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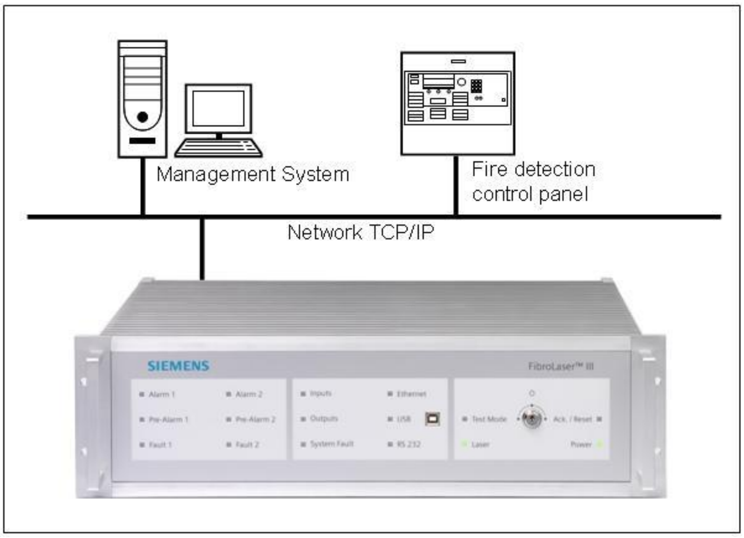

FibroLaser™ III

System Introduction and Planning

Building Technologies

CPS Fire Safety

1 About this Document

1.1 Documentation Structure

This document is part of the FibroLaser III documentation. The various elements of the technical documentation for FibroLaser III are listed below:

- **System introduction and planning:**
  The document provides an overview of the FibroLaser III system and includes important notes to be adhered to during the project planning.
- Installation Manual:
  The document includes all relevant information required for the successful installation of a FibroLaser III system.
- Operating Manual:
  This document comprises all information required to commission the device with the commissioning software FibroManager.
- Maintenance and Repair:
  This document contains the information required for the system maintenance.
  In addition, the document contains instructions for field repair work.

1.2 Purpose of the Document

The document System Introduction and Planning provides important information for persons who, as part of their duties, are responsible for project design and must be familiar with the FibroLaser III system.

2 Introduction

2.1 Use

The system FibroLaser **III** is the latest generation of a linear heat detection system based on fiber-optic sensors. Due to the measuring characteristics the system is especially suitable for a trouble-free fire protection of objects where conventional fire detection is not suitable due to local and environmental conditions.

Fields of application are car railway tunnels, production and warehouse buildings, cable lines, conveyor belts, false ceilings or power plants.

2.2 History

The evaluation unit OTS30xx (OTS = **O**ptical **T**emperature **S**ensing) is a further development of OTS-X, which has been successfully used in many applications for many years.

Since the end of the 1980s, quartz glass fibers enclosed in stainless steel tubes have been integrated into outdoor lines and power cables as optical fibers in order to transfer information (network control technology) undisturbed by electrical and mechanical fields. Experience with these optical fibers confirmed that these fiber-optic systems were not only suited for transmitting information, but could also be used as locally distributed measurement sensors.

2.3 Measuring Principle

Physical measurement values, such as temperature or pressure and tensile forces, can affect glass fibers and locally change the characteristics of light transmission in the fiber. As a result of the dampening of the light in the quartz glass fibers through scattering, the location of an external physical effect can be determined, so that the optical fiber can be used as a linear sensor.

The so-called Raman effect is especially suited for temperature measurement with optical fibers made of quartz glass. The light in the glass fiber scatters at microscopically small density fluctuations, which are smaller than the wavelengths.
In addition to the elastic scatter share (Rayleigh scatter), which has the same wavelength as the irradiated light, the backscatter also contains additional components with other wavelengths, linked to the molecular oscillation and thus to the local temperature (Raman scatter, see annex).

In the case of OTS, with semiconductor laser diodes and a new type of evaluation procedure, it is possible to measure both scatter effects (Rayleigh and Raman scatter) in optical fibers of up to 10 km length. By optimizing the measurement interval time and the local resolution, it is possible to display temperature changes of a few degrees Celsius per minute safely and without malfunction. For these reasons, OTS is especially suitable for fire detection in objects in which the use of conventional fire detectors is not suitable due to extreme environmental conditions.

