pferd das Rennen macht.

Im Dschungel der Kommunikationsstandards findet man sich besser zurecht, indem für die einzelnen Standards der Bezug zum OSI Modell (Open System Interconnection) hergestellt wird. Das OSI Modell ist in der internationalen Fachwelt bestens etabliert und ist selbst als Standard verankert. Das OSI Modell befasst sich mit der Kommunikation zwischen Computern und definiert eine hierarchische Protokollarchitektur mit sieben Lösungsebenen. Jede Lösungsebene behandelt eine in sich geschlossene Teilaufgabe und ist über definierte Schnittstellen im gesamten Modell eingebunden. Das OSI Modell beschreibt lediglich die Architektur eines Kommunikationssystems und lässt offen, ob die einzelnen Protokollebenen sehr umfassend, nur rudimentär oder gar nicht ausgebildet sind.

Ein Kommunikationsstandard bezieht sich in der Regel auf eine eingeschränkte Anzahl von Protokollebenen und deckt somit lediglich einen Teil der Kommunikationsaufgabe ab. Die Interoperabilität zwischen Systemen setzt aber voraus, dass die Kompatibilität auf allen Protkollebenen gegeben ist. Es zeigt sich, dass die Standardisierung insbesondere auf Anwendungsebene (OSI Layer 7) wenig fortgeschritten ist. Auf dieser Ebene wird das (Allzweck-) Kommunikationssystem auf eine spezifische Anwendung zugeschnitten. Dabei steht weniger die Kommunikationstechnik als die Kompetenz bezüglich einer spezifischen Anwendung im Vordergrund.

Das Manko an Standards auf Anwendungsebene trifft auch für die Gefahrenmeldetechnik zu. Bisher sind uns keine etablierten Standards bekannt. Eine vielversprechende Vorgehensweise besteht darin, bei den Standardisierungsaktivitäten der verwandten Anwendungsgebiete, wie Automatisierungstechnik und Gebäudetechnik die Anforderungen der Gefahrenmeldetechnik einzubringen. Einzelne Interessegruppen mit dieser Zielsetzung wurden bereits gebildet.

Siemens Cerberus Division hat die Entscheidung zu Gunsten des BACnet Standards getroffen, wobei verschiedene Argumente dazu beigetragen haben. BACnet ist auf das Anwendungsgebiet Gebäudetechnik ausgerichtet, weist aber aus historischen Gründen eine starke Prägung bezüglich HLK (Heizung, Lüftung, Klima) auf. Für die Zusammenarbeit mit der Gefahrenmeldetechnik besteht ein grosses, gegenseitiges Interesse. BACnet wird bei SBT (Siemens Building Technology) im HLK Bereich bereits angewendet. BACnet deckt die

Anforderungen der Gefahrenmeldetechnik zu einem grossen Teil bereits ab. BACnet definiert eine kontrollierte Offenheit bezüglich der Informationsübertragung innerhalb des Netzwerks. Dies erlaubt im Rahmen des Standards sowohl kosten- als auch leistungsoptimierte Lösungen.

Der BACnet Standard

BACnet (Building Automation and Control Network) ist ein offenes Protokoll für die Datenkommunikation, welches unter der Führung von ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) entwickelt und 1995 als ANSI Standard anerkannt wurde. BACnet ist eine Antwort auf die chronische Inkompatibilität von Systemen innerhalb des Gebäudes. Die Architektur von BACnet umfasst vier Ebenen: Physikalische, Data Link, Netzwerk und Anwendungsebene. Der Standard definiert umfassend die Anwendungsebene und regelt auf einfache Weise den Informationsaustausch zwischen lokalen Netzwerken (Netzwerkebene). Den Informationsaustausch innerhalb eines lokalen Netzwerkes legt BACnet fest, indem existierende Protokolle (Data Link Ebene) und physikalische Medien (physikalische Ebene) ausgewählt und bezeichnet werden. Die fünf Optionen, die von Ethernet bis LONtalk reichen, erlauben kompatible Lösungen trotz inhomogenen Anforderungen bezüglich Kosten und Leistung.

BACnet Modell

<table>
<tr><td colspan="5">BACnet Anwendungsebene</td></tr>
<tr><td colspan="5">BACnet Netzwerkebene</td></tr>
<tr><td colspan="2">ISO 8802-2</td><td rowspan="2">MS/TP</td><td rowspan="2">PTP</td><td rowspan="3">LonTalk</td></tr>
<tr><td rowspan="2">ISO 8002-3</td><td rowspan="2">ARCNET</td></tr>
<tr><td>EIA 485</td><td>EIA 232</td></tr>
</table>

OSI Modell

<table>
<tr><td>Anwendung</td></tr>
<tr><td>Netzwerk</td></tr>
<tr><td>Data Link</td></tr>
<tr><td>Physikalisch</td></tr>
</table>

Die BACnet Anwendungsebene

Die BACnet Anwendungsebene sieht zwei grundlegende Konzepte vor, nämlich BACnet Objekte und BACnet Services.
Die Objekte beschreiben die einzelnen Teilnehmer als abstrakte Datenmodelle und machen die relevanten Informationen auf einheitliche Weise auf dem Netzwerk sichtbar. Bei der Implementation des Standards werden die spezifischen Datenstrukturen und Eigenschaften eines bestimmten Gerätes auf die standardisierte, abstrakte Sicht der BACnet Objekte abgebildet.
Das BACnet Objekt ist somit ein Mittel, welches die Identifikation und den Zugriff von Informationen erlaubt, unabhängig von der individuellen Realisierung der einzelnen Geräte. Ein BACnet Objekt stellt die verschiedenen Aspekte eines Gerätes durch Datenfelder, die sogenannten Properties dar. Der Zugriff und Austausch von Informationen erfolgt auf der Ebene dieser Properties unter Verwendung der BACnet Services. Darüber hinaus erlauben bestimmte BACnet Services das Anstossen von Aktionen sowie das Signalisieren von Ereignissen innerhalb des Netzwerks.

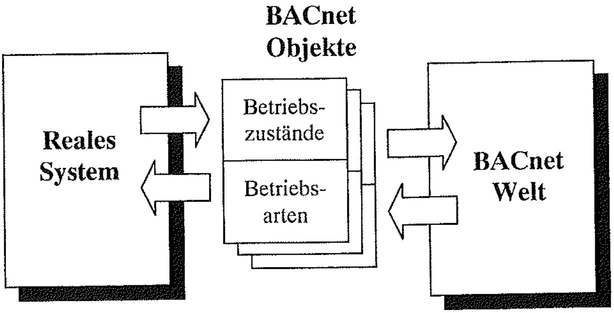
Die Implementation eines BACnet Gerätes umfasst Objekte und Services. In der Regel ist jedoch nur ein Subset der Implementation notwendig, um die zugewiesene Aufgabe erfüllen zu können.
Dieser Tatsache wird Rechnung getragen, indem der Standard Konformitätsklassen definiert und damit die kontrollierte Bildung von Subsets unterstützt.

Umgekehrt bietet BACnet auch Mechanismen zur Handhabung von herstellerspezifischen Erweiterungen an. Aus der formalen Gesetzmässigkeit der Erweiterungsmöglichkeiten leitet sich die Modifikation und Dekodierung aller Meldungen gleichermassen ab, was die Interoperabilität selbst für die herstellerspezifischen Erweiterungen ermöglicht.

Das Gefahrenmeldesystem in der BACnet Welt

Die Topologie einer Anlage bestimmt massgebend den Ort einzelner Funktionen des Gefahrenmeldesystems. Funktionen wie Erfassung, Auswertung, Anzeige usw. erfolgen an verschiedenen Orten und führen zu einem geographisch verteilten System, mit einer Vielzahl von Kommunikationspfaden, die den Informationsaustausch zwischen den einzelnen Funktionen gewährleisten. Der BACnet Standard ist nicht für jeden Kommunikationspfad sinnvoll anwendbar. Der Bereich Sensor, Aktor beispielsweise ist nach wie vor den Feldbussen mit optimierten Kommunikationsprotokollen vorbehalten.

Im Übrigen gelingt es nicht, die vielfältigen Kommunikationsanforderungen auf einen Nenner zu bringen. Dies führte zu drei Modellen unterschiedlicher Ausprägung. Allen Modellen gemeinsam ist die Darstellung der verschiedenen Aspekte eines Gefahrenmeldesystems in Form von BACnet Objekten, welche sowohl physische als auch logische Aspekte modellieren. Diese Objekte machen einerseits den Betriebszustand, andererseits die Betriebsart des Gefahrenmeldesystems in der BACnet Welt sichtbar. Das Modifizieren der Betriebsart eröffnet der BACnet Welt eine Möglichkeit auf das Gefahrenmeldesystem einzuwirken.



Der Unterschied zwischen den drei Modellen liegt wesentlich bei der Differenzierung von Betriebszuständen und Betriebsarten

Das private Modell

Das private Modell zeichnet sich durch hohe Kongruenz zum realen System aus. Es lässt eine hohe Differenzierung bezüglich Betriebszustand und Betriebsart zu. Der Schwerpunkt der Anwendung liegt innerhalb einer einzelnen Disziplin, oder bei der Einbindung von Leitstellen, falls ein hoher Detailierungsgrad gefordert wird. Interoperabilität zu Dritten ist hier nicht beabsichtigt und erfolgt ausschliesslich nach Vereinbarung.

Das private Modell erlaubt mehrere Dimensionen zur Darstellung von Betriebszuständen und Betriebsarten. Das Modell kann beispielsweise einen Betriebszustand „Störung“ und gleichzeitig einen Zustand „Beeinträchtigung“ unabhängig handhaben. Dadurch lassen sich zwei Störungssituationen unterscheiden, die aus Sicht des realen Systems dann wichtig sind, wenn für beide Fälle unterschiedliche Störungsbehandlungen vorgesehen sind.

Die BACnet Standardobjekte werden den Anforderungen des privaten Modells nicht gerecht, was eine herstellerspezifische Erweiterung notwendig macht.

Das öffentliche Modell

Das öffentliche Modell vermittelt eine vereinfachte Sicht des realen Systems. Die Beschränkung auf vitale Informationen steht im Vordergrund, denn das Modell soll universell und auf unterschiedliche reale Systeme innerhalb der Disziplin anwendbar sein. Weitere Schlüsselfaktoren sind Einfachheit und Stabilität. Insbesondere sollen nur vitale Veränderungen auf dieses Modell zurückwirken. Der Schwerpunkt der Anwendung liegt beim Informationsaustausch zwischen Disziplinen, oder bei der Einbindung von Leitstellen. Die Interoperabilität zu Dritten wird angestrebt, soweit die Konformität zu den gültigen Vorschriften gegeben ist.

Das öffentliche Modell erlaubt je eine Dimension zur Darstellung von Betriebszustand und Betriebsart. Bei der Abbildung eines realen Systems auf dieses Modell ist normalerweise eine Verdichtung der Information erforderlich. Die nachfolgende Tabelle zeigt am Beispiel von „Störung" und „Beeinträchtigung" die Verdichtung von zwei Dimensionen auf eine Dimension.
Drei Mechanismen bieten sich grundsätzlich an:
Das Weglassen von Informationen, das Setzen von Prioritäten oder das Zusammenfassen.

Störung	Beeinträchtigung	weglassen	Prioritäten setzen	zusammenfassen
-	-	-	-	-
-	ja	-	Beeinträchtigung	Störung
ja	-	Störung	Störung	Störung
ja	ja	Störung	Störung	Störung

Das öffentliche Modell folgt grundsätzlich der Philosophie von BACnet. Ein Standardobjekt mit Zuschnitt auf die „Life Safety" Anwendung wurde dem Standardisierungskomitee vorgeschlagen. Die laufenden Abstimmungsgespräche werden zeigen, ob und wann die Palette der BACnet Standardobjekte entsprechend ergänzt wird.

