Modern Trends of Fire Protection in Rolling Stock 2013

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Summary

The author at first emphasizes that a key role in the protection of human life and protection against damage to equipment in the event of a fire plays proper and early detection. Then discuss the physical phenomena used in different detection techniques used in rail vehicles also providing concrete practical solutions. In the article author also takes into account the impact of the proper placement of detectors in the efficiency of the system, and presents the results of their effectiveness.

Key words: fire protection, fire fighting, water mist, rolling stock

Fire Detection Systems

An early detection of fire plays a key role in safety of human lives and preservation of the goods by fire hazards. Therefore fire detection systems play a fundamental role, as the effectiveness of the complete fire protection systems depends on their good working performances. Good working performances for fire detection systems can be depicted by the following features [2–4]:

- quick detection, normally according to the norms used for validation,
- sectional detection, to identify as much possible in detail the location of the fire event,
- robust design in regarding of factors that could cause a false fire alarm,
- low needing of maintenance and competitive RAMS and LCC values in general, according to train design targets,
- right and adequate interface standards with train management systems, to exchange necessary information.

In rolling stock application different fire detection systems are commonly used, in combination or not with a fire suppression system. Fire detection systems are basing on the three main „detectable" aspects of the fire: smoke and combustion

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gas release, temperature increase, visible radiation emission. Smoke and gas production and temperature growth are the most used fire effects used to detect it. Technologies usually used in fire detection in rolling stock applications are therefore:

- smoke detection, in detail: point smoke detection and smoke aspiration systems,
- gas detection,
- temperature detection: point temperature detection and linear temperature detection.

Moreover, other methods are possible, like:

- fire (flame) detection by CCTV,
- temperature detection by thermal cameras (infrared cameras).

Each solution has its own advantages and limits, and the different features will be now presented, considering also the specific application in a rolling stock scenario.

1. Smoke detection systems

Smoke is one of the most common products of combustion, especially in case of incomplete combustions in atmosphere, as likely in a real rolling stock scenario. In rolling stock applications two main types of smoke detection are used: point smoke detection (*smoke detectors*) and smoke aspiration systems (by *sampling points* connected to a centralized detector) [2]. Smoke detection is widely used in rolling stock, especially in passenger areas, where early detection of fire plays an important role in the life safety of occupants. In a coach, smoke detectors or sampling points of smoke aspiration systems can be placed in the ceiling or in wall panels.

Smoke detection, as smoke is normally heated up by combustion reaction and dragged by air movement due to thermal gradients, makes fire detection possible even in scenarios where fire can start in a hidden location: a clear example for the reader can be a fire ignited by vandalism between or under seats in the passenger compartment of a coach. Such technology can also be used to detect smoke coming from outside, and therefore discriminate between real and false alarms, by placing the point detectors or the sampling points in HVAC ducts or in inlet / outlet air dampers.

In passenger areas smoke detection is a preferable solution, as location of fire is variable and potentially hidden, and often smoke production is the higher risk associated to a fire event in a passenger coach. Due to its clear sensitivity to dust and dirt, smoke detection is in opposite not preferable in application like diesel loco engine room or underfloor boxes due to high risk of pollution (which will shorten the life cycle) and false alarms.

Both solutions, point detectors and smoke aspiration systems, will be presented afterwards in their specific features; their main and shared feature is the way of detection of the smoke. Smoke detection is in fact in both solutions based on an optical analysis of air in a specific chamber, known as *measuring chamber*, where the light from an emitting diode is scattered by smoke and reflected in a receiving diode. In rolling stock field smoke detection works therefore by *optical* detection, based on the principle of the *scattered light* (Fig. 1).

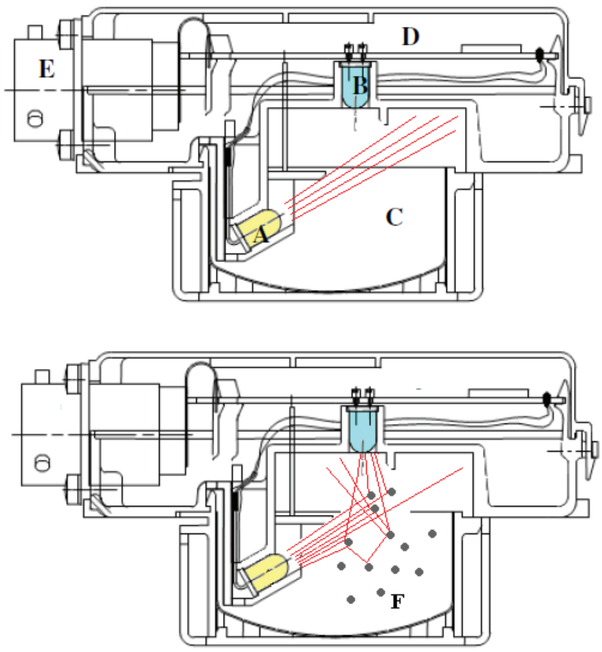

Fig. 1. Internal components of a smoke detector and scattered light principle: A) emitting diode, B) photoelectric receiver sensor, C) measuring chamber, D) motherboard, E) feeder and communication interface with fire protection system, F) smoke particles [2]

The light emitted (typically the diode is an infrared LED) is normally directed against the walls of the measuring chamber, which are designed with a specific geometry in the way to not scatter the light to the receiver. When smoke gets inside the measuring chamber, then light is reflected and scattered inside the chamber, hitting the photoelectric sensor. A photoelectric sensor is normally a receiving LED, means a diode which is able to give an electrical signal while hit by an electro-magnetic radiation in specific wavelengths[2]. The measuring chamber measures