2.4 Features

The system consists of two principal elements: the controller and the fiber-optic sensor cable.

Sensor cable features

- It is a component of a linear fire detection system that can detect hot gases and radiated heat and is adaptable to the individual object.
- It contains no electronics and is therefore immune to electromagnetic disturbances of all kinds, and so is ideal for temperature measurement in electromagnetically contaminated areas.
- The design of the sensor cable (life expectancy up to 30 years) is very robust and therefore resistant to environmental influences, such as temperature, pressure and moisture, but also to pollution and exhaust gases, which include corrosive materials.
- Installation and maintenance of the sensor cable is simple; defective locations can be repaired (spliced).
- The sensor cable can be cut over kilometers to the required length without restrictions.

Controller features

- The temperature profile is calculated over the entire sensor length; alarming is triggered when a defined alarm criterion is exceeded.
- Exact location of the seat of fire or hot spots.
- Information on the direction of the fire spread or hot spot.
- Activation of pre-programmed control sequences regarding traffic signaling, ventilation control, video systems and extinguishing systems.
- Transmission of all relevant information to a superordinate management system.
- Visualization of the system status.

2.5 Applications

In addition to the original application of optimizing the load of power cables, fiber-optic temperature sensors are used today in various applications, among others for monitoring:

– road icing
– leaks, e.g. in pipelines

In the area of fire detection, apart from the main application in road and railway tunnels, the system is increasingly applied in other fields:

– in underground mining, to monitor transport systems
– in steel production, to monitor production facilities
– in power plants, to monitor cable platforms and shafts
– in underground train stations and shopping centers, to monitor escalators
– in nuclear power plants, to monitor radioactively contaminated areas (interim storage, pump sump)

3 The System

3.1 System Architecture

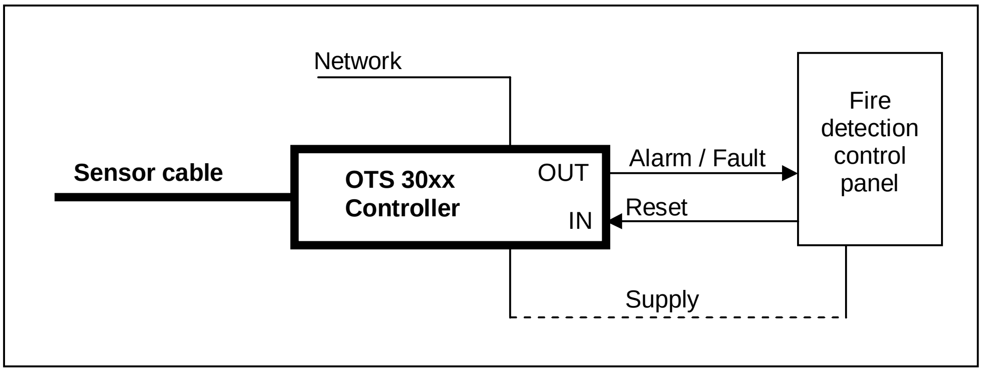

Fig. 1 System architecture (single channel system)

The linear heat detection system consists of the following system architecture:

- Fiber-optic sensor cable
- OTS30xx controller with laser light generation, measuring signal evaluation and control functions
- Up to max. 106 potential-free outputs for alarm and fault messages
- Up to max. 40 opto-decoupled inputs for reset or external alarm monitoring
- Network connection to transmit the system status and temperature profiles, to visualize the system status on a PC, or to integrate the controller into a superordinate danger management system
- Power supply

3.2 Sensor Cable

The sensor cable consists of an inner tube made of stainless steel or polyamide, housing two independent quartz fibers. The fibers have different colors for a better distinction.

To improve the mechanic stability and the handling during installation, the pipe is encased with a black plastic insulation layer.

To facilitate the classification into zones, check marks are imprinted on the sensor cable at intervals of 1 meter.

In addition to the sensor cables for standard applications MFLT4FRNC and SWLT4FRNC, cables for special applications are also available.