Das öffentliche, passive Modell

Das öffentliche, passive Modell ist ein Subset vom öffentlichen Modell, indem es ausschliesslich den Betriebszustand darstellt. Falls dieses Modell zur Anwendung gelangt, ist das Einwirken auf das reale System nicht möglich. Infolge dieser Einschränkung ist das Modell auch im Einklang mit konservativen Vorschriften.

Der auf eine Richtung beschränkte Informationsfluss erlaubt die Auswertung von Zustandsinformationen durch intelligente Peripherie. Die Interoperabilität zu Dritten ist gegeben. Das Modell ist BACnet konform und verwendet ausschliesslich BACnet Standardobjekte.

Zusammenfassung

Mit der Anwendung von BACnet bringen wir die Interessen von Kunde und Hersteller auf einen Nenner. Die sorgfältig entworfenen Schnittstellen auf Anwendungsebene (Modelle) decken die Anforderungen aller relevanten Kommunikationspfade im Gefahrenmeldesystem ab, und ermöglichen die kontrollierte Öffnung gegenüber Dritten. Wir gehen davon aus, dass sich der BACnet Standard in Europa durchsetzen wird und so die Kompatibilität von Systemen innerhalb von Gebäuden entscheidend erhöht wird.

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Automatische Brandschutztechnik und ihr Zusammenwirken mit der Hausleittechnik

Abstract

Reliable working automatic fire protection technique requires automatic fire detecting and reporting systems that are based on different effects of fire.

The detection and or the extinguishing of a fire is only one of several possibilities of automatic fire protection technique. In case of fire also smoke-venting-equipment and fire-protection-doors can be activated or closed e. g.

For more effectiveness in automatic fire protection it is one way to use measurements and also equipment from building facility management to control and activate devices of fire protection equipment or to use certain parts of building facility management equipment for fire protection direct.

The conditions for that are named and the boundaries for their successful use are shown.

Vorbemerkungen

Für zuverlässig funktionierende automatische Brandschutztechnik ist automatische Branddetektion eine unerläßliche Voraussetzung. Durch intensive Entwicklung und Erschließung neuer Detektionsmöglichkeiten wie auch durch die gekoppelte bzw. kombinierte Detektion unterschiedlicher Brandeffekte bis hin zu sich an verändernde Umgebungsbedingungen anpassenden Meldeelementen erfolgte eine Reihe von Entwicklungen, die die Fehlalarm- bzw. Täuschungsalarmquote auf ein solches Maß senkten, daß die Akzeptanz der automatischen Brandentdeckung und ihre daraus erwachsenden Vorteile die möglichen Probleme einer Fehlauslösung deutlich überwogen. Mit der wachsenden Zuverlässigkeit sicherer Detektion eines Brandes entwickelte sich parallel dazu die Palette möglicher automatisch ausgelöster Schutzhandlungen bzw. Vorgänge, die das Ereignis abwenden bzw. so rechtzeitig detektierten, daß ein gezielter Eingriff mit optimaler Wirkung noch vor Eintritt des Schadensereignisses möglich wurde.

Andererseits entwickelte sich mit zunehmender Gebäudegröße und mit wachsenden Anforderungen an die Nutzung der Gebäude vor allem unter dem Aspekt gesteigerter Komfortbedingungen und gezielter Energieökonomie die Hausleittechnik in einer solchen Weise, daß regelnde und steuernde Einflußnahmen auf die Haustechnik nicht mehr die Ausnahme, sondern der Normalfall sind. In dem Maße wie steuernde und regelnde Einflußnahmen möglich wurden, wuchsen auch die Bestrebungen, diese Möglichkeiten zur Havariebekämpfung bzw. zur Begrenzung der Havariefolgen im Brandfall mit zu nutzen. Aus diesen sich ursprünglich getrennt entwickelnden Zweigen erwächst ein System von Informationsverflechtungen und Handlungsfolgen, welches völlig neue Wege auf dem Gebiet der Sicherheitstechnik und der Havariebegrenzung eröffnet.

Automatische Brandschutztechnik

Das Spektrum der automatischen Brandschutztechnik hat sich sowohl von der gerätetechnischen Seite als auch von den zugrunde gelegten Zielfunktionen und Wirkprinzipien erheblich gegenüber den vor längerer Zeit üblichen Elementen „Alarmierung der Feuerwehr“ und „Auslösen von Löschanlagen“ gelöst und unterscheidet sich heute durch eine Vielzahl möglicher weiterer Anwendungsgebiete. Zusätzlich zu den beschriebenen beiden Möglichkeiten gehören heute dazu als unverzichtbare Elemente beispielsweise die Betägigung von Rauch- und Wärmeabzugsanlagen wie auch nach bestimmten Gesichtspunkten und Vorgaben bestimmte Lüfter im Falle eines Brandes außer Betrieb genommen werden bzw. bestimmte Lüfter im Brandfall in Betrieb genommen werden. Dies wiederum kann für die normale lüftungstechnische Anlage innerhalb des Hauses separat bzw. über die ebenfalls separat angeordnete, aber zusätzlich zur normalen Lüftungsanlage vorhandene Rauchableitungsanlage auf maschinell gestützter Basis erfolgen. Hier werden über spezielle Schaltverknüpfungen differenzierte Ansteuerungen von Zuluft- und Ablufttechnik in Betrieb genommen.

Ungehinderte Verkehrs- und Transportprozesse innerhalb von großräumigen Anlagen, häufig verbunden mit flurfreien oder flurgebundenen Förder- und Transportanlagen, führen aus produktionstechnischer Sicht dazu, das Gebäude möglichst ungestört in allen Bereichen und ohne Grenzen nutzen zu können. Dem widerspricht die Schutzabsicht des Besitzers bzw. des Betreibers, der im Falle eines Brandes den Verlust verständlicherweise so gering wir möglich halten will. Die Folge davon ist, daß die im Normalfall gut funktionierende Transporttechnik, die die unterschiedlichen Bereiche und möglichen Brandabschnitte problemlos verbindet, im Havariefall auf den jeweiligen Erstreckungsbereich begrenzt bleibt und die im Nichtbrandfall gewünschte Großräumigkeit im Brandfall wieder in eine sehr wirksame brandschutztechnische Separierung zurückführt. Dies sollte aufgrund der Vielzahl der Öffnungen in brandschutztechnisch qualifizierten Wänden und Decken möglichst automatisch erfolgen, ohne im Falle einer Fehlauslösung in größerem Umfang Rücksetzungsarbeiten betreiben zu müssen. Insofern gehört im direkten bzw. indirekten Umfang der ganze Komplex der Ansteuerung von Transportsystemen und das Schließen von beweglichen Schottungen für Transportsysteme im Havariefall heute zum selbstverständlichen Standard der automatischen Brandschutztechnik. Selbstverständlich gehört es dazu, auch bestimmte Zwangsverriegelungen zu anderen techologischen Prozessen

1. zu kennen
2. zu berücksichtigen und
3. funktionsfähig (im erforderlichen Zeitraum) zu halten.

Ziel ist es in jedem Fall, durch Schutzmaßnahmen auf der einen Seite Folgeschäden auf der anderen Seite durch nicht bedachte technologische Zwangsverriegelungen sicher zu vermeiden.

In die gleiche Richtung aus der Sicht der vorbeugenden Schadensvermeidung funktionieren und gehören Arretierungen von Türen in Offenstellung über zugelassene Arretierungs- und Feststellvorrichtungen, die im Bedarfsfall automatisch aktiviert werden, um Schäden an den sicherheitstechnisch wichtigen Elementen durch unqualifizierte Arretierungen und Blockaden sicher ausschließen zu können.

Andererseits gehört es zum indirekten Kapitel der automatischen Brandschutztechnik, zur Sicherung kurzer Rettungswege im Brandfall bestimmte Türen und Ausgänge zu öffnen, die sonst aus unter „Normalbedingungen“ verständlichen Sicherheitsgründen verschlossen gehalten werden müssen.

Hausleittechnik

Für das Gebiet der Hausleittechnik ist es heute selbstverständlich, neben den klassischen Gebieten Heizung, Lüftung, Klima vor allen Dingen die Bereiche der Energieverfügbarkeit und der Überwachung einer Reihe von technischen Einrichtungen auf Einhaltung von Betriebszuständen und Schaltungszuständen zu ihrem Spektrum und vorzugsweisen Anwendungsgebiet zu zählen. Daneben gehören in erheblichem Umfang Aufgaben der Zeiterfassung , der Einlaßkontrolle, der Zutrittsberechtigung sowie der Ausfahrt- und Auslaßkontrolle dazu. Die Überwachung der Betriebszustände der Aufzüge und der Fahrtreppen sowie gewisser Havariefahrzustände bis hin zu allgemeinen Sicherungssystemen wie Personenüberwachung, Diebstahlschutz und Einbruchschutz gehören ebenfalls mit in den großen Bereich der Hausleittechnik, wenn auch nicht alle Sektoren bei jedem Objekt gnerell bzw. in gleichem Umfang vertreten sind.

Berührungspunkte bzw. Problembereiche

Diese beiden Zweige (automatische Brandschutztechnik und Hausleittechnik) entwickeln sich zunehmend weiter (Umfang und Perfektionierung), wobei ein Ende der Entwicklung sowohl in technischer als auch in anwendungstechnischer Sicht m. E. noch nicht abzusehen ist. Nach einer Reihe von Versuchen, trotz fehlender Reglementierung für die beiden nebeneinander existierenden Wirkungsbereiche nutzbringende Verknüpfungen abzuleiten, ist nunmehr eine zielstrebige Absicht erkennbar, eine Anlagenvereinfachung bei gleichzeitigem Sicherheitsgewinn daraus herleiten zu können. Allerdings sind dabei eine Reihe von Besonderheiten und unterschiedlichen Aspekten zu beachten. Erste Erfahrungen zeigen, daß es bei ungenügender Berücksichtigung der jeweiligen spezifischen Besonderheiten zwischen Brandschutzautomatik und Hausleittechnik zu unerwünschten Effekten kommen kann, so daß gut gemeinte Absichten technisch ins Gegenteil umschlagen oder zu sicherheitstechnisch fragwürdigen Ergebnissen führen, wobei dabei davon ausgegangen werden kann, daß diese Ergebnisse weder beabsichtigt noch gewollt sind, sondern aus der Situation resultieren, daß bestimmte gegenseitige Abhängigkeiten und Verflechtungen nicht berücksichtigt bzw. nicht weit genug in ihren Konsequenzen verfolgt wurden.

Art der Signalverfügbarkeit

Bei der für die automatische Brandschutztechnik unverzichtbaren Brandmeldetechnik werden zwar kontinuierlich Werte gemessen, die Auswertung erfolgt jedoch ausschließlich an Grenzwerten in Form einer Ja- / Nein-Entscheidung, in deren Folge dann bestimmte Handlungen ausgelöst werden. Ort und Zeitpunkt der zur Auslösung führenden Impulse sind im Brandfall selbstverständlich nicht vorhersehbar, eine Vorwarnstufe ist üblicherweise technisch bzw. sicherheitstechnisch nicht verwertbar, obwohl sie bei entsprechender Kriterienauswahl nachweisbar sein dürfte.

