

Method and device for configuring a tunnel fire detection system**Description**

5 The invention lies in the area of fire detection in tunnels, for which purpose detection systems comprising a linear heat sensor are currently used. Such a detection system is sold under the name "FibroLaser" by Siemens Building Technologies AG, Cerberus Division, formerly Cerberus AG. Said system comprises a glass-fibre cable fitted to the tunnel roof, a laser light source and an optoelectronic receiver. The light generated by the
10 laser is coupled into the glass-fibre cable and conveyed in longitudinal direction of the latter. Variations of the density of the silica glass caused by the effect of heat give rise to a continuous scattering (Rayleigh scattering), which in turn gives rise to subduing of the laser light. In addition, thermal lattice vibrations of the glass material lead to further light scattering, so-called Raman scattering.

15 A fraction of the scattered light falls into the acceptance angle of the waveguide and scatters both in forward and in backward direction. The scattered light is detectable by the optoelectronic receiver; by evaluating the intensity of specific backscatter frequencies the local glass-fibre temperature may be determined. The local resolution of the temperature profile along the glass-fibre cable is effected by measuring the subduing of
20 the waveguide light. The magnitude of the fire is a function of the heated cable length: a short heated length corresponds to a small fire and a long heated length corresponds to a large fire.

The present invention relates to a method of configuring a tunnel fire detection system comprising a linear heat sensor with a sensor cable. The method according to the
25 invention is to enable tunnel fire detection systems to be individually adjustable as early as during the planning stage in a highly flexible manner to the physical and local conditions of a tunnel.

The stated object is achieved according to the invention in that on the basis of parameters of the tunnel and sensor cable as well as on the basis of a fire model the fire development
30 and the fire alarm time are calculated and the installation point of the sensor cable and the alarm limit values of the detection system are optimized in such a way that a potential fire is quickly and reliably detected.

The method according to the invention is substantially a model for simulating various fires in a tunnel in order to achieve efficient and targeted planning of new systems and define
35 suitable test fires for testing said systems.

A first preferred embodiment of the method according to the invention is characterized in that the parameters of the tunnel comprise data regarding the tunnel dimensions and the wind conditions in the tunnel.

5 A second preferred embodiment of the method according to the invention is characterized in that the parameters of the sensor cable are determined by the physical properties of the cable, its position and installation geometry and by the physics of metrology.

A third preferred embodiment is characterized in that the fire model comprises partial models, which contain sets of parameters obtained from theoretical calculations and practical experience.

10 The fire model preferably comprises the two partial models, namely fire development in the reaction zone and behaviour of the combustion gases in the cooling-down zone above the reaction zone.

The partial model, fire development, involves calculating the reaction enthalpy, the energy balance and the ascending force in the reaction zone and the fire development. The
15 partial model, behaviour of the combustion gases in the cooling-down zone (so-called plume model), substantially involves calculation of the behaviour of the flow of hot combustion gases as a result of blending with the ambient gas in a turbulent peripheral area.

The invention further relates to a device for configuring a tunnel fire detection system
20 comprising a linear heat sensor with a sensor cable. The device according to the invention is characterized by the following components:

- a. storage means for storing parameters of the tunnel and sensor cable and parameter sets of a fire model;
- b. computational means for calculating the fire development and the resultant heating
25 of the sensor cable on the basis of the stored parameters and parameter sets;
- c. input means for entering data and parameters;
- d. display means for the display and/or output of the fire alarm times, which are obtained for specific parameters, or the tunnel and sensor cable parameters to be used for preset alarm limit values and fire alarm times.

30 The device according to the invention is formed, for example, by a laptop or other portable computer having an entry keyboard, a display screen, a printer connection and a CD-ROM drive, wherein the parameter sets of the fire model and the programs for calculating the fire development, the heating of the sensor cable and the fire alarm times are stored

on a CD-ROM and the parameters of the tunnel and sensor cable may be entered using the entry keyboard.

There now follows a detailed description of an embodiment of the invention with reference to the drawings; the drawings show:

- 5 Fig. 1 a flow diagram of the main program for calculating the fire alarm times of a tunnel fire detection system comprising a heat sensor,
 Fig. 2 a flow diagram of the subroutine for calculating the fire development; and
 Fig. 3 a flow diagram of the subroutine for temperature calculation in the sensor cable.

Experiences gained in the field of tunnel fire detection have demonstrated that for reliable
 10 and fast fire detection it is necessary to take into account the burn-up behaviour and the magnitude of the fire, the wind conditions, the tunnel geometry, the spatial arrangement of the sensors and the location of the fire. In many cases use is then made of a detection system with a linear heat sensor, such as is sold, for example, by Siemens Building Technologies AG, Cerberus Division, formerly Cerberus AG, under the name of
 15 FibroLaser. The FibroLaser is assumed to be known; in said connection reference is made to the introduction of the present description and to the brochures of the FibroLaser system.