3.2.1 Metal-free Sensor Cables

The glass fibers used are multi-mode waveguide with the gradient 62.5/125/250 (international standard dimensions and features) and are suited to generate a strong Raman effect.

The glass fibers are located in a polyamide tube which is sheathed by an aramid thread for reinforcement.

The cable is clad by an infrared absorbing cable insulation made of FRNC with a diameter of 4 mm.

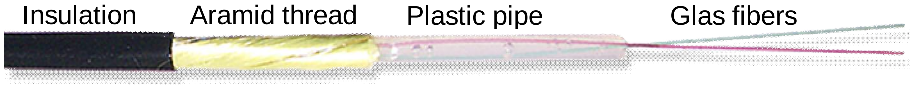

Fig. 2 Sensor cable MFLT4FRNC

3.2.2 Sensor Cables Stranded with Steel Wire

The glass fibers used are multi-mode waveguide with the gradient 62.5/125/250 (international standard dimensions and features) and are suited to generate a strong Raman effect.

The glass fibers are located in a stainless steel tube which is stranded with stainless steel wires for reinforcement.

The cable is clad by an infrared absorbing cable insulation made of FRNC with a diameter of 4 mm.

Fig. 3 Sensor cable SWLT4FRNC

3.2.3 Cable Length

The total active sensor cable length must be shorter than the distance range of the controller. When calculating the total sensor cable length, cable lengths outside the measurement section must be taken into account. These are:

- feed cable from controller to measurement section,
- connection cables and fibers,
- avoidance of obstacles,
- test and reference lengths,
- height differences and
- about 5 m of fiber length in the controller cabinet.

In addition to the active sensor cable length, a few sampling intervals (e.g. 20 m at a sampling interval of 3 m) of inactive fiber length are required at the end of the measurement section to suppress influences of a possible fiber end reflex. The controller accepts an inactive fiber length of up to 100 m in addition the distance range. By this, proper temperature readings are obtained for the full distance range.

Only use the controller with a minimum total fiber length of at least 100 m.

3.2.4 Accessories

Pigtails

Pigtails are tailored connection cables linking the installed sensor cable to the OTS controller. An optical APC (angled physical contact) E-2000 8° is mounted on one end of the pigtail; the other end is spliced to the sensor cable.

Splice box
Splicing means welding two glass fiber cable ends together using a special tool. When splicing, a few meters of the cable ends are insulated and the stainless steel pipe is removed. The cable ends are thoroughly reeled up in the splice box and thus protected against magnetic influences.

3.3 OTS Controller

3.3.1 Functional Units

The OTS controller is the transmission, evaluation and control unit of the linear heat detection system FibroLaser and consists of the following modules:

– Transmission module
  In this module the laser light is processed and then sent to the sensor cable glass fiber via an optic system.

– Receiver module
  This module receives the scattered light sent back by the sensor fiber, converting it from an optical signal to an electrical signal.

– Evaluation module
  The evaluation unit calculates the temperature profile along the sensor cable based on the recorded measuring values.

– Control module
  The control module controls the measuring sequence and manages the integrated inputs used for monitoring functions or for resetting and forwarding external alarms. The outputs used for the transmission of alarms and fault messages to a fire detection control panel are equally controlled by this module.

– Communication module
  The communication module includes the USB and Ethernet ports and an RS232 port. The controller can be commissioned via the USB port of the Ethernet port. The controller can be connected to a superordinate management system or a PC with a visualization software, optionally via the Ethernet or (for older systems) the RS232 port.

– Supply module
  The power supply unit feeds all the controller components with the required operating voltage.

3.3.2 Variants

The FibroLaser III controllers OTS30xx are available as single channel and dual channel devices with maximum measuring lengths of 1, 2, 4, 6, and 10 km.

These devices are optionally equipped with either a 24VDC supply unit (standard) or a 115/230VAC supply unit (option).

In the basic variant the devices are equipped with 4 inputs and 12 outputs that can be used for control and activation functions. The devices can be optionally equipped with up to 40 inputs or 106 outputs.