Die für die Gebäudeleittechnik verfügbaren Signale werden gleitend verfolgt und geben über ihren Verlauf vor Erreichen bestimmter Grenzwerte Auskunft über ggf. einzuleitende Maßnahmen. Für diese Fälle existieren Verhaltensmuster und Lösungsschemata, die aus theoretischem Training abgeleitet werden können und durch praktische Erfahrungen unterstützt und geprägt sind.
Dies ist darin begründet, daß für die Hausleittechnik die Signale üblicherweise Ursache / Anlaß zu steuerbaren und steuerungsfähigen Handlungen sind, während für den automatischen Brandschutz das Signal in Form einer Ja- / Nein-Entscheidung vorprogrammierte feste Abläufe in Bewegung setzt, die kaum bzw. nicht mehr steuerbar sind.
So störend dies auf den ersten Blick erscheinen mag, so ist doch die Berechtigung für diese unterschiedliche Verfahrensweise darin begründet, daß für normale Regel- und Steuerprozesse ausreichende Zeit (u. U. auch für Korrekturen) zur Verfügung steht, während im Havariefall diese Zeit nicht zur Verfügung steht, sondern die Abläufe in einer im Verhältnis zur Hausleittechnik extrem kurzen Zeitfolge vor sich gehen (müssen).

Umfang und Ort der Verfügbarkeit

Ein weiterer wesentlicher Unterschied ergibt sich dadurch, daß im Bedarfsfall für die Haus- bzw. Gebäudeleittechnik die Meßwerte aus dem gesamten Haus permanent zu ggf. komplex abgestimmten Vergleichs- und Steuerzwecken zur Verfügung stehen. Kritische oder Steuerungsvorgänge auslösende Zustände kündigen sich demzufolge an und werden entsprechend großflächig erfaßt bzw. so erkannt, daß ein ausreichender Zeitraum zur Reaktion zur Verfügung steht. Für den Bereich der Brandschutzautomatik ist dieser Zeitraum nicht verfügbar. Darüber hinaus ist für diesen zweiten Bereich der Brandschutzautomatik festzustellen, daß die verfügbaren Signale nur punktuell auftreten und sich keinesfalls über eine größere Fläche in Form einer sich ankündigenden Meßwertentwicklung anzeigen. Dem vermeintlichen Nachteil der nicht flächigen Überwachung steht der Vorteil der punktuellen Anzeige in der Weise gegenüber, daß damit eine genaue Lokalisierung des Schadensortes möglich ist. Während sich also für die Gebäudeleittechnik das gesamte Haus in permanenter Überwachung und Kontrolle befindet und somit die Möglichkeiten der Einflußnahme auf das gesamte Haus gegeben sind, ist es im Zusammenhang mit Signalen aus der automatischen Brandschutztechnik nur möglich, eng begrenzte Bereiche zu erfassen und dort bestimmte Schutzmaßnahmen auszulösen.

Diese Begrenzung auf eng begrenzte Bereiche wie Brandabschnitte oder Brandbekämpfungsabschnitte bzw. bis auf Einzelräume kann insofern für die Brandschutzautomatik positiv verwertet werden, als es möglich ist, über andere Bereiche gezielt Maßnahmen auszulösen, ohne daß sich dort bereits das Schadensereignis manifestiert hat. So ist es beispielsweise ohne weiteres möglich, vom Schadensort entfernt liegende Schutzvorrichtungen zu aktivieren, ohne daß eine entsprechende Schadensentwicklung am Ort nachweisbar ist.

Priorität der Signale

Bei Umsetzung der zweckmäßigen und künftig auch nicht vermeidbaren Absicht, Elemente der Hausleittechnik in sinnvoller Weise mit Elementen der Brandschutzautomatik zu verknüpfen, um Effektivitätssteigerungen zu bewirken, ist es unerläßlich, nachhaltige Gedanken zur Priorität der Signale anzustellen. So dürfte es sicherlich unstrittig sein, daß Signale zur Sicherung des Brandschutzes Priorität gegenüber den Signalen der Komfortbedingungen erlangen. Damit müßte es möglich sein, z. B. für den Fall, daß eine lüftungstechnische Anlage auch zur Rauchableitung aus einem Gebäude mit eingesetzt wird, jeglichen aktuellen Betriebszustand, der aus energieökonomischen oder sonstigen hygienischen Bedingungen eingehalten wird, bei Auftreten eines Brandsignales zu verlassen und die Anlage auf einen reinen sicherheitsorientierten Betriebszustand umzuschalten bzw. zu fahren. Daß dies natürlich die Grenzen der Leistungsfähigkeit der Anlage erreichen kann, sei als selbstverständlich dahingestellt.

Andererseits ist es offensichtlich rechtlich nicht vertretbar, Signale zur Sicherung des Sachschutzes über die Signale der Sicherung des Personenschutzes zu stellen und entsprechende Handlungen auszulösen. Hier ist Handlungsbedarf auch in juristischer Art erforderlich, um eindeutige Interessenabwägungen und Grenzen der Prioritätensetzung aufzuzeigen. So ist es beispielsweise nach aktueller Rechtslage nicht denkbar - sofern in einem Bereich, in dem diebstahlgesicherte Objekte aufbewahrt werden und gleichzeitig auch Brandmelder installiert sind - bei gleichzeitigem Auftreten von Brandalarm und Diebstahlalarm die Türen verschlossen zu halten, um sicherzugehen, den Dieb bzw. die Person mit unbefugter Handlungsabsicht am Verlassen des Gebäudes zu hindern. Hier hat der Personenschutz Priorität und der Sachwertschutz hat dahinter zurückzutreten, d. h. konkret, die Türen sind von ihrer Zwangsverriegelung freizustellen. Andererseits ist sicherzustellen, daß bei

Fehl- / Täuschungsalarm das Objekt nicht für jedermann unkontrolliert zugängig wird.

Technische Realisierung

Die Probleme der technischen Realisierung gestalten sich naturgemäß komplizierter als es auf den ersten Blick erscheint. Während es für die Hausleittechnik in ihrer bestimmungsgemäßen Nutzung sicherlich Komforteinbußen bei zeitlich befristetetem Energieausfall gibt, der jedoch zu keinem bedrohlichen Zustand in irgendeiner Form führen muß, so ändert sich diese Situation schlagartig, wenn die Hausleittechnik und die von ihr betreuten technischen Anlagen für brandschutztechnische Zwecke Verwendung finden sollen. Die Fragen der gesicherten Energieversorgung sowohl für die Meldetechnik als auch für die Betriebstechnik zur bestimmungsgemäßen Nutzung - allerdings dann unter dem Aspekt des Brandschutzes - erlangen somit einen völlig veränderten Stellenwert. Die daraus resultierende ggf. nicht unerhebliche Kostensteigerung zur Sicherung der Energie unter allen Betriebszuständen setzt im Augenblick noch Grenzen für die uneingeschränkte Kombination von Brandschutzautomatik und Gebäudeleittechnik.

Dies gilt gleichermaßen auch für die Baustoffauswahl für bestimmte Einrichtungen, die von der Gebäudeleittechnik versorgt werden. Während unter Normalbedingungen die Baustoffauswahl nach reinen Komfortbedingungen gewählt werden kann, wird es erforderlich, diese Elemente, sofern sie für brandschutztechnische Zwecke Verwendung finden sollen, auf entsprechende Temperaturstabilität auszulegen und die Energieversorgung entsprechend gesichert auszuführen. Dies gilt vor allem dann, wenn die Energie nicht nur in elektrischer Form zur Verfügung stehen muß, sondern auch als Hydraulik oder Pneumatik verwendet wird.

Zusammenfassung

Die automatische Brandschutztechnik hat einen entsprechenden Entwicklungsstand erreicht. Gravierende Neuentwicklungen sind im Gegensatz zu Verfeinerungen der Wirk- und Detektionsmethoden in absehbarer Zeit vermutlich nicht zu erwarten. Die Entwicklungen in der Vergangenheit haben aufgezeigt, daß es Grenzen gibt, die mit vertretbarem Aufwand nicht wesentlich weiter ausgedehnt werden können. Der Nutzen aus diesem Aufwand muß in angemessenen Relationen dazu bleiben. Insofern sind eher Entwicklungen zu erwarten, die sich aus Rückkopplungen aus dem Bereich der Gebäudeleittechnik ergeben.

Die Entwicklungen auf dem Gebiet der Gebäudeleittechnik lassen andererseits erwarten, daß sich hier noch größere Veränderungen abzeichnen. Der bisher erreichte Stand der Verknüpfung zwischen Brandschutzautomatik und den Möglichkeiten der Gebäudeleittechnik dürfte noch nicht das Ende der Entwicklung charakterisieren. Bei konsequenter Entwicklung der technischen Möglichkeiten und sicherer Ausschaltung von Störfaktoren dürften hier noch größere Reserven erschließbar sein.

Multivalente Nutzung bestimmter Einrichtungen bis hin zu Verbesserungen der Energieversorgungssicherheit stecken den Rahmen der künftigen Entwicklung ab.

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Eine informationstechnische Multifunktionsplattform für heterogene Haussysteme

Abstract

One trend in our homes is that more and more components are equipped with „local intelligence", that means intelligence embedded in sensors, actuators and microcontrollers. If the components will be able to communicate together, new functionalities with more safety, comfort and less wasting of energy are possible. Such a system that consists of components communicating together we call an „integrated Home System". While an increasing degree of domestic homes will be equipped with standard communication-infrastructures like EIB, ISDN, RF- and broadcast-networks, alarm systems will even use home system networks in future for a better detection of dangerous situations. Therefore it is necessary to define interface standards between products of different manufacturers and get experiences with reliability of applications that based on different communication systems. To support research and development activities in the field of home automation we create the „InHaus"-project. The aim of the project is to bring different manufacturers in contact to each other, enabling them to achieve interworking standards, create common configuration procedures and test the reliability of new applications that are based on heterogenous networks.

Zusammenfassung

In der Haustechnik findet zur Zeit ein Übergang von Geräten mit lokaler Intelligenz zu netzwerkfähigen Geräten mit standardisierten Kommunikationsinterfaces statt. Damit verbunden ist, daß Wohngebäude mehr und mehr mit Kommunikations-Infrastrukturen ausgerüstet werden, die die Grundlage für neuartige

Funktionalitäten darstellen. Beispiele für Kommunikations-Infrastrukturen sind EIB, ISDN, Breitband-Verkabelung aber auch Funk-Netzwerke und Powerline-Datenübertragung.
Gefahrenmeldeanlagen (GMA) für die Einbruchs- und Branderkennung stützen sich bisher im wesentlichen auf proprietäre Kommunikationsnetzwerke. In Zukunft ist davon auszugehen, daß die o.g. Kommunikations-Infrastrukturen verstärkt auch für die Übertragung von Statusinformationen der Gefahrenmeldeanlagen genutzt werden. Gerade der Mehrfachnutzen der Infrastruktur bietet die Gelegenheit, GMA-Funktionalität als „Add-On" in heterogene Haussysteme zu integrieren. Aufgrund der Zugriffsmöglichkeit auf eine breitere Informationsbasis, nämlich den Statusinformationen aller an der Infrastruktur angeschlossenen Sensoren und Geräte lassen sich Gefahrensituationen einfacher erkennen und möglicherweise auch Fehlalarme reduzieren. Konzepte zukünftiger GMA sollten die neuen Möglichkeiten berücksichtigen. Den neuen Möglichkeiten stehen bislang offene Fragen bzgl. der Sicherheit, Zertifizierbarkeit und Praxistauglichkeit (wie werden die Systeme in ein Gesamtkonzept einbezogen, wer installiert diese Systeme, wer trägt die Verantwortung bei Fehlfunktionen?) entgegen. Es ist zu vermuten, daß auch der VDS diese Installationen in Zukunft auch für höhere Sicherheitsanforderungen zulassen wird, wenn durch technische Weiterentwicklungen die Praxistauglichkeit nachgewiesen wird. In Duisburg entsteht ein Gebäude, das mit einer Entwicklungsplattform für integrierte Haussysteme ausgestattet ist (InHaus-NRW). Die vielfältigen Untersuchungsmöglichkeiten dieser Plattform lassen sich auch zur Klärung der zur Zeit noch offenen Fragenstellungen bzgl. der Kopplung von GMA-Funktionalitäten und integrierten Haussystemen nutzen.