[2] The same physic effect is used in photovoltaic cells.

the level of smoke in the air passing inside, defining a certain level of pollution or obscuration of the air due to the smoke. The physical quantity used to define the level of smoke is the *optical density per meter*[3] (x), defined as:

$$D = -\frac{1}{x} \cdot \lg \frac{I}{I_0}.$$

Where I is the intensity of the source light and I_0 is the light effectively passed through the smoke. The quantity is defined by a logarithm, therefore is common to measure it by using the logarithmic unit *bel* [B]. Bel unit is commonly used in its linear multiple *decibel* [dB] and, while reported to a linear distance, holds the definition of *obscura*[4] [ob]:

$$1 \, \mathrm{dB}/\mathrm{m} = 1 \, \mathrm{ob}.$$

The smoke density level can also be reported to an equivalent percent of obscuration, normally defined as the percent of light transmitted, the threshold set is used by the detector to define the alarm status and activate a switch or a signal.

1.1. Point smoke detection: smoke detectors

A typical smoke detector looks like a device, made normally in plastic, with a disk shaped measuring chamber housing with external diameter of around 60–80 mm and approximately 20–35 mm thick, and a slightly bigger base for electrical connections or for integrated motherboard housing. In complete, a common smoke detector has overall external dimensions ranging between 70–100 mm in diameter and 50–60 mm in thickness (Fig 2). Shape and dimensions can of course vary by manufacturer, product line, technological solutions adopted.

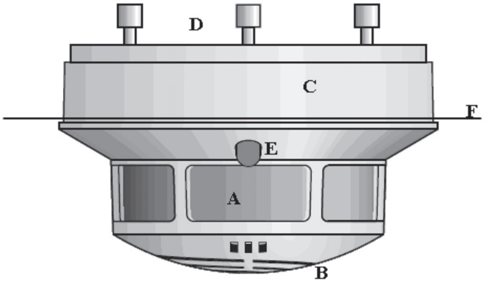

Fig. 2. General layout of a smoke detector: A) measuring chamber, B) housing with openings for smoke entrance, C) housing for motherboard and electrical connectors, D) electrical connectors, E) external LED for status information, F) line of the ceiling, indicating the hidden and on view parts

[3] Optical density per meter is actually an *absorbance* reported to a linear distance.
[4] As for decibel, obscura is a non-dimensional measurement.

The housing of the smoke detector incorporates the measuring chamber, where the emitting diode and the receiving photoelectric sensor are located. In some different application, like cheap home solutions, smoke detectors can be fed by a local 9–12 V DC battery; for clear safety and availability reasons, in rolling stock application smoke detectors are always powered by train low voltage line, via a central fire alarm unit or individually by train line, usually under a voltage of 24 V or 110 V DC, depending on train manufacturer's design. Smoke detectors are installed in the interior panels or in apposite racks while used in not furnished technical areas: typically, in passenger area application, the measuring chamber is on view and the housing for connectors and motherboard remains covered by the panel.

Point smoke detectors used in rolling stock field work by optical smoke detection as explained before. The signal taken from the photoelectric receiver is evaluated by the software in the motherboard of the detector, which decides to define or not an alarm situation. At this step, depending on the type of detector, different solutions are chosen to forward the signal:

- The signal from the local processor can be used to activate a switch, creating therefore an open circuit in a low voltage line monitored by a CPU.
- The values are elaborated by a local processor and can be forwarded in a defined communication standard to a CPU which evaluates the situation and defines the alarm status.

In simple smoke detectors, sometimes the software elaboration is not foreseen and the photoelectric sensor is directly used to commutate the alarm switch. Smoke detectors using this layout are often defined as *smoke switches*. A wide range of detectors uses both solution, with a switch in the low voltage line and a communication line checked by software, especially in solutions where smoke detectors are included in a system with several of them in line. Some high-end series smoke detectors are also able via local software to evaluate the pollution level together with the velocity of increasing of the smoke, or correlating the smoke value with the time: e.g. can be foreseen the condition to have smoke increasing with a minimum gradient and smoke standing in the chamber for a certain time, before confirming the alarm (Fig. 3).

On-detector installed software allows also detectors to an automatic calibration during the working life, calibration necessary because the exposition to environmental conditions, like greasy dust in a diesel engine room of a shunter or organic pollution in a passenger area, can dirt the smoke chamber and influence the correct measurement. For this, normally the software resets the zero level of smoke according to the actual pollution status, to avoid false alarms due to pollution or loss of effectiveness. Nevertheless, all smoke detectors foresee a maximal

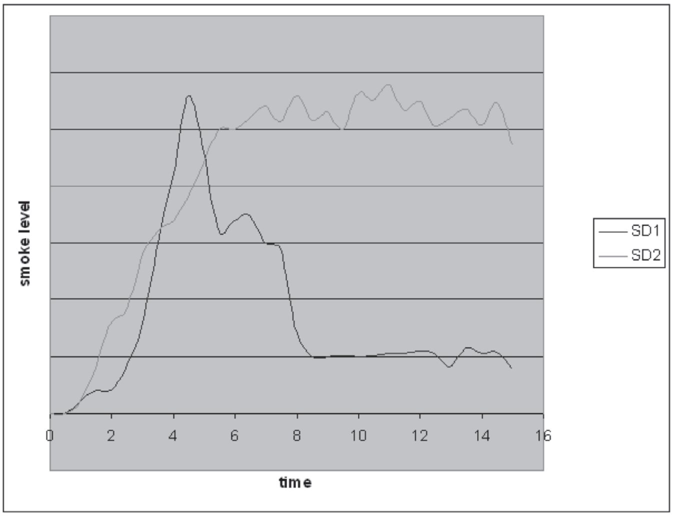

Fig. 3. Smoke level threshold value (red line), confirmed fire alarm (SD2), exceeded threshold for a certain time, or aborted when smoke value lower down again (SD1)

life cycle before cleaning or a continuous checking of the optical capacity, and the recalibration is always done up to a certain limit of dirt, whose overcoming lead to the necessity of replace the detector with a new one. Sometimes detectors can also carry optional functionalities, which can be useful for a single specific application or systems, like:

- a sounder or siren included,
- a flashlight included,
- input / output interfaces, to control other components of the fire protection system or to get information from them,
- specific aesthetic design features, like smooth or plate design,
- protective metallic cages, for heavy applications where contact with moving object can be possible.

Depending on the application, smoke detectors can be installed as stand alone detectors, directly connected to a simple evaluation unit; or in complete systems where several detectors communicate between themselves and with one or more central processing unit, connected in open line or in a loop, depending on the communication standard, interface possibilities and on the redundancy necessities. In more advanced detection systems based on point smoke detectors a central processing unit monitors the complete series of detectors, analyzing detector's data, defining systems alarms, checking system functionality with diagnostic utilities, communicating at train level with the train control management system, (Figure 4).

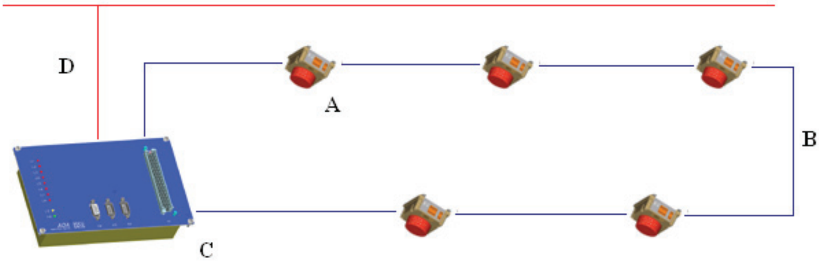

Fig. 4. Example layout of smoke detection system, based on point smoke detectors connected in loop with a central processing unit: A) point smoke detectors, B) connecting loop, C) central processing unit, D) communication with train control management system

While connected together in a smart systems monitored by a central unit, point smoke detectors can detect fire with a high accuracy, using the possibility to set their sensitiveness at different levels, or use logical procedures related to their activation to define position and even potential direction of the fire. A two or more detectors redundancy can be foreseen to validate an alarm, while in the same loop a detector can be specifically set up for being used to protect a toilet or a driver cabin (Fig. 5).

Fig. 5. Examples of different detectors and application in a EMU's vestibule [2]

1.2. Positioning of smoke detectors

Right positioning of smoke detectors in fundamental in the design of a smoke detection system, as by its layout is strongly belonging the effectiveness of the system to detect fires. Detection of fire by smoke detectors is often defined as passive, that means the smoke is naturally dragged up to the detectors by the relevant air movements in the scenario, due to heat of fire, air conditioning concept and presence of movable windows. Positioning of detectors in rolling stock applications is therefore based in following aspects:

- system specific design: what, where and in which way has to be monitored,
- volume of the ambient to protect,
- geometry of the volume to protect,
- air conditioning koncept,
- presence of specific sources of air movement, like told, as fans for over pressurizing (e.g. corridor between the driver's cabins of a loco), or windows that can be opened,
- project-related specific inputs, like presence of doors (and normally open or close?) or hidden spaces where a fire can start (e.g. luggage rack with closed deck and lateral panels).

While talking about smoke detectors, it is moreover important to discriminate between positioning and number: while the number of detectors can be defined mainly only by knowledge of volume a dimensions, like in applications as hotel rooms or offices, rolling stock application and especially passenger areas need specific positioning taking into account all factors introduced. In a rough assumption such aspect can be mistaken bringing to a positioning based only on volumes, making a system potentially not effective or not achieving homologation standards. It is clear how in a variable and irregular layout like a rolling stock application, the potential different scenario of fire are several and the impact of a HVAC fan or a door in air movements is absolutely relevant. Moreover, a train is not a real confined or controlled space, and whoever can go inside: such aspect has to be always considered, meaning possibility of vandalism, misuse or infringement of regulations.

As typical example, the role of an ingenuously unprepared smoking passenger can be dangerous in two ways: as potential source of false alarms, by smoking hidden in a toilet where detection is foresee; and as potential source of fire, while throwing a still burning cigarette end in the onboard trash. For this reason, normally first evaluations is made by checking the volumes and roughly estimate a number of detectors, basing on the „range" of applicability of the detector itself: such value can be only approximated in 4–5 meters per detector, and it is normally used in building application where volumes are more regular. But, as told, for rolling stock application this step can't be considered sufficient for an adequate positioning of detectors, therefore further steps have to be done.

The preliminary layout must therefore consider, as introduced, subdivision of volumes, presence of doors, presence and direction of HVAC ducts, presence of object that can stop the smoke as tables or luggage racks. The positioning must consider as well the different operational status of the stock. Are there doors, dividing e.g. staff area and passenger saloon? Are such doors normally closed of open? It is clear that, in case of doors normally closed, smoke produced on one side of the doors can't be properly detected on the other side.