Examples:

OTS3004 24VCD	Single channel system for 4 km maximum measuring length and a 24VDC supply unit
OTS3010-SC 115/230VAC	Dual channel system for 2x 10 km maximum length and a 115/230VAC supply unit

3.4 Power Supply

The FibroLaser III controllers must be operated with a power supply module of either 24VDC or 115/230VAC, depending on the type.

As FibroLaser is a safety-relevant system, the energy supply must be designed in such a way that a redundant energy source is available in case of a failure of the main energy source.

3.5 Commissioning

FibroManager is software facilitating an efficient commissioning and functional check of the system.

The FibroManager software installed on a PC communicates with the controller via the USB or Ethernet port.

3.6 VdS Approval

The German VdS approval EN 54-22 of the OTS30xx relates to the combination of sensor cable and controller as a linear heat detector, which is part of a fire detection system.

The following system configuration applies (Fig. 1):

- Energy supply by a power supply unit in accordance with EN54-4
- Alarm and fault reports to the fire detection control panel via the controller's voltage-free contact outputs
- Alarm acknowledgements of the fire detection control panel via a digital controller input

3.7 Integration into an Overall System

The FibroLaser III controllers are equipped with an Ethernet and an RS232 port. The integration into an overall system is possible via these ports.

With newer systems, the Ethernet port is preferably used.

The RS232 port facilitates an easy and cost-optimized modernization of existing installations, as the OTS 30xx also supports the protocols of previous FibroLaser generations (OTS100 and OTS-X). If an OTS100 or an OTS-X is substituted by an OTS30xx, the entire network connection can be maintained without any adaptation.

4 Functions

4.1 Overview

The OFDR technology used in FibroLaser makes it possible to determine the temperature over the entire sensor cable length.

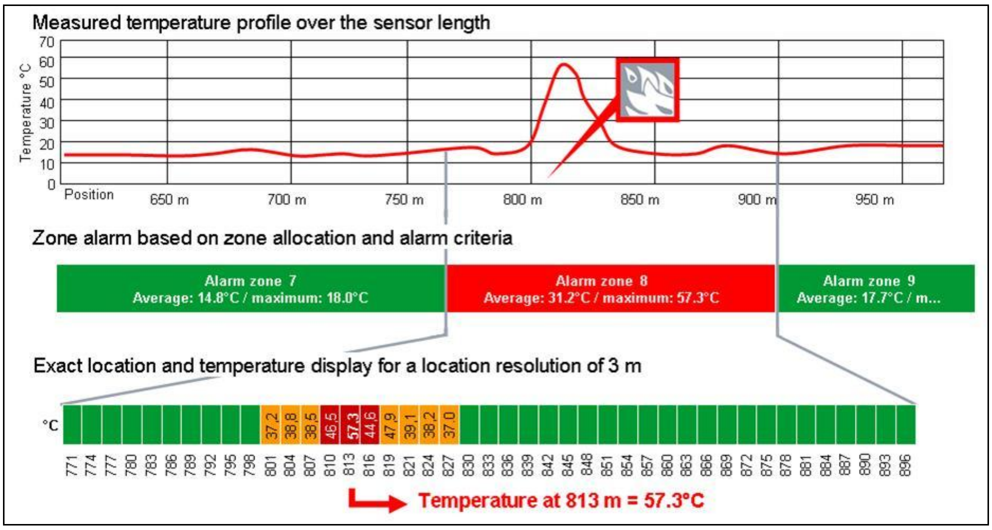

Fig. 4 Temperature – Zone – Spatial resolution

The controller calculates a temperature profile over the entire sensor length. The temperature is measured periodically, i.e. in measuring cycles.

When the temperature profile in a zone exceeds one of the alarm criteria defined for this particular zone, a collective alarm and a zone alarm are generated.

The accuracy of the position at which the temperature is exceeded is determined by the spatial resolution (in this example, with an accuracy of 3 m)

4.2 Alarming

With the OTS30xx it is possible to define pre-alarm criteria in addition to the regular alarm criteria. This enables the system to generate a warning before the actual alarm threshold is reached.

A pre-alarm or alarm is generated when one of the 3 following criteria is exceeded:

1: Maximum temperature

2: Temperature increase over time

3: Temperature difference between a measuring point and the average zone value