Architekturen zukünftiger integrierter Haussysteme

In einem integrierten Haussystem (hier abgekürzt mit IHS) sind wesentliche Geräte und Subsysteme so miteinander vernetzt, daß zwischen ihnen bestimmte Informationen zur Bedienung, Zustandsabfrage etc. ausgetauscht werden können (Abb. 1).

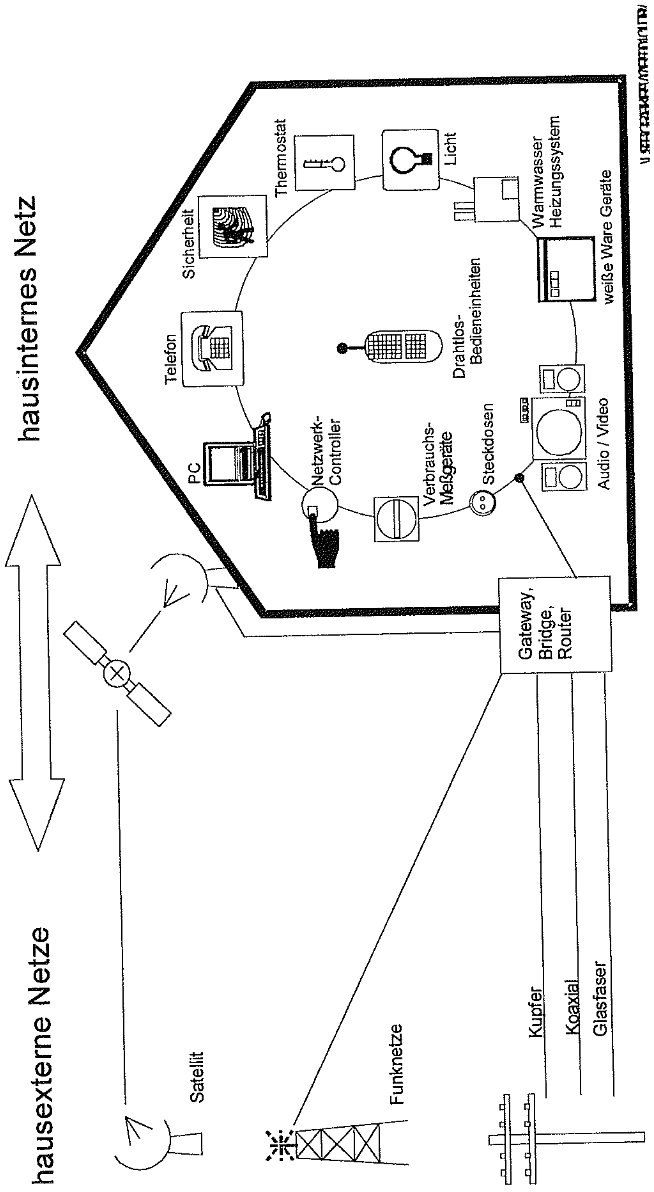

Abb. 1: Prinzip Integriertes Haussystem

Die Anforderungen an die Kommunikation zwischen den Geräten hängt dabei von den jeweiligen Anforderungen ab. Während für steuer- und regelungstechnische Anwendungen meist geringe Datenmengen unter niedrigen Echtzeitanforderungen ausgetauscht werden, sind für die Bild- und Tonübertragung große Datenmengen unter hohen Echtzeitanforderungen zu transportieren. Mobile Einheiten wie z.B. Drahtlos-Telefone werden zukünftig in die jeweiligen Anwendungs-Szenarien einbezogen werden. Eine wichtige Rolle spielt die Möglichkeit, Informationen zwischen den internen und externen Netzen auszutauschen.
Die unterschiedlichen Anforderungen an die Kommunikation lassen erwarten, daß es auf absehbare Zeit im Hausbereich verschiedene Kommunikationssysteme geben wird. Neben den existierenden Hausbussen (EIB, Batibus, LON) werden zukünftig Multimedia-Kommunikationssysteme (ISDN, Ethernet, Firewire, USB, IrDA) stärker als bisher in die Anwendungsszenarien einbezogen. Für die Nachrüstung bestehender Gebäude wird Funk eine wesentliche Rolle spielen. Zur Kopplung von internen und externen Netzen stehen im wesentlichen neben der analogen Telefonie ISDN und GSM zur Verfügung. Daneben laufen Versuche, Power-Line für diesen Informationsaustausch zu verwenden.

Den Anwendungen in integrierten Haussystemen lassen sich schwerpunktmäßig verschiedene Kommunikationssysteme zuordnen. So werden meß-, steuer und regelungstechnische Applikationen überwiegend über Hausbusse, Applikationen mit einem Schwerpunkt auf der Bild- und Tonübertragung über Multimedia-Busse abgewickelt. Die GMA werden entweder aufgrund der Sicherheitsanforderungen zunächst über ein eigenes Subnetz mit Übergängen zum integrierten Haussystem verfügen, es werden zukünftig aber auch verstärkt GMA-Funktionalitäten unter Nutzung der verschiedenen Kommunikationsmöglichkeiten realisiert. Der Zugang zu externen Netzen ist für eine Reihe von Applikationen interessant (z.B. Weiterleitung von Alarmen, Fernauslesung von Energiezählern bis hin zum Fernwirken). Gleichwohl wird dieser Zugang vermutlich nur einmal vorhanden sein, so daß eine Abstimmung bzgl. der Nutzung erforderlich ist.
Daraus folgt, daß integrierte Haussysteme vor allem heterogene Systeme sein werden, in denen die Schnittstellen der verschiedenen Geräte untereinander

abgestimmt sind und in denen ein einfacher Informationsaustausch zwischen den verschiedenen Subsystemen möglich ist.

Trends und Entwicklungsbedarf in integrierten Haussystemen

Weltweit wurden wegen des enormen Marktpotentials der IHS-Technologie vor allem von großen Firmen bereits große Investitionen in die Entwicklung von Basistechnologien getätigt, wie

- Hausbusprotokolle und zugehörige Buskoppler (z.B. EIB, EHS, LON, Batibus);
- Anbindung der Haushalte an geeignete externe Netze (z.B. ISDN, Datenfunk, Power-Line Übertragung);

Diese stehen zum Aufbau von integrierten Haussystemen weitgehend zur Verfügung bzw. werden zur Zeit weiterentwickelt. Zur Erschließung der Marktpotentiale, die in der IHS-Technologie liegen, fehlen vielen Firmen ausreichende Erfahrungen mit den Vernetzungstechnologien und der Konfiguration von gewerkeübergreifenden Systemen. So ist bisher nur ein geringer Teil der von den mittelständischen Firmen gefertigten Produkte hausbusfähig und erfüllt damit die Voraussetzung für die Kommunikation in integrierten Haussystemen. Darüber hinaus besteht in Fragen der Standardisierung und eines übergreifenden modularen Systemkonzepts noch Forschungs- und Entwicklungsbedarf. Auch zu berücksichtigen ist, daß zur Zeit neue Möglichkeiten der hausexternen Kommunikation (ISDN, Mobilfunk, Datenfunk, leistungsfähige Breitbandkommunikation („Datenautobahn")) entstehen, die ebenfalls neue Anwendungen im Hausbereich ermöglichen. Hier ist zu ermitteln, welche Anforderungen daraus an die Architektur integrierter Haussysteme (speziell der internen Kommunikation) resultieren.

Die technische und strategische Grundlage für die benötigten kommunikationstechnischen IHS-Infrastrukturen sind breit am Markt etablierte Kommunikationssysteme (de-facto-Standard) und eine offene Systemplattform für die Implementierung von Anwendungen. Die mittelständischen Firmen müssen sich aktiv an den Entwicklungen in diesen Bereichen beteiligen, damit die sich etablierenden Standards offen sind und damit genügend Potential für die Einbindung der eigenen Produkte und Dienstleistungen bieten. Wegen der hohen Vorlaufzeiten bis zur Entwicklung marktfähiger Produkte ist eine abwartende Haltung auf dem Gebiet der IHS-Technologie mit erheblichen Risiken verbunden. Die ersten Firmen, die erfolgreiche Anwendungen im IHS-Bereich entwickeln und am Markt etablieren, setzen de-facto Standards und besitzen neben dem technologischen Vorsprung einen großen strategischen Wettbewerbsvorteil (Image, "time to market"). Gerade für die qualitativ hochwertigen Geräte mit hohen Wertschöpfungen, wird es in Zukunft immer wichtiger, daß sie sich in IHS einbinden lassen. Daher ist jetzt der strategisch richtige Zeitpunkt, sich intensiv mit den Möglichkeiten der IHS-Technologie auseinanderzusetzen.

Zur Entwicklung innovativer Haustechnik-Produkte ist vor allem zu klären, wie der reibungslose Informationsaustausch zwischen Geräten und verschiedenen Kommunikationssystemen organisiert werden kann und welche Anwendungen mit einem hohen Nutzen/Kosten-Verhältnis sich bereits heute oder in naher Zukunft realisieren lassen. Wesentliche Anwendungsgebiete sind Erhöhung von Komfort, Sicherheit und Einsparung von Ressourcen durch optimierte Gerätesteuerung. Insbesondere die Sicherheitsfunktionen wie Einbruchserkennung, Branddetektion oder Warnung bei Gasleckage spielen bei der Motivation, eine Wohnung oder ein Gebäude mit einem Haussystem auszurüsten, eine wesentliche Rolle.

Das InHaus-NRW-Projekt

Um die Entwicklung der erforderlichen Integrationstechnologien zu erleichtern, errichtet das IMS ein Gebäude, das mit einer Test- und Evaluierungsplattform für

Integrierte Haussysteme ausgestattet ist. Die Ausstattung des Gebäudes wurde in Kooperation mit Firmen aus dem Bereichen

- Heizungstechnik
- Hausgerätetechnik
- Energielieferung und -abrechnung
- Installationstechnik
- Sicherheitstechnik
- Telekommunikation
- Kommunikationstechnik
- Wassertechnik
- Lichttechnik

geplant und ermöglicht die schnelle Realisierung neuartiger Funktionalitäten von integrierten Haussystemen. Sie enthält die für die Entwicklung von integrierten Haussystemen relevanten Kommunikationsmöglichkeiten (EIB, ISDN, Ethernet etc.) und die Geräte der am Projekt beteiligten Firmen. Bestehende, z.Teil nicht netzwerkfähige Geräte können unter Verwendung eines vom Fraunhofer-Institut Mikroelektronische Schaltungen und Systeme entwickelten Multifunktionsmoduls ohne große Modifikationen an die InHaus-Kommunikationssysteme angeschlossen werden. Das Modul kommuniziert mit nicht netzwerkfähigen Geräten über deren proprietäre Schnittstelle für Test- und Wartungszwecke und konvertiert die dort verfügbaren Statusinformationen Nachrichtenobjekte, die über Standard-Kommunikationssysteme übertragen werden können. Die Statusinformationen der Geräte, Sensoren und Aktoren werden in einer Datenbank gespeichert, die sich für den Informationsaustausch zwischen den Geräten, aber auch zur Fernabfrage nutzen läßt. Abb. 2 zeigt die Architektur der InHaus-Plattform.