Recirculation and HVAC can cause situations where the smoke is dragged far from a detector even if the fire is very close, or hidden spaces where smoke can accumulate far from the detectors. Interior furniture as well plays an important role in definition of smoke dynamics: a table can create a situation where smoke by vandalism stands under it, and only a detector placed very close can avoid detecting it too late.

The analysis of such factor can therefore give answers completely different and more reliable comparing with a rough estimation based only on vehicle's volumes. Typical mistake related to missing this vehicle oriented approach are:

- number of detectors higher than necessary: some detectors can be useless considering the air movement, sometimes a reduced number of detectors in the right places gives the same effectiveness of a higher number placed only basing on spacing,
- lack of detection in some possible scenarios, typically a fire starting right under an aspiration point of HVAC, or smoke bottled by two opposite fans in a volume were no detectors are placed.

Due to presented aspects, an adequate approach to smoke detector's positioning can't be free of a real scale, real conditions evaluation of the effectiveness. That's the approach followed on adopting the ARGE-Guideline for fire detection in rolling stock applications, where a real scale smoke test is considered necessary to certify the layout of the smoke detection system, carrying on smoke test in different conditions, especially in the potential worst-case, e.g. with max power in HVAC or open windows with running train. The design involves as well the detector's integration in the complete fire detection concept.

By exploiting the software possibilities given by the detectors and the central processing unit used, which may vary by manufacturer and product series, detections system layout can be configured in different way, considering e.g. stand alone detectors for toilets of special location, or detectors connected in loop that interexchange information about smoke and temperature, or two detectors dependency for confirmation of alarm (Fig. 6).

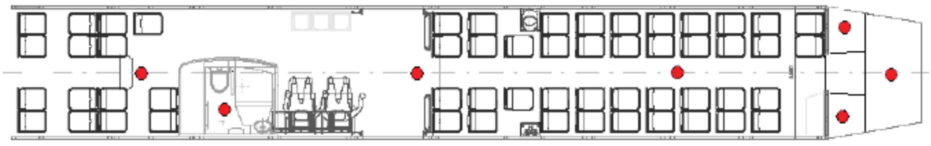

Fig. 6. Example of possible positions of point smoke detectors in a EMU driving coach. Can be seen three detectors in passenger areas, one in the toilet, one in the driving cab and two protecting the medium voltage electrical cabinets placed right behind the driving cabin

1.3. Smoke aspiration systems

Smoke detection can be done also via using a system that samples the air in different places and analyses it in a centralized detector. These systems are known as *smoke aspiration systems* and often sold with different acronyms, even if the main architecture is commonly shared. A smoke aspiration system is composed by centralized processing and control unit, which consists in one or more measuring chambers, similar to the point detectors depicted before, a fan to aspire the air from the monitored areas and an evaluation motherboard for the definition of system status and interfacing with train. Via the central unit is often possible to inspect system functionalities, check the data and run diagnostic tests, as presented for point detectors based systems.

Aspiration system consists in a certain number of plastic piping running through the areas to protect. Depending on the possibilities given by the central smoke detection unit, it is possible to have one or more channels ending in the devoted measuring chambers. The piping presents in different point some boring where air is aspirated by the depression created by the central fan. Such holes are connected normally via a flexible rubber hose to a same number of *sampling points*, consisting in small (usually, around 20–40mm diameter) inserts to place in the interior panels with a central opening, like an orifice or a boring, sometimes protected by a filter or a net to avoid bigger dirt particle to pollute the interior.

The air is therefore dragged by the flow up to the central unit, where the smoke is detected in a similar way as traditional optical smoke detectors. Also in that case, depending on type of central unit, a less or more sophisticated software analysis is carried out to define the alarms. Use of smoke aspiration system gives similar limits of point smoke detection regarding installation in dirt areas like engine room, where the dust normally present in the atmosphere can bring to false alarms or premature necessity of maintenance (cleaning).

Otherwise use of smoke aspiration systems can give some advantages; instead of point smoke detectors based systems, by the initial costs point of view, as its reduced number of components.

A major limit is found in system functionality: as point smoke detectors can monitor different areas at same time and their results be evaluated with accuracy to detect the right involved area, smoke aspiration systems can obviously define the location of smoke only with a limited precision, which limit is set by the number of possible parallel sampling channels and by the length of the aspiration duct.

Its low invasiveness by design point of view can anyway result helpful in interior integration, while, on the opposite, piping installation can in some application be not easy, e.g. in double deck coaches with reduced thickness of ceiling and wall panels.

The presence of active components like the fans and the natural higher propensity to dirtying (air is aspired and therefore its pollution is easier) can bring to higher life cycle costs which has to be always evaluated with attention.

1.4. Positioning of smoke sampling points and design of aspiration system

As for point detectors, mainly the positioning of sampling points have to be defined based on the system architecture necessities and on the specific application, considering volumes, air movements, HVAC layout. Sampling points can be defined as active elements, meaning that the air is forced inside measuring chamber by a fan and not by natural air movements. This can sometimes create a situation where boundary conditions (like HVAC inlet / outlet points) are less influent, as the smoke is anyway dragged to the detector by the fan.

One advantage of sampling points is that, due to their cheapness, even in a big number they don't affect system costs as much as a big number of detectors. By dimensioning point of view, sampling points can have different boring diameters in the way to adopt the sampling flow to the specific conditions. It might be necessary to have a sampling point which aspirates more than the other ones; or, on the opposite, the same flow rate can be requested to all sampling points. Both cases requests a specific boring diameter, due to the fact that the aspiration effect due to the fan is not constant all piping long: the specific piping design introduces friction losses (skin- and form-friction) which affect the pressure at the different sampling points. Also in such a case, like for point detectors positioning, a real accurate dimensioning and positioning of the sampling point can't be carried out without the support of smoke detection testing activities and precise analysis of train layout and boundaries conditions.