Since, because of the complex thermodynamic processes which occur during a fire, it is virtually impossible for all of the influencing quantities to be taken even only partially into
 20 account, the configuration of a detection system comprising a linear heat sensor is extremely laborious and time-consuming and entails numerous practical trials. The present method simplifies configuration quite substantially in that it provides the application engineer with a simulation program, which has been verified by tests to a bench scale and large scale and by means of which the fire alarm time resulting from
 25 given system parameters is calculated, thereby allowing the system parameters to be tuned to a preset fire alarm time.

The calculation method is based on a thermodynamic modelling of the combustion processes, wherein the thermodynamic models fulfil the conservation quantities of physics (mass, energy, momentum) and require only a few empirical values. The simulation
 30 model comprises the following partial models:

- calculation of the reaction enthalpy on the basis of an ultimate analysis of the incendiary materials
- energy balance and mass balance in the reaction zone
- length of the reaction zone

- energy balance in the plume (= cooling-down zone above the reaction zone)
- flow mechanics in the plume based on a free jet model
- influence of the wind in the tunnel upon reaction zone and plume
- fire development
- 5 • heat exchange by virtue of radiation and convection as well as heat conduction in the sensor cable.

The simulation model receives in particular the following input parameters:

- fire diameter: diameter of the circle equal in area to the total surface of the combustible;
- 10 • tunnel height: distance between carriageway and tunnel height, wherein in the case of a tunnel with an arched roof a mean roof height in the arch region is generally accepted but has always to be situated above the sensor cable;
- tunnel width: shortest distance between the tunnel walls at mid-height of the tunnel;
- 15 • distance between sensor and ground: shortest distance between sensor cable and carriageway; said distance is always smaller than the tunnel height;
- distance between sensor and fire: shortest distance between the centre of the fire surface and the sensor cable; said distance is generally greater than the distance between the sensor and the ground;
- 20 • wind: the wind velocity corresponds to the air speed along the carriageway taken as a mean over the tunnel cross section. Should fans generate a strong transverse flow which is greater than the wind velocity along the carriageway, the transverse velocity is used;
- wind in the region of the sensor cable: the wind in the tunnel presents a profile which generally tends towards zero at the walls and at the roof. Should the sensor cable be fitted close to the roof or a wall, said effect has to be taken into account. The guide values are obtainable from a table;
- 25 • tunnel pressure: ambient pressure in the fire region; depends above all on the height above sea level;
- 30 • tunnel temperature: ambient temperature in the fire region; in winter has an influence upon the tripping of the alarm temperature in the detection system;
- sensor diameter: outside diameter of the sensor cable;
- alarm temperature: temperature threshold value, at which or above which the detection system is to indicate a fire alarm. Said value is generally in the region of

50° to 80°C. Alarm temperatures below 50°C may trigger false alarms in the entrance and exit region of the tunnel;

- gradient of the alarm temperature: the increase of temperature over time is used to determine the gradient which forms the threshold value for triggering a fire alarm.

5 Should the temperature rise per second faster than the threshold value, an alarm is triggered. Said threshold value is generally 0.1°C/sec., corresponding to 6°C per minute;

- fire acceleration rate: given an unlimited supply of air to the seat of the fire, the rate of growth of the fire increases linearly with time. For the burn-up capacity Q^* of a fire having the fire surface A at time t , $Q^* = A \cdot B \cdot t^2$ applies, in which the so-called fire acceleration rate B is a measure of the fire development up to full combustion. For B there are empirical values, which are stored in a table.

15 In principle, the basis for all of the said parameters is the worst-case scenario. This is, e.g. for the distance between sensor and fire, the length of the diagonal from the sensor cable to the edge of the carriageway. Naturally, a burning tarpaulin of a lorry is situated much closer to the sensor cable but this is not a problem because such a fire would be detected far earlier. The fire diameter, i.e. the fire surface, is known for cars and lorries in tunnels and is assumed to be e.g. 1 metre, which corresponds to a fire surface of approximately 0.8 m².

20 Fig. 1 shows a flow diagram of the main program for calculating the fire alarm times of the tunnel fire detection system according to the invention. In a first step the requisite parameters of the tunnel and sensor cable are entered; the parameter sets of the fire model are stored in the system.

25 This is followed by the selection of the calculation model in the sensor cable. The latter comprises a glass fibre coated with heat transfer compound, a steel capillary tube surrounding the glass fibre and its coating and having a diameter of e.g. 1.6 mm, and a polyethylene outer sheath having a diameter of approximately 8 mm. The sensor cable is heated both by combustion gases flowing around it (convective heat exchange) and by radiation and both types of heat flow may occur separately or simultaneously. For the
30 heating of the cable and glass fibre two different calculation models - the homogeneous model and the differential model - may be used, which differ in accuracy and in computing speed.