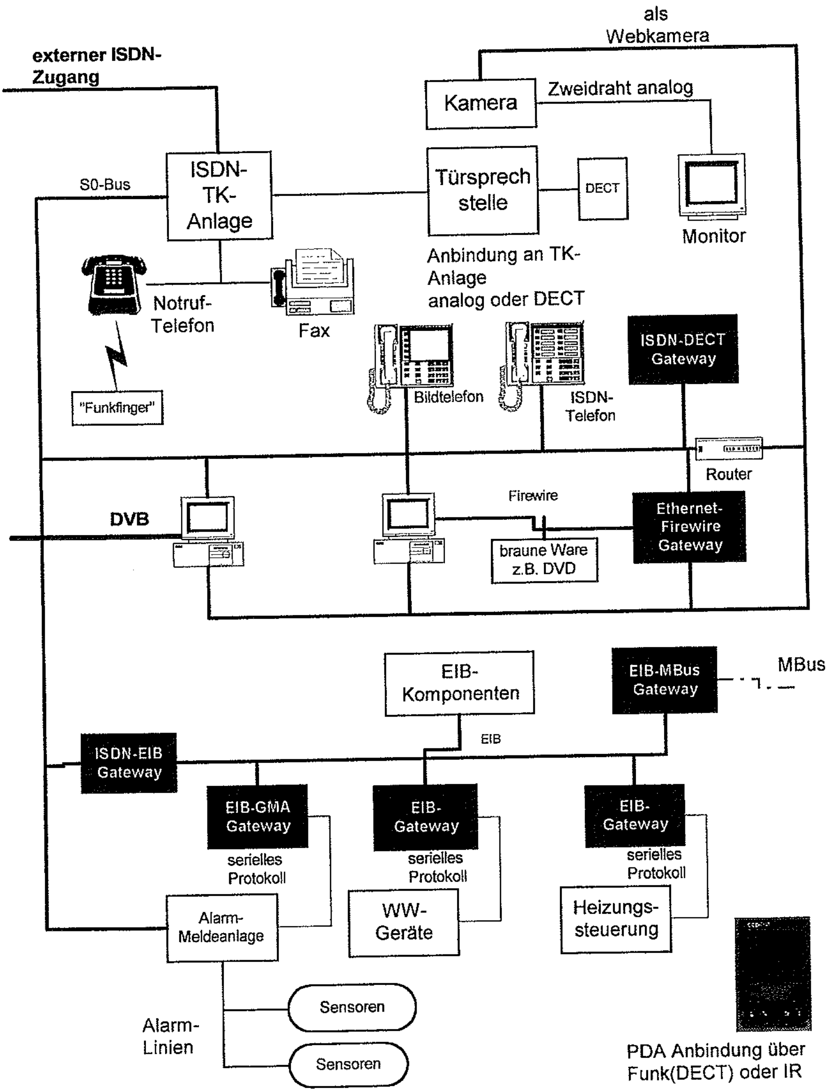

Abb. 2: Architektur der InHaus-Plattform

Das Konzept erlaubt es den Projektbeteiligten, zunächst weitgehend auf bereits bestehenden Produkten aufzusetzen und den Fokus auf die Entwicklung von neuartigen Funktionalitäten zu legen. Beispiele sind:

- Heizungs- und Lüftungsmanagement
(z.B. automatisch nutzungsadaptive kombinierte Einzelraum-Heizungs-Lüftungs-Regelung mit Einbeziehung von Gebäudeparametern und aktuellen und vorhergesagten Wetterdaten);

- automatische Raum- und Personenüberwachung
(z.B. Intrusionsschutz durch Netzwerk von Anwesenheitssensoren, hiermit auch Überwachung von zeitlich-räumlicher Plausibilität von Bewegungsprofilen von Personen zur Sturzdetektion; Einbeziehung der Brand- und Wasserschadens-Sensorik)

- Energiemanagement
(z.B. Erfassen und Steuern der Einschaltzeiten und der Energieaufnahme von Elektrogeräten in Kombination mit Daten des EVU inkl. spot-pricing)

- Wassermanagement
(z.B. Minimierung des Trinkwasserverbrauchs durch Management von getrennten Kreisläufen von Brauch-, Ab- und Trinkwasser; Sensorik zur Wasserqualität)

- Kommunikation und Unterhaltung
(z.B. Telefon, TV, Internet und In-Haus-Kommunikation über ein transparentes Netz mit Multimediafähigkeit)

Das Gebäude und die darin enthaltene Entwicklungsplattform soll im August 1999 in Betrieb gehen und steht dann den Projektbeteiligten für die Entwicklung von neuen Produkten und Dienstleistungen im Bereich der integrierten Haussysteme zur Verfügung.

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Einsatz des Europäischen Installationsbusses in der Sicherheitstechnik

Abstract

The European Installation Bus (EIB) is an open international communication standard. It is used for monitoring, control and data exchange in installations for lighting, sun protection, heating, ventilation, air conditioning, energy management, intrusion and fire detection, as well in commercial and industrial as in residential buildings. Special features of the EIB system technology have been develloped to fullfill the demands of intrusion and fire detection applications. So large central stations for alarm systems can be replaced by a set of small devices with distributed intelligency, networked by the EIB.

Von der Elektroinstallation zur Gebäudesystemtechnik

Der Wunsch nach immer größerem Komfort, höherer Sicherheit und mehr Energieeinsparung erfordert einen immer höheren Installationsaufwand, da hierzu elektrische Energie an immer mehr Stellen benötigt wird. Eine konventionelle Elektroinstallation führt dann, in Verbindung mit den zusätzlichen Steuerleitungen für die Meß-, Steuer- und Regeltechnik der Ver- und Entsorgungseinrichtungen in Gebäuden, zu einem regelrechten Kabelgewirr, das bei Störungen und Nutzungsänderungen nur schwer überschaubar ist, dessen Installation mit hohem Platzbedarf und hohen Kosten verbunden ist und das entsprechend hohe Folgekosten verursachen kann.

Bei der Gebäudesystemtechnik auf Basis des "Europäischen Installationsbus (EIB)" werden die Übertragung von Energie und Information klar getrennt (s. Bild 1). Die Energieleitung wird ohne Umwege direkt zu dem Verbraucher bzw. zu dem im Verbraucher oder in seiner unmittelbaren Nähe installierten Fernschalter (Aktor) geführt. Alle Steuergeräte (Sensoren) und alle Fernschalter (Aktoren) sind an den Installationsbus EIB angeschlossen und tauschen ereignisgesteuert Informationen miteinander aus.

So werden bis zu 60% der Leitungen eingespart und die Brandlast entsprechend reduziert. Die Elektroinstallation wird wieder überschaubar. Sie läßt sich einfacher planen und ausführen sowie später, bei Nutzungsänderungen oder Änderungen der Raumaufteilung, problemlos anpassen und erweitern, vielfach ohne daß Leitungen neu verlegt werden müssen.

Mit einer zeitgemäßen und zukunftsicheren Elektroinstallation in standardisierter EIB-Technik werden außerdem sowohl im Zweckbau als auch im Privathaus die Voraussetzungen für eine Gebäude- bzw. Haus-Automation geschaffen.

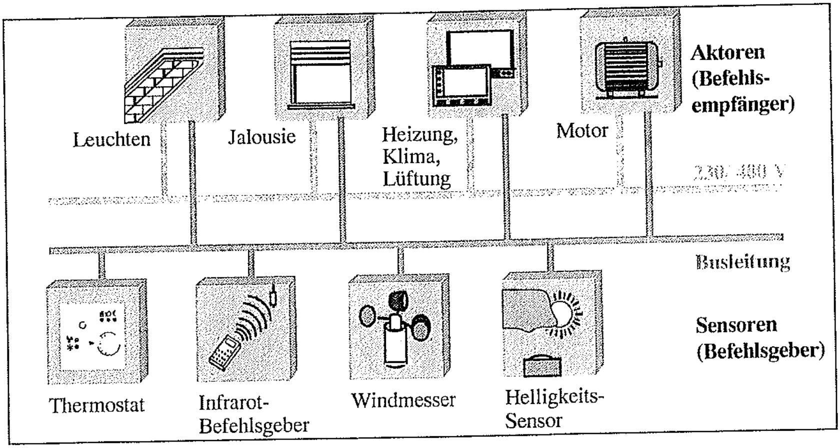


Bild1. EIB mit getrennter Übertragung von Energie und Information

Kompatibilität und Interoperabilität

Kennzeichnend für die konventionelle Elektroinstallation ist die Austauschbarkeit (Kompatibilität) von Installationsgeräten und das problemlose Zusammenarbeiten (Interoperabilität) von Installationsgeräten unterschiedlicher Hersteller.

Diese Wahlfreiheit muß natürlich auch bei einer Elektroinstallation in Bus-Technik gewährleistet sein. Beim EIB wurde daher von Anfang an darauf geachtet, daß Kompatibilität und Interoperabilität von EIB-Geräten sichergestellt sind. Dies zu gewährleisten ist eine der Hauptaufgaben der EIBA, der "European Installation Bus Association" mit Sitz in Brüssel. In ihr sind heute über 110 Hersteller zusammengeschlossen (s. Bild 2). Jedes neue Produkt muß von einem neutralen Prüflabor getestet werden. Erfüllt es die strengen technischen Anforderungen (z.B. die EMV-Klassifizierung) und ist die Bus-Schnittstelle in Hardware und Software EIB-konform, so erhält das Gerät die Zertifizierung und darf das EIB-Logo als Qualitäts-Merkmal führen. Die strengen Anforderungen an Kompatibilität und Interoperabilität beim EIB ermöglichen außerdem, daß anstelle inkompatibler Einzelsysteme für die Steuerung von Beleuchtungs-, Beschattungs-, Heizungs-, Lüftungs- und Klima-Anlagen sowie von Systemen zur Raum- und Gebäudeüberwachung nunmehr Produkte eingesetzt werden können, die alle an eine gemeinsame Busleitung, den EIB, anschließbar sind. So können Sensoren und Steuergeräte mehrfach genutzt, Investitions- und Betriebskosten gesenkt werden.

European Installation Bus Association

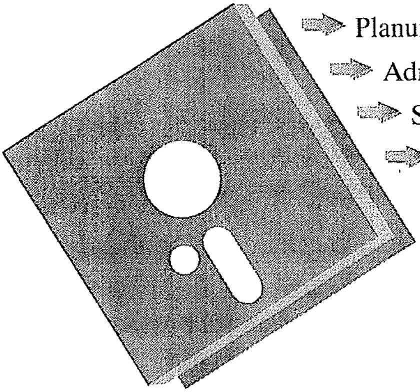
abgekürzt: EIBA,
eine Genossenschaft nach belgischem Recht,
gegründet am 8. Mai 1990 mit Sitz in Brüssel

Warenzeichengemeinschaft
Ziel: internationale Verankerung des EIB als Gütesiegel

Bild 2. European Installation Bus Association

Zur Planung, Parametrierung, Inbetriebnahme, Test und Dokumentation von EIB-Projekten steht den Anwendern ein standardisiertes, herstellerneutrales Software-Werkzeug, die EIB Tool Software (ETS) zur Verfügung (s. Bild 3).
Die herstellerneutrale Tool-Software ETS stellt sicher, daß ein Anwender nur einmal in Anschaffung und Schulung investieren muß, daß Produkte verschiedener Hersteller mit demselben Tool geplant und in Betrieb genommen werden können und daß auf einer Baustelle Mitarbeiter verschiedener Firmen und Gewerke einerseits unabhängig voneinander arbeiten, andererseits aber Projektdaten untereinander austauschen und in eine gemeinsame Projekt-Datenbank einbringen können.
Das Bindeglied zwischen der herstellerneutralen Tool-Software ETS und den herstellerspezifischen Produkten ist die Produkt-Datenbank, der "elektronische Katalog" eines Herstellers.