Joint with such fundamental activities, then software can help in modeling the piping and evaluate the friction losses as well as to define boring sizes. The piping size is normally defined by the manufacturer, and ranges in rolling stock applications around 20 mm. The most important component in such systems is the central unit, where the fan, the measuring chamber and the evaluation unit are located.

Depending on manufacturer and product range, systems can have one or more separated aspiration duct and devoted measuring chambers; the evaluation unit can be more or less sophisticated and differ in the interface standards at train level.

Basing on the fan adopted, the central unit can work with a specific maximum length of piping and maximum number of sampling points: typical limits are around 100–400 m in length[5] and some ten sampling points. To adapt the fan aspirating effect to working conditions, often the central units give the possibility to set the speed of the fan. The higher the speed, the stronger will be the aspiration effect of the fan; thus giving the chance e.g. to reduce speed (limiting therefore life cycle costs) while a limited sampling points number is monitored, or to set up a higher aspiration effect when piping architecture or length bring to high friction losses (Fig. 7).

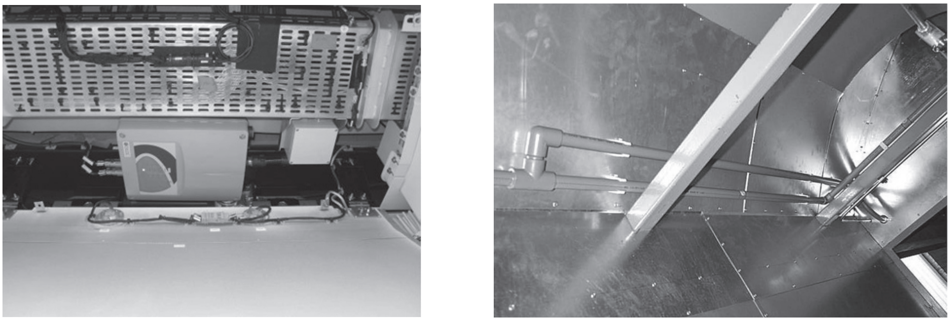

Fig. 7. Example of integration in the carbody of a smoke aspiration system

2. Gas detection systems

Combustion gases are always produced during the exothermal reaction between fuel and oxidizer, therefore one of the ways to detect the presence of a fire is to monitor the release of gases produced by the combustion process. Most monitored common combustion gases are carbon monoxide, NOx, sulfur dioxide or hydrogen chloride and bromide. Carbon dioxide, even if it is a common product of combustion, is not used for gas detection, as its presence in the atmosphere is usual due to its role in breathing cycle.

Different types of commercial gas detectors can be found, designed in the way to detect a specific gas (CO, SO_2) or multi-detectors allowing detection of a range of gases (Fig. 8). Gas detectors have only a limited diffusion in rolling stock applications, mainly because of the variety of potential combustion gases generated in such environment; anyway their use can't be excluded in prior. Their application is typical is specialized scenarios, where one specific known gas can be released and therefore its presence is used as indicator of alarm. The better service given by gas detectors is in case of smoldering fires, where no relevant smoke or heat

[5] In all fluid moving in a pipe, the length itself is often not adequately depictive, caused by different nature of the friction related losses of pressure: for this, in fluid dynamics is often used the equivalent length, means a linear length which considers also non-linear losses like in corners, clogging or connections.

releases happen. In such applications, a smoke or temperature detection could not be able to detect a fire, up to the moment where the smoldering fire spread out in a fast way leaving no chances of surviving (in passenger areas) or preserving the integrity of not affected materials (in a technical area). Normally gas detection systems are based on point gas detectors. They can be anyway implemented in gas aspiration systems as view in before for smoke detectors, even if such solution is not used in rolling stock application. By external point of view, a gas detector can look similar to a point smoke detector, even if slightly bigger in most of the cases, or like a simple metal box of similar dimension. Normally gas detectors for rolling stock application are based on semiconductor gas detection technology. The sensor itself is a metal oxide wafer (e.g. Tin dioxide, SnO_2), which is continuously heated up by electric energy. Over a certain temperature, the oxygen reacts with the semiconductor increasing its resistance.

The temperature threshold for activation of the chemical process can be even some hundred Celsius degrees, depending on kind of semiconductor used and kind of gas to be detected. While specific gases (deoxidizing gases) like combustion products go in touch with the heated up semiconductor, they react with the oxygen causing a reduction of the semiconductor resistance. This value can be checked and used as indicator of the presence of specific gases in the atmosphere. Set a certain current, the voltage resulting at the two extremities of the semiconductor varies in relationship with the resistance; and, depending on sensor features, the coefficients of a specific equation will be determined, giving the chance to express gas concentration as function of the variable resistance / voltage.

The selection of a gas detector has to start by the analysis of the possible combustion gases released, choosing therefore the devoted detector. Then its installation is easy, normally needing only electrical supply and an intercommunication connection. By interfacing, often such detectors are used in simple systems, where detector works stand-alone and only with an electrical signal (relay) with the control unit.