In the case of the homogeneous model, the temperature profile through the outer sheath is disregarded and it is assumed that the entire cable is heated to a mean temperature. In

the case of the differential model, which takes far more computing time, precise calculation of the heating of the glass fibre in the sensor cable is effected by solving the non-steady heat conduction quadratic equation. In the present case, said equation has to be extended as a simultaneous differential equation system because the sensor cable has various layers. The subroutine for the differential model for temperature calculation in the sensor cable is shown in Fig. 3.

After input of the technical data regarding the sensor cable, calculation of full combustion without wind influence is effected in accordance with the subroutine of Fig. 2. This supplies the temperature in the reaction zone (flame zone) and in the plume, i.e. the two quantities responsible for heating the sensor cable. According to Fig. 2, for calculating the full combustion the thermodynamic starting values and the starting values for the burn-up rate WSBR are entered, wherein by burn-up rate is meant the fire development up to full combustion. The starting value for the burn-up rate is iterated in increments ΔW until the burn-up rate meets the value corresponding to the total mass balance.

In a fire, substances in the incendiary material are oxidized by the atmospheric oxygen in the reaction zone, wherein the thermal energy released by said oxidation reactions heats the gases in the reaction zone. With most fires, the elements carbon, hydrogen and sulphur oxidize: any halogens contained in the incendiary material react preferably with the hydrogen. For the simulation, the halogen content as well as the rare-earth elements content is assumed to be negligible.

In the reaction zone there is a build-up of above all CO_2 , H_2O and SO_2 , wherein specific heat quantities per mole are liberated. Given an oxygen deficiency there is an increased build-up of CO and at the same time the water-gas reaction plays an important part, wherein said energy-consuming reduction is dependent upon the supply of educts and upon the temperature in the reaction zone. From the known reaction scheme the oxygen demand for ideal, full combustion may be determined stoichiometrically and from the latter, the fire mass and the mass fraction of the inlet air the stoichiometric air mass.

In the case of a fire with natural convection, in the reaction zone more air is converted than the stoichiometry of the combustion reactions demands, said extra air being the excess air number. The latter may be calculated from the so-called k_b factor, which is used to determine the minimum oxygen fraction from the guidelines for inert-gas fire extinguishing plant. The minimum oxygen fraction is the O_2 concentration which is required to maintain the combustion reactions and which may lie above the stoichiometric air demand.

In the case of incomplete combustion, at the cost of CO_2 there is an increased build-up of CO and free hydrogen. In said case the oxygen demand is greater than the inlet air in the reaction zone may supply. From the mass fractions of carbon, hydrogen, sulphur and oxygen in the incendiary material and from the mass fraction of the inlet air it is possible to
 5 determine the fraction of CO_2 in the combustion gas and from the latter the other reaction products and the reaction enthalpies.

The liberated combustion heat or reaction enthalpy of the incendiary material may be likewise stoichiometrically determined. Furthermore, the combustion enthalpies of most materials have been experimentally determined in the fire regulations (Sprinkler
 10 Guidelines, DIN 4201, DIN 18232, etc.) and may be obtained from appropriate tables.

From the combustion gas composition in the reaction zone the heat output in the reaction zone is calculated and the resultant temperature is iterated with the flame length and the enthalpy- and mass balance. Finally, from the gas volumetric flow and the gas velocity over the reaction zone the momentum balance in the region of the reaction zone is
 15 determined and an iteration of the burn-up rate according to the total mass balance is effected. As soon as the burn-up rate meets the value corresponding to the desired fire duration, the plume development from the reaction zone up to the roof is additionally included in the momentum-, mass- and enthalpy balance and the air admixture and wind correction are taken into account.

20 In the cooling-down zone above the reaction zone the hot combustion gases mix in a turbulent peripheral area with the ambient gas, e.g. air, with the result that the vertically upward streaming gas flow widens. For the simulation it is assumed that the behaviour of the rising combustion gases corresponds to a turbulent free jet, with the reaction zone as the jet core. The temperature reduction as a function of height may be acquired by
 25 means of an energy balance over the vertical layer and the mean rate of ascent may be acquired by means of a momentum balance over the local plume cross section, so that finally the local speed reduction in the plume is obtained.

It is assumed that the plume opens like a turbulent free jet, of which the angle of spread is 8° to 15° . Said angular dependence may be determined from the pressure difference
 30 between jet and environment. Wind velocities of up to 10 m/s give rise in the tunnel cross section to a turbulent longitudinal flow, the turbulence clusters of which are much smaller than the tunnel cross section. Said air flow, despite the high Reynolds' number in the region of 10^6 compared to the tunnel dimensions, may be described as laminar. From said point of view, the assumption is allowable that the flow of momentum of the wind is

superimposed on the flow of momentum of the plume so that the gases in the plume are carried away by the wind without the plume being completely swirled. The influence of the wind lends the plume a specific angle of inclination, which may be determined from the ratio of the gas velocity in the plume to the wind velocity in the tunnel.