Unterstützung durch die ETS (EIB-Tool-Software)
bei allen Arbeitsschritten:



⇨ Planung und Projektierung

⇨ Adressierung und Inbetriebnahme

⇨ Systemanpassung im Betrieb

⇨ Wartung

Bild 3. EIB Tool Software

Auf einer Diskette oder einer CD speichert ein Hersteller die Angaben, welche EIB-Produkte und zugehörigen Applikationsprogramme, die ein Installateur dann nur noch parametrieren muß, er anbietet. Eine Produkt-Datenbank muß von der EIBA zertifiziert werden um sicherzustellen, daß sie nur zertifizierte Produkte enthält. Eine nicht zertifizierte Produktdatenbank und somit auch nicht zertifizierte Produkte können mit der ETS nicht bearbeitet werden.

Entwicklung der Gebäudesystemtechnik

Mitte der Achtziger Jahre wurde mit der Entwicklung der Gebäudesystemtechnik begonnen. Mit der Gründung der EIBA im Mai 1990 trat der EIB ins Rampenlicht der Öffentlichkeit. Die ersten serienmäßigen Busgeräte waren ab Juni 1991 lieferbar. Anfang 1992 gingen die ersten Gebäude mit EIB-Installation in Betrieb. Inzwischen sind allein in Deutschland mehrere zehntausend Gebäude, von privaten Einfamilienhäusern bis zu Gebäudekomplexen, mit dem EIB installiert worden.

Die Produkt-Vielfalt hat sprunghaft zugenommen. Bei der EIBA sind inzwischen über 2500 Produktgruppen mit über 5000 Geräten mit EIB-Schnittstelle registriert bzw. zertifiziert worden. Auf dem Markt findet inzwischen ein reger Wettbewerb statt.

Während sich die Anbieter von EIB-Geräten in der Phase der Markteinführung auf den Zweckbau konzentrierten, wird seit einigen Jahren der Wohnbau als weiteres Einsatzgebiet erschlossen. Welche Möglichkeiten ein "Home Elektronik System (HES)" auf Basis des EIB bietet, wurde erstmals auf der DOMOTECHNIKA im Februar 1995 in Köln öffentlich gezeigt.

Topologie des EIB

An die kleinste Einheit des EIB-Systems, eine "Linie", können bis zu 64 busfähige Geräte (Teilnehmer) angeschlossen und an ihr betrieben werden. Mit Linienkopplern, die an die sogenannte "Hauptlinie" angeschlossen werden, können bis zu 15 Linien zu einem Bereich zusammengebunden werden (s. Bild 4). Bis zu 15 Bereiche können über Bereichskoppler, die an die sogenannte "Bereichslinie" angeschlossen werden, zu einer größeren Einheit zusammengefaßt werden. Die Linien-/Bereichskoppler realisieren die notwendigen Filter- oder Routingfunktionen.

An die Bereichslinie können auch die Schnittstellengeräte (Gateways) zu Fremdsystemen (ISDN, Gebäudeautomation, Brandmeldeanlage, usw.) oder zu weiteren EIB-Systemen angeschlossen.

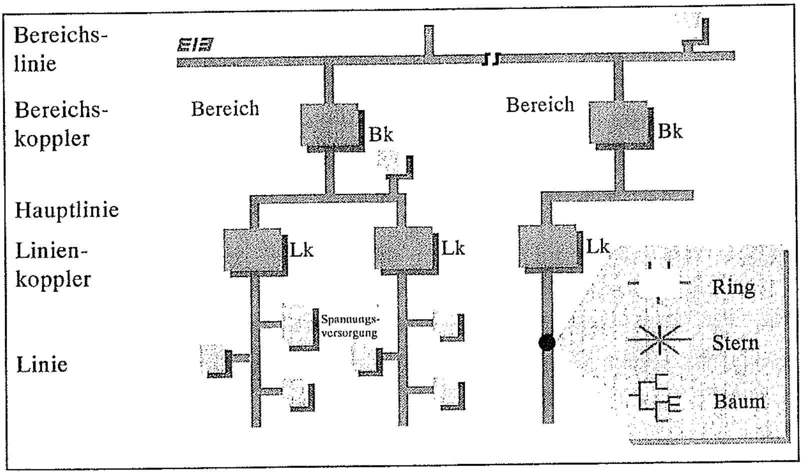


Bild 4. Topologie des EIB

Übertragungstechnik

Der EIB ist ein dezentrales, ereignisgesteuertes Bussystem mit serieller Datenübertragung zum Steuern, Überwachen und Melden betriebstechnischer

Funktionen. Über einen gemeinsamen Übertragungsweg, die Busleitung, können alle angeschlossenen Busteilnehmer Informationen austauschen. Die Datenübertragung erfolgt seriell und nach exakt festgelegten Regeln (dem Busprotokoll). Dabei wird die zu übertragende Information in ein "Telegramm" verpackt und über den Bus von einem Sensor (Befehlsgeber) zu einem oder mehreren Aktoren (Befehlsempfängern) transportiert. Jeder Empfänger quittiert bei erfolgreicher Übertragung den Empfang des Telegramms. Bleibt diese Quittierung aus, wird die Übertragung bis zu dreimal wiederholt. Wird das Telegramm dennoch nicht quittiert, wird der Sendevorgang abgebrochen und der Fehler im Speicher des Senders vermerkt.

Die Übertragung beim EIB erfolgt nicht galvanisch getrennt, da die Versorgungsspannung (DC 24 V) für die Busteilnehmer über dasselbe Adernpaar mit übertragen wird. Die Telegramme sind dieser Gleichspannung aufmoduliert (s. Bild 5), wobei eine logische Null als Impuls übertragen wird. Das Ausbleiben eines Impulses wird als logische Eins interpretiert.

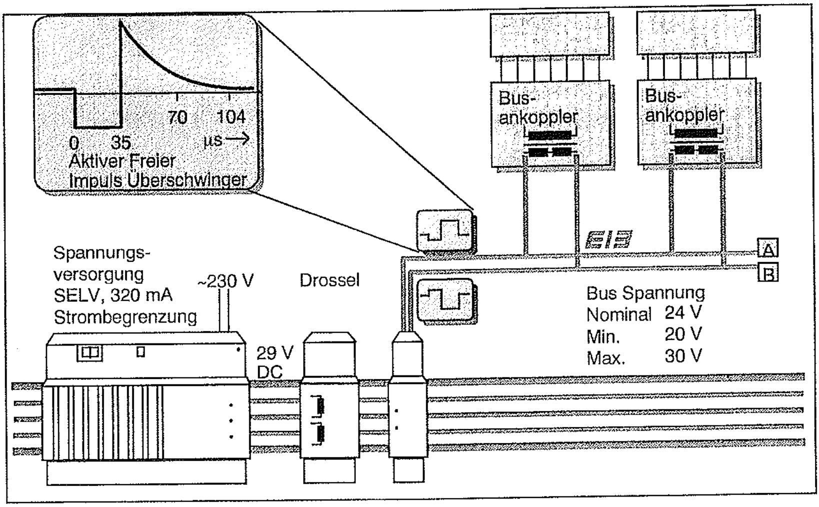


Bild 5. Datenübertragung beim EIB

Die einzelnen Daten der Telegramme werden asynchron übertragen. Durch Start- und Stop-Bits wird die Übertragung jedoch synchronisiert. Für den Zugriff auf den Bus wird beim EIB das CSMA/CA-Verfahren verwendet.

Jede Linie benötigt ihre eigene Spannungsversorgung für die Teilnehmer. Damit wird gewährleistet, daß auch bei Ausfall einer Linie das restliche EIB-System funktionsfähig bleibt. Die Spannungsversorgung versorgt die einzelnen Teilnehmer der Linie mit SELV (Schutzkleinspannung) DC 24 V und kann je nach Ausführung mit 320 mA oder 640 mA belastet werden. Sie besitzt sowohl Spannungs- als auch Strombegrenzung und ist damit kurzschlußfest. Für sicherheitstechnische Anwendungen gibt es gepufferte Spannungsversorgungen.

Die Systemdaten sind in Bild 6 zusammengefaßt wiedergegeben.

- Zweidraht-Übertragung mit Fernspeisung der Busgeräte (24 V DC-SELV, 320/640 mA)
- Geringe Stromaufnahme der Busgeräte (<10 mA, 5V)
- Freie Verdrahtungstopologie/kein Abschlußwiderstand
- Leitungslänge 1000 m pro Linie, Übertragungsreichweite 700 m
- Symmetrische Basisband- Übertragung
- Übertragungsgeschwindigkeit 9.6 kbit/sec
- Serielle asynchrone Übertragung
- Dezentrales Buszugriffsverfahren (CSMA/CA für hohen Datendurchsatz)
- 256 physikalische Adressen pro Linie
    - 64 physikalische Anschlüsse pro Linie (ohne Verstärker)
- 15 Linien pro Bereich (+ Hauptlinie)

Bild 6. EIB Systemdaten

Systemfunktionen für Sicherheitstechnik

Um den breiten Einsatz der EIB-Systemtechnik in der Sicherheitstechnik, speziell der Brand- und Einbruchmeldetechnik für den privaten Wohnbereich zu ermöglichen und die Voraussetzungen für eine VdS-Zulassung sicherheitstechnischer Geräte und Applikationen für die Klassen A und B zu schaffen, wurden beim EIB-Betriebssystem Funktionen zum Zugriffsschutz auf Programme und Daten in Busgeräten sowie zum schnellen Pollen der Busgeräte ergänzt.

Als Zugriffsschutz werden vier Byte lange Codeworte verwendet. Beim Zugriff auf Geräte und Daten werden mehrere Zugriffsebenen berücksichtigt.

Das schnelle Pollen ermöglicht ein ständiges Überwachen der Datenübertragungsleitung zu den Busgeräten und der Busgeräte selber auf Unversehrtheit und einwandfreies Funktionieren, ohne den normalen Datenverkehr relevant zu verzögern oder zu verlangsamen. Das Pollen beruht auf einem Master/Slave-Konzept. Der Polling-Master kann mit einem Polling-Telegramm bis zu 14 Slaves innerhalb von 30ms abfragen. Ein Polling-Master kann bis zu 142 Slaves an derselben Buslinie pollen.

Von einer Expertengruppe der EIBA wurden außerdem spezielle "EIB Object Interworking Standards" (ObIS) für die Sicherheitstechnik erarbeitet, um ein problemloses Zusammenarbeiten sicherheitstechnischer Geräte verschiedener Hersteller in einer gemeinsamen Alarmanlage sicherzustellen. Hierzu wurde eine Alarmanlage in ihre Teilfunktionen untergliedert und für jede der Teilfunktionen die mit den anderen Teilfunktionen auszutauschenden Informationen als spezielles EIB-Objekt definiert. Ein EIB-Objekt besteht aus einer Anzahl zugehöriger Datenelemente (properties), die entweder immer vorhanden sein müssen (mandatory properties) oder wahlweise hinzufügbar sind (optional properties). Die Datenelemente eines EIB-Objektes sind über den EIB abfragbar und bei Bedarf (und entsprechender Berechtigung) auch änderbar.