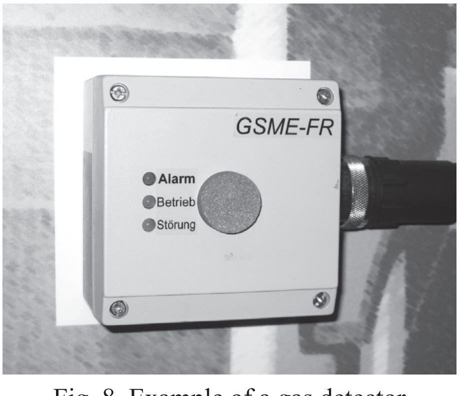

Fig. 8. Example of a gas detector

3. Temperature detection systems

Combustion is an exothermal reaction: it means a certain heat release amount is always present. Such released heat is a major fire effect and can therefore be used as detection element in a wide range of applications and with different technologies. The main technologies used for fire detection by temperature detection are:

- detection by linear heat sensitive electrical detectors,
- detection by point temperature detectors as thermocouples, thermostats or resistance thermometers,
- detection by linear heat sensitive pneumatic pressurized detectors,
- detection by point temperature glass bulb detectors.

Last two solutions include always, in rolling stock applications, integrated fire suppression / extinguishing systems. In rolling stock applications such technologies are widely used, especially for detection of fires in engine areas or electrical cabinets. Normally such components, especially electrical linear detectors and thermocouples, support highly harsh installation conditions, like dust, dirt, vibrations, pollution: for this their use in technical areas is very common. Their use in passenger areas is on the opposite limited and not preferable: in case of fire, temperature raise up is in fact slower than smoke creation; therefore detection of fire by temperature in passenger compartments can be too slow to ensure life surviving conditions for persons.

Some guidelines like e.g. the ARGE-Guidelines [1], often used for the systems validation, even don't foresee such chance of detection system in passenger areas. Temperature detection can be done additionally by using infrared or ultraviolet sensitive cameras: such technology will not be presented in this paper due to the length of this paper.

3.1. Linear heat sensitive electrical detectors

Electrical linear detectors are typically made by using a metallic cable running along the area to protect. The cable is protected by devoted sheaths, made in polymeric materials with different thermal sensitivity, set by the specific application. Internally, the cable is made by two or more conductor wires (in copper, aluminum or tin) which in normal conditions are electrically isolated by rubber sheaths. An interface box with a power supply applies a voltage to the cables and checks the wiring via a resistor on the opposite extremity. The resultant circuit is therefore a simple generator-resistor circuit, where the voltage at the resistor is monitored for checking the integrity of the wire.

In the real industrial products, then several resistors can be additionally present in the circuit to stabilize the current / voltage and have the possibility to discriminate between possible different false alarms. If a fire will affect the protected area, the heat release will cause an increase of temperature: when such temperature will reach the thermal decomposition limit of the protective sheaths, the protective sheaths will get damaged, therefore the internal wires will be melted transferring an electrical signal (short circuit or resistance disequilibrium) to the evaluation unit (Fig. 9).

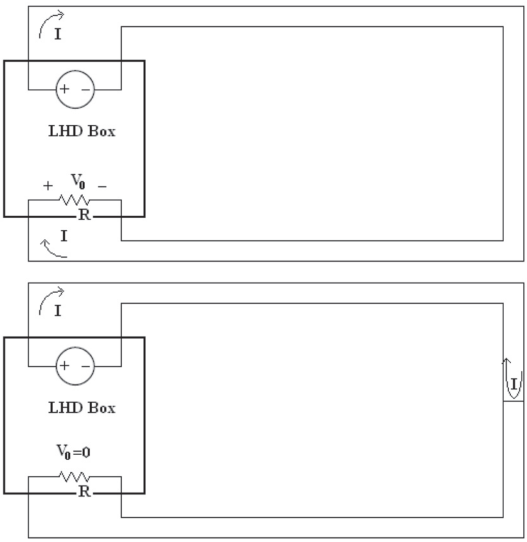

Fig. 9. Linear heat sensitive electrical detector layout. If the wires are melted, the line is short-circuited and the voltage at monitoring resistor *R* is zero

Such solution is very simple and easy to install and maintain, due to absence of stressed parts, and can afford high harshness conditions. The external sheath as well as the internal isolating rubber can be designed with different temperature thresholds, depending on the supposed associated fire risk.

Normally the fire sensitive cable is accompanied by a protective corrugated hose to protect it from mechanical stresses. The protective hose has to be integrated in the way to disrupt at a lower temperature then the internal electric cable. By installation point of view, the cable can be ran long or beside the risk affected components or areas, e.g. along an electrical cabinet hat rails or along the internal corners in a roof mounted module.

The fixing points can be realized by using cable ties, ring-screws or fasteners. The limit length of the cable is normally set by the manufacturer, ranging normally even up to some ten of meters. The complete system consists normally in the cable and an interface unit, which must be able to communicate with other components or systems depending on the design. The interface unit normally includes the monitoring components and the evaluation logics where present.

Depending on aim, application, type of stock, can be designed simple systems where the detection is only communicated at driver desk level, or where detection signal is used to control and activate a suppression agent release, or even detection subsystems included in complex fire protection systems which intercommunicate between each other and at train level, like introduced for loop designed point smoke detectors based systems (Fig. 10).

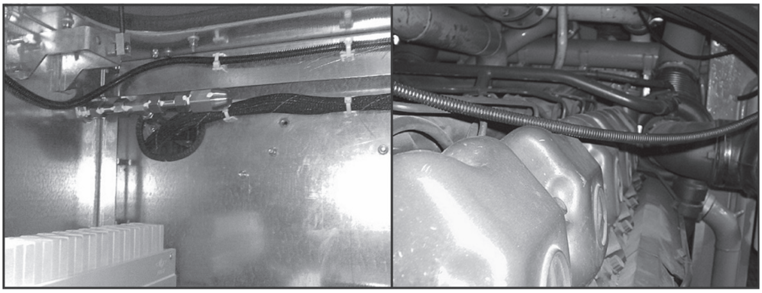

Fig. 10. Example of LHD cable and protective wire installation, along the internal walls of an electrical box (left, also fixing fasteners can be seen) or lying over cylinder head and turbocharger of a diesel locomotive engine (right)

3.2. Point temperature detectors

Point temperature detectors are a big family of detectors. Even if slightly different on the technological solutions adopted, they share a working logic based on the thermal properties of the metals. All metals present a specific relation between their temperature and their electrical resistivity. The relation can be approximated by a linear equation[6] lying temperature and resistivity, like:

$$\rho(T) = \rho_0 \cdot \left[1 + \alpha\left(T - T_0\right)\right][\Omega\text{m}].$$

Where *ρ(T)* is the electrical resistivity of the material at a temperature T; T_0 is, as reference, the ambient temperature of 298 K; ρ_0 is the electrical resistivity of the same material at T_0 and α is a specific coefficient depending on the material used. By the resistivity of the material, the resistance of the component can be defined, including in the calculation the length (L) and the cross section al area (S) of the conductor:

[6] Basing on the approximation adopted, equivalent non linear-relations can be found, where temperature appears at second or higher exponentiation.

$$R = \frac{\rho L}{S}\,[\Omega].$$

Therefore:

$$R(T) = R_0 \cdot \left[1 + \alpha\left(T - T_0\right)\right][\Omega\text{m}].$$

On such kind of equation are based all sensors which uses the resistance of a component as monitored quantity for the definition of the temperature. Depending on the specific sensor and manufacture technology, different solutions can be in detail used, monitoring the resistance by a voltage or a current control. Devices based on this feature can be in general joined by the definition of resistance thermometers. An example of basic design of such components can be a simple circuit, with a power supply and a Wheatstone bridge connected.

A Wheatstone bridge consists in two parallel branches of two resistors in line, and a central ammeter connected between the two parallel lines (Fig. 11). Considering the four resistors having the same features, in normal conditions all four resistors will have the same temperature and therefore the same known resistance value. If one of the resistors is subjected to an increase of temperature, the equilibrium of the bridge is altered and the related electrical signal (voltage or current gradient) can be used as monitored quantity.

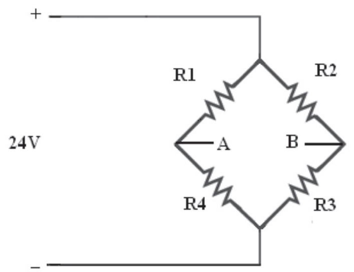

Fig. 11. Wheatstone bridge for resistance thermometer

Other kinds of sensors (often defined as thermostats or thermal switches) are instead based on the *thermal expansion* of specific components, to have a mechanical commutation of a switch following the reaching of a set-up temperature. The thermal expansion is the feature of a matter to expand its volume when subjected to an increase of temperature. As main assumption, this is valid for the most of materials, even though some specific materials can present a *negative* thermal expansion. For linear expansion, the equation can be expressed as:

$$\frac{\Delta L}{L} = \alpha_L (\Delta T).$$

Where α_L is the coefficient of linear thermal expansion; $\Delta L/L$ is the increasing ration of linear expansion; ad ΔT is the temperature delta. This feature is used to create devices in which the deformation associated to the thermal expansion is exploited to activate a switch.

As typical example of realization, a bi-material sheet, made by two metals having different thermal expansion coefficient, will deform when subjected to a thermal increase, bending in the direction of the material which have a the smaller coefficient (Fig. 12). With the right dimensioning, devices can be designed where the bent sheet will close or open an electrical circuit, giving therefore a signal that can be used as alarm (Fig. 13).

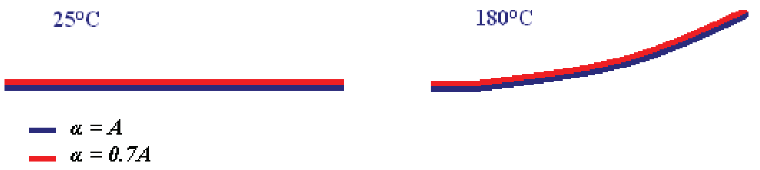

Fig. 12. A sheet made by two materials coupled, having different thermal expansion coefficient, will bend in the direction of the material having the lower coefficient, when subjected to a temperature increase

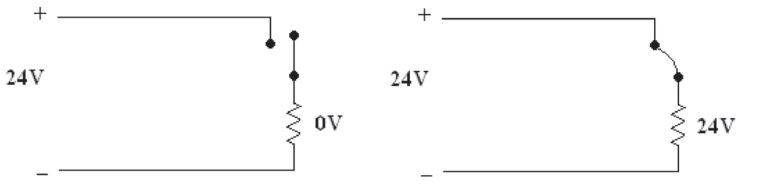

Fig. 13. Example of basic circuit with an integrated thermal switch. Depending on the design, several additional components (resistors, ammeters etc.) can be present; the switch can be normally closed or normally open

In a rolling stock application, temperature detectors of different type are widely used, in different scenarios and with different roles. Typical use or point detectors like resistance thermometers or thermal switches are e g. stand alone detectors directly connected to a CPU for evaluating the signals and forward alarms, to a suppression system or at train information system level (Fig. 14, 15). Depending on manufacturer and design of the detector, additional characteristics can be present, like electronic evaluation of the temperature data and interface and communication standards for applications in different complex systems.