- 5 The result obtained from the subroutine for calculating the fire development is the temperature in the reaction zone and the temperature in the plume in the case of full combustion.

The time iteration is then started, wherein all thermo-dynamic states are calculated at time increments Δt of 1 second, thereby enabling precise mapping of the fire development.

- 10 The simulation runs for a specific maximum time t_{End} of several minutes and is terminated on reaching t_{End} with the display and/or print-out of the fire alarm criteria. As is evident from Fig. 1, the actual fire surface is entered and then the fire without wind influence is calculated. Then the wind influence upon reaction zone and plume is entered, as is the distance from the fire surface to the detector cable. Then, using the temperature in the
- 15 reaction zone and in the plume, the fire calculation with wind and the calculation of the temperature of the turbulent hot gas layer and of the temperature given complete turbulent blending in the tunnel cross section are effected. The heat flow into the cable surface (convection or radiation) is then determined and it is subsequently estimated whether convection heat and radiation are acting jointly upon the cable.

- 20 Calculation of the heat conduction through the sensor cable to the glass fibre is then effected according to the differential model shown in Fig. 3. According to Fig. 3, the material data of the cable and the initial and marginal conditions at time $t=0$ are entered and the integration increment Δt_k is fixed. The latter is e.g. 10^{-3} seconds. Calculation of the temperature profile in the cable is effected every 10^{-3} seconds but the value is
- 25 transferred in accordance with the time increment in the main program only every $t_k = t_n$, i.e. for example every second, to the main program. Then the heat conduction quadratic equation is solved using the differential method and after time t_n , in each case, the temperature profile in the cable is available.

- Using the temperature profile in the cable, the temperature gradient is then formed in the
- 30 main program. It is subsequently checked whether, during the simulation, the plume reaches the cable within the radiation field; if so, there is superimposition of convection and radiation. There then follows a test to ascertain whether two measuring locations of the cable are situated within the radiation field; if not, there is damping of the radiation surface temperature. Finally, the alarm criteria are tested and the fire alarm time is

printed out in the time increment t . After reaching the preset total duration of the simulation t_{End} , the alarm criteria are printed out and the simulation is terminated.

The user now knows whether the desired fire alarm time may be achieved with the entered parameters or whether all or some of the parameters need to be altered.



Claims

1. Method of configuring a tunnel fire detection system comprising a linear heat sensor with a sensor cable, characterized in that on the basis of parameters of the tunnel and sensor cable as well as on the basis of a fire model the fire development and the fire alarm time are calculated and the installation point of the sensor cable and the alarm limit values of the detection system are optimized in such a way that a potential fire is quickly and reliably detected.
2. Method according to claim 1, characterized in that the parameters of the tunnel comprise data regarding the tunnel dimensions and the wind conditions in the tunnel.
3. Method according to claim 1 or 2, characterized in that the parameters of the sensor cable are determined by the physical properties of the cable, its position and installation geometry and by the physics of metrology.
4. Method according to one of claims 1 to 3, characterized in that the fire model comprises partial models, which comprise parameter sets obtained from theoretical calculations and practical experience.
5. Method according to claim 4, characterized in that the fire model comprises a partial model, fire development in the reaction zone, and a partial model, behaviour of the combustion gases in the cooling-down zone above the reaction zone.
6. Method according to claim 5, characterized in that the partial model, fire development, involves calculation of the reaction enthalpy, the energy balance and the ascending force in the reaction zone and the fire development.
7. Method according to claim 5 or 6, characterized in that the partial model, behaviour of the combustion gases in the cooling-down zone, involves calculation of the behaviour of the flow of hot combustion gases as a result of mixing with the ambient gas in a turbulent peripheral area.
8. Device for configuring a tunnel fire detection system comprising a linear heat sensor with a sensor cable, characterized by the following components:
 - a. storage means for storing parameters of the tunnel and sensor cable and parameter sets of a fire model;



- b. computational means for calculating the fire development and the resultant heating of the sensor cable on the basis of the stored parameters and parameter sets;
 - c. input means for entering data and parameters;
 - 5 d. display means for the display and/or output of the fire alarm times, which are obtained for specific parameters, or of the tunnel and sensor cable parameters to be used for preset alarm limit values and fire alarm times.
9. Device according to claim 8. characterized by a laptop or other portable computer having an entry keyboard, a display screen, a printer connection and a CD-ROM
- 10 drive, wherein the parameter sets of the fire model and the programs for calculating the fire development, the heating of the sensor cable and the fire alarm times are stored on a CD-ROM and the parameters of the tunnel and sensor cable may be entered using the entry keyboard.