Die EIB-Objekte für Sicherheitstechnik ermöglichen das Dezentralisieren einzelner Funktionen in ein dediziertes Gerät, aber auch das Zusammenfassen mehrerer Funktionen in einer größeren Funktionseinheit. Speziell in der Sicherheitstechnik bietet ein Systemkonzept mit dezentral installierten Systemkomponenten einen erhöhten Sabotage- und Ausfallschutz. Speziell die bisher in einer Alarmzentrale zusammengefaßten Funktionen können so auf mehrere Geräte mit unterschiedlichen Installationsorten aufgeteilt werden. Redundant installierte Geräte können so wichtige Teilfunktionen auch bei Ausfall oder gezielter Sabotage eines einzelnen Gerätes weiterhin aufrechterhalten.

EIB-Produkte zur Brand- und Einbruchmeldung

In den vergangenen Jahren wurden in EIB-Installationen im privaten Wohnbereich zahlreiche sicherheitstechnische Funktionen außerhalb der VdS-Klassifizierung realisiert. Sie bieten für den Betreiber den Vorteil, daß er Sensoren mehrfach nutzen und im Alarmfall z.B. Innen- und Außenleuchten gezielt einschalten sowie Rollos hochfahren kann. So dient ein Fensterkontakt im Normalbetrieb zum Schließen der Heizkörperventile bei geöffnetem Fenster und trägt zur Reduzierung der Heizkosten bei. Im Sicherheitsbetrieb dagegen löst das Öffnen des Fensters einen Alarm aus. Innen- und Außen-Bewegungsmelder dienen im Normalbetrieb zum Ein- und Ausschalten von Leuchten sowie zum Umschalten der Heizung vom Energiesparbetrieb mit abgesenkter Raumtemperatur im nicht genutzten Raum auf den Komfortbetrieb bei Anwesenheit von Personen im Raum. Im Sicherheitsbetrieb dagegen löst eine im Raum anwesende Person einen Alarm aus.

In vielen Gebäuden wird bereits ein elektronisches Schloß mit EIB-Schnittstelle (Fa. Winkhaus) eingesetzt. Beim Abschließen der Tür können über zusätzlich parametrierbare Befehle gleichzeitig die Beleuchtung abgeschaltet, die Rollos herabgefahren, die Raumtemperaturen in den Räumen abgesenkt und ggf. die Alarmanlage scharfgeschaltet werden. Beim Aufschließen der Tür kann die Alarmanlage unscharf geschaltet, die Raumtemperaturen wieder angehoben und bei Dunkelheit die Beleuchtung eingeschaltet werden.

Ein EIB-Gerät zum Überwachen und Öffnen von Fluchttüren im Brandfall wird ebenfalls von der Fa. Winkhaus angeboten. Einen EIB Kombi-Brandmelder, der die Rauchkonzentration und den Temperaturanstieg überwacht, hat die Fa. Siemens entwickelt (siehe Bild 7). Wird an den EIB zusätzlich ein Telefon-Wählgerät angeschlossen, so kann z.B. im Brand-Alarmfall eine Text- oder Sprachmeldung an ein Mobiltelefon (Handy) abgesetzt werden.

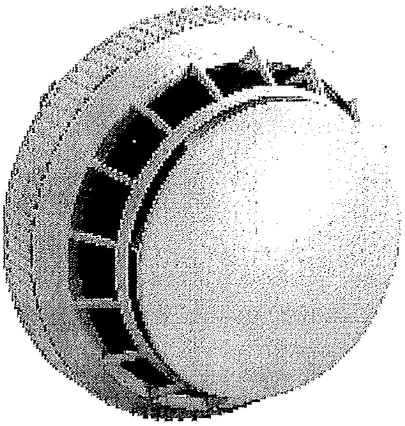


Bild 7. Brand-Kombimelder

Verfügbar sind ferner eine Einbruchmelderzentrale der VdS-Klasse A (bis C aufrüstbar) mit optionaler EIB-Schnittstelle sowie ein EIB-Meldergruppenterminal der Fa. ABB Stotz-Kontakt. Das Meldergruppenterminal (s. Bild 8) ist ein 72mm breites Reiheneinbaugerät mit 4 Eingängen für auf Kurzschluß und Unterbrechung überwachte Meldelinien, zum Anschluß vom Meldern mit Kontaktausgang und Glasbruchmeldern.

Bosch Telecom bietet sowohl ein EIB GMA-Interface mit je 8 Eingängen und Ausgängen an, das zur Ankopplung des EIB an die Meldelinieneingänge bzw. die Meldeausgänge einer konventionellen Einbruchmeldezentrale dient, als auch einen EIB Sicherheits-Controller (s. Bild 9). Der Sicherheits-Controller ist ein Reiheneinbaugerät, das die Zwangsläufigkeit und die Zustandsverwaltung einer Einbruchmeldeanlage realisiert. Außerdem fragt er zyklisch alle übrigen EIB-Geräte ab, die Bestandteile der EIB-Einbruchmeldeanlage sind. So wird sichergestellt, daß Kurzschlüsse und Unterbrechungen der Busleitung als Alarme erkannt und gemeldet werden. Für das Meldergruppenterminal und den Sicherheits-Controller wurde eine Zulassung für die Klasse A beim VdS beantragt.

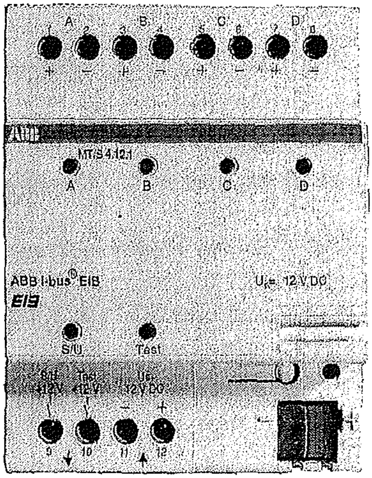


Bild 8. Meldergruppenterminal

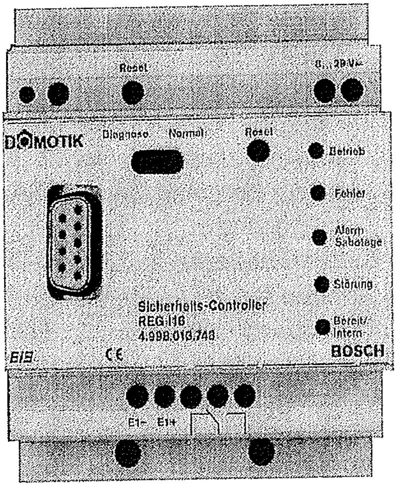


Bild 9. Sicherheits-Controller

Zusammenfassung

Während bisher Gefahrenmeldeanlagen auf Basis des EIB häufig außerhalb der VdS-Klassen realisiert wurden, ist nun für erste Geräte eine VdS-Zulassung der Klasse A beantragt. Die EIB-Systemtechnik beinhaltet jedoch auch Funktionen, die eine Zulassung nach Klasse B ermöglichen.

Das dezentrale Konzept des EIB bietet darüber hinaus alle technischen Voraussetzungen, um eine neue Generation von Gefahrenmeldeanlagen zu realisieren, die anstelle einer großen Zentrale, an die alle Melder und sonstigen Systemkomponenten angeschlossen werden, auf dezentral und ggf. redundant installierten, intelligenten und untereinander über den EIB vernetzten Geräten beruht.

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Direkte und stets aktuelle Informationen zum EIB sind abrufbar über das Internet unter "http://www.eiba.be".

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Integrated Systems - Proposals for addressing fire detection and alarm system integrity issues as the level of integration increases

Abstract

Fire detection and alarm systems, together with other security systems, are now being integrated with other building monitoring and management systems within larger buildings. It is predicted that over the next few decades the level of integration will increase as a result of technical capabilities and economic pressures. Means of preserving the integrity of the fire detection and alarm system are proposed which will require the co-operation of organisations involved with design, installation, maintenance and certification of the systems.

Introduction

There have been a number of technological revolutions in the last few centuries. These have included the Industrial Revolution, the Electromagnetic Revolution and most recently the IT Revolution.

This last revolution has lead to the situation where we can now achieve things which were considered absolutely impossible only a few decades ago. Imagine explaining to an aircraft pilot of the 1950s that it would be possible for electronic processors to reliably fly an inherently unstable aircraft. This would have been science fiction at the time but it is now a reality in many military aircraft.

Moving to matters which directly affect integrated fire detection and alarm systems, we should not expect to be insulated from the effects of technological evolution nor from the commercial pressures which rule our very existence in the western world.

Smaller fire detection and alarm systems may continue to stand alone for the foreseeable future however larger fire detection systems are already being integrated with building management systems. There is no reason to believe that this trend towards integration will not continue.

While some standards may be drafted with the objective of minimising integration , this approach is almost certain to fail in the medium term as will control by national legislation, particularly in Europe where the European Union is opening up the whole of Europe as one trading community.

This prediction of evolution does not negate the work presently under way to develop European [1] and ISO [2] standards for fire detection and fire alarm systems and for integrated systems [3] but does mean that the present work should only be considered a first step. Future standards development work for integrated systems should be focused on specifying more innovative means of protecting the integrity of fire detection and alarm systems rather than relying on limiting the application of modern technology.

This paper will initially examine the types of integration that are used today and a prediction for the future. The key issues that need to be addressed to protect the performance of fire detection and alarm systems will then be considered and finally some proposals for the way forward will be proposed.

Current integrated system architecture

At the present time, one of the main objectives of integration is to concentrate the display of information on building control and monitoring systems. This permits a small number of security staff and technicians to monitor the various systems and take appropriate actions when necessary. Typical integrated systems include environmental control, intruder detection, CCTV and fire detection systems and it is not uncommon to have one visual display unit providing all the information and one keyboard permitting the control of all the systems. Figure 1 shows a typical system architecture.

An alternative architecture is where different systems are combined usually by means of a shared control and indicating equipment. This arrangement is becoming popular for smaller systems, often installed in private houses, and commonly includes intruder detection and fire detection facilities. While there is no fundamental technical reason why such systems cannot be used in large premises, there may be issues relating to the combination of the various functions of the overall system which may make them less popular. Figure 2 shows a typical arrangement of a combined system.