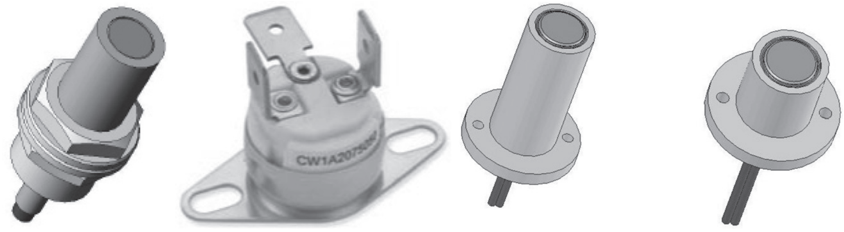

Fig. 14. Examples of point temperature detectors

Fig. 15. Electronic incremental temperature detector,
able to interface with complex systems

Due to their features, temperature detector can ensure a prompt and quick activation only if placed directly in contact or very close to the potential fire source to be monitored. This is way their use is common in technical areas, where the potential burning components can be identified in detail and with specific information concerning their limit temperature.

Use of this kind of components to protect passenger areas is, contrarily, not suggestible and improper: the wide range of possible fire sources, fire locations and possible fire temperatures, due to variety of the possible scenarios, makes not easy to define where and with which specific features a fire event can happen. For this reason, use of such kind of temperature detectors in passenger areas is never done. Application of temperature detection in passenger area can be found in combination with smoke detection (e.g. several marketed point smoke detectors include temperature detection) or, like in building borrowed sprinkler and water mist system, with thermo-sensitive glass bulb sensors directly connected to the piping of the suppression agent. Such solution will be presented in the next subchapter.

3.3. Glass bulb detection systems

As presented before, another kind of point temperature detection is the technology known as *glass bulb* detection systems. The main feature of such detectors is that, instead of the previously presented which can be integrated in a complete firefighting system or as a stand-alone fire detection system, they are only used in combination with water-based fire suppression systems like sprinkler and water mist systems.

As already explained, only temperature is not an adequate indicator for fire alarms in passenger areas of rolling stock, where the different fire scenarios, together with the bigger danger associated to smoke instead of heat, makes the smoke detection (point or aspiration based) the most effective and performing solution.

Temperature detection by glass bulb detectors is a technology borrowed from building industry, where volumes are bigger and the direct smoke and heat associated danger for people is not as highly relevant, as an escaping route can be normally foreseen.

In a passenger train, a possible escaping route cannot be considered in principle, and the fire detection has to be very fast to ensure the alarm definition before the overcoming of the on board surviving conditions.

Glass bulb detectors integrate the water sprinkler or the water mist nozzle in one component: this is the main advantage of such solutions, also called *glass bulb nozzles* or *glass bulb sprinklers*, depending on use of water mist or water as suppression technology.

A glass bulb detector-nozzle or sprinkler presents a glass bulb integrated in its body design, filled with an alcohol. If the bulb is heated up, the alcohol increases its temperature: the subsequent increase of pressure due to vaporization process breaks the glass at the defined set-up temperature. The integrated body of the detector-nozzles is designed in the way that, when the glass bulb breaks, a mechanical device is triggered to open the nozzle. Normally, a spring is forced by the glass bulb to maintain close the nozzles orifice by acting on a small piston. If the glass bulb breaks, the reaction force of the spring is no more balanced and the piston is positioned in the way to open the orifice. Glass bulbs are standardized by building norms, especially in the color of the bulb which is an indicator of set-up temperature of the bulb (Table 1).

Table 1

Standardized glass bulb colors in relation with temperature

Temperature	57°C	68°C	79°C	93°C	141°C	182°C	260°C
Color	(orange)	(red)	(yellow)	(green)	(light blue)	(purple)	(black)

In some applications heat sensitive glass bulb nozzles can be found integrated in the so-called *pre-action systems*: with such design, an independent fire detection system, typically a smoke detection system, is used together with glass bulb activation (Fig. 16).

Fig. 16. High-pressure water mist automatic nozzle with glass bulb temperature sensitive head, for building applications

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Systemy wykrywania pożaru do zastosowań w taborze szynowym 2013

Streszczenie
Autor na wstępie podkreśla, że kluczową rolę w ochronie życia ludzkiego oraz zabezpieczeniu przed stratami materialnymi w przypadku ewentualnego pożaru odgrywa sprawne i wczesne jego wykrywanie. Następnie omawia zjawiska fizyczne wykorzystane w różnych technikach detekcji stosowanych w pojazdach szynowych, przedstawiając również konkretne praktyczne rozwiązania. W artykule Autor uwzględnia również wpływ właściwego rozmieszczenia czujek na efektywność działania instalacji, a także prezentuje wyniki badań ich skuteczności.

Słowa kluczowe: ochrona przeciwpożarowa, straż pożarna, mgła wodna, tabor kolejowy

Системы обнаружения пожара, предназначенные для применения в подвижном составе

Резюме
В начале статьи автор подчёркивает, что ключевую роль в защите человеческой жизни и сохранении от материальных потерь в случае возникновения пожара играет чёткое и раннее его обнаружение. Затем обсуждает физические явления, используемые в разных техниках детектирования, применяемых в подвижном составе, представляя также определённые практические решения. Автор рассматривает также влияние соответствующего месторасположения извещателей на эффективность функционирования системы, а также даёт результаты испытаний их эффективности.

Ключевые слова: пожар, обнаружение пожара, детектирование пожара в подвижном составе, пожарные извещатели