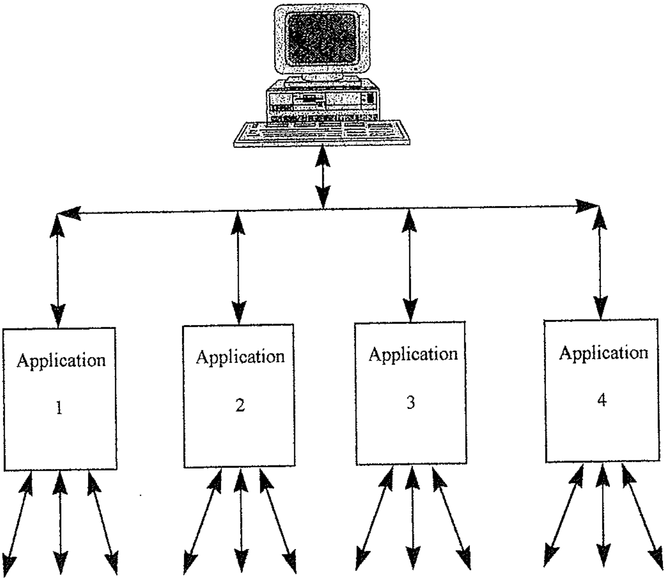

Figure 1 Architecture of an integrated system

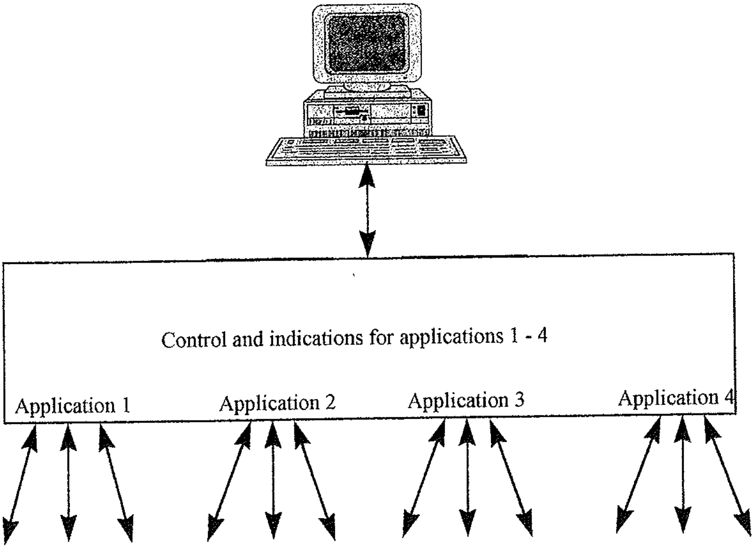

Figure 2 Architecture of a combined system

Both examples of system architecture are quite simple and it is not difficult to provide examples of how existing technology can increase the level of integration. Indeed there are a number of standards and codes which have been published or are being drafted which include more innovative examples, these include:

a BFPSA/BSIA guidance document published in the early 1990s
a Euralarm guidance document published in the mid 1990s
a British Standard, BS7807, published in 1995

Reasons for the lack of development of more innovative approaches to integration include regulatory pressures in some countries and the existing partition of expertise between the providers of the various building monitoring and management systems. This situation is likely to change quite radically over the next one or two decades and now is the time to start addressing the issues that will arise.

Integrated systems in the 21st century

The key drivers for greater levels of integration will include:

- Commercial pressures to reduce costs of buildings and their installed systems
- The formation of groups of companies with a combined knowledge of the various monitoring, management and information systems installed in buildings
- Readily available technology

To discuss commercial pressures at AUBE 99 might appear wrong but we all live in a commercially orientated society and we cannot escape from the fact that businesses are continually striving to increase efficiency and cut costs. This is as true for those companies who erect and fit out buildings as it is for building occupiers who may be operating a production line or a large retail shopping complex.

Installing cabling systems in buildings is costly in terms of the cables themselves but is also very labour intensive. There are therefore economic advantages to be gained from installing systems which can share common wiring and possibly other facilities.

In the past, most companies involved with building monitoring and management have been quite insular. Some may have been involved with both fire and intruder detection but rarely much more. Wider groupings of companies are now becoming more common and strategic alliances between various groups are not unknown. This extends the applications knowledge that is available and permits, for example, a company with energy management expertise to also take responsibility for fire detection and intruder detection systems.

The technology required for greater integration is available today. This paper is not intended to pass judgement on which will be used but the possibilities include:

- Field bus technology and there are a number of commercially available systems [4]
- Local Area Networks used within buildings for IT data transmission
- Digital telecommunications networks within buildings

For each of these possibilities there will be some good reasons why they are unsuitable, for example they are too slow, or too fast, too limited in application or too expensive to use or not secure enough. It is unlikely that any of these reasons will stand the test of time and there are unlikely to be any technically insurmountable problems.

One example of the architecture of a more advanced integrated system is shown in Figure 3. This shows a system consisting of a number of nodes. Each node may be unique to a single application but could be multi-purpose and include, for example, the sensors and actuators for more than one building management or monitoring system. Each node is likely to transmit and receive data via the common data transmission system. Processing of the data will occur where it is considered most appropriate within the overall integrated system.

The system integrity issues to be addressed

Existing standards or draft standards for fire detection and alarm systems tend to be written in a form whereby they do not recognise integration and in fact some are written to exclude all but the very simplest forms of interconnection with other non fire protection systems. Such standards are therefore of little benefit when considering the means for maintaining the integrity of the more advanced integrated systems. Standards and codes written for combined and integrated systems do provide some guidance for the installer, the maintainer and the system user but if any party were to choose to ignore the recommendations the system could fail to satisfy desirable integrity requirements. It is therefore proposed that the fundamental requirements for the fire

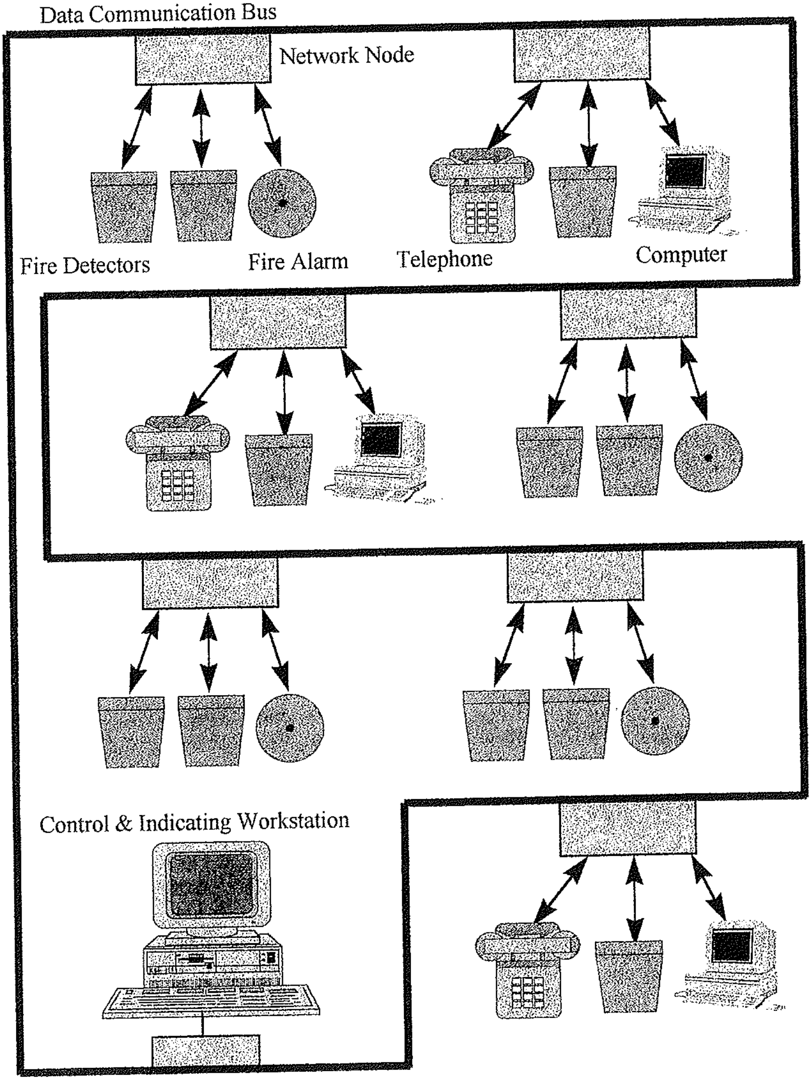

Figure 3 Architecture of an integrated system sharing a common data communications bus throughout a building

detection and alarm system be identified and examples of means of achieving the requirements be offered. Other security systems may have other requirements which will also need to be addressed.

The fundamental requirements for the fire detection and alarm system are:

1. that component parts of the integrated system associated with the fire detection and alarm system should, wherever reasonably possible, meet requirements specified within the EN54 series of standards
2. that the system be designed in such a manner that it can self monitor the configuration and functionality of the fire detection and alarm system
3. that any changes to the configuration, functionality or software and hardware of the fire detection and alarm system be automatically reported to an independent third party with appropriate fire detection and alarm system expertise
4. that operation of other functions of the integrated system should not prevent the operation of the fire detection and alarm system without this being indicated
5. that changes to other functions of the integrated system should not affect the performance of the fire detection and alarm system without this being indicated
6. that a single wiring fault or power supply fault should not affect the operation of the fire detection and alarm system
7. that the wiring of the integrated system be undertaken in such a manner that requirements relating to mechanical and thermal etc. integrity that are specified in national application guidelines for fire detection and alarm systems are met
8. that an independent organisation with appropriate fire detection and alarm system expertise should evaluate the installation and performance of the integrated system and provide a positive report prior to the system being put into service
9. that maintenance is undertaken in a manner that is acceptable to an independent organisation with appropriate fire detection and alarm system expertise

What we need to do to confirm system integrity

These nine proposals will require changes to the design of products and also changes to the roles of some organisations who may already be involved with the installation, maintenance and certification of fire detection and alarm systems.

Items 1 to 5 on the list affect product design. The most radical proposal is that the fire detection and alarm system be capable of self monitoring its configuration and functionality. While in no way wishing to prescribe the means of achieving this, it should not be too difficult for systems to be designed whereby they continually self test their configuration and self monitor the reactions of their output drivers, e.g. to alarm sounders and actuators, when the triggering of system inputs is simulated. Any failure of an output to react to a simulated actuation signal would indicate a failure of the configuration of the system or its functionality.

Most of the other proposals within items 1 to 5 could be achieved by addressability and the recognition of unique characteristics of system components e.g. software encoded serial numbers.

The proposal within Item 3 that an independent organisation monitors the system could be seen as overkill but could also be seen as advantageous by insurers and other interested parties such as fire detection system maintainers. As many integrated systems will already be connected to an alarm call receiving station, this proposal may well be achieved by an existing receiving station capable of monitoring some additional information.

Items 6 and 7 are mainly concerned with system design and are no different to the requirements of simpler integrated systems. They do however raise a number of issues relating to the choice of cable types, their routing and mechanical protection. There is also an implied need for transmission path redundancy within Item 6.

Item 8 is probably the most radical. This recognises that it will not be possible to test integrated systems in test houses even though some components such as fire detectors may have already been tested. It is proposed that a competent inspection organisation considers the integrated system and evaluates the quality and characteristics of the installation and its performance. This does not imply that the testing is undertaken by the inspection organisation themselves but they should assess the commissioning test results and report accordingly. This proposal is not intended to provide the same level of confidence as would be achieved by fully testing a system at a test house but it is totally impractical for integrated systems of this type to be subjected to a full test programme.

Item 9 requires the use of competent maintainers whose performance has been assessed by a third party organisation. Such schemes already exist or are being developed for maintainers [5] so it should not be particularly difficult to introduce.

Conclusions

This paper has been prepared and presented as a means of raising some slightly controversial proposals to meet a challenge that will certainly confront us in the reasonably near future. We will not be able to hide behind our existing standards and national regulations. There is no historical evidence to support regulation being successful and the European Commission will not support such an approach.

If we now start the debate on how product designs need to change and how test and certification bodies should change to meet the new challenges then we will continue to install modern and reliable systems in which we can have justifiable confidence. If we fail to meet the challenge and suppliers of integrated systems have no effective regulation, we run the risk of unreliable systems for monitoring the safety of buildings and their occupants. This would be an unacceptable situation which we are certainly able to prevent.

References

[1] EN 54 Fire detection and fire alarm systems

[2] ISO 7240 Automatic fire detection systems

[3] prEN 5013X Combined and integrated alarm systems

[4] Examples include: ECHELON - LONWORKS, PROFIBUS, EIBus

[5] Loss Prevention Certification Board Standard LPS1014 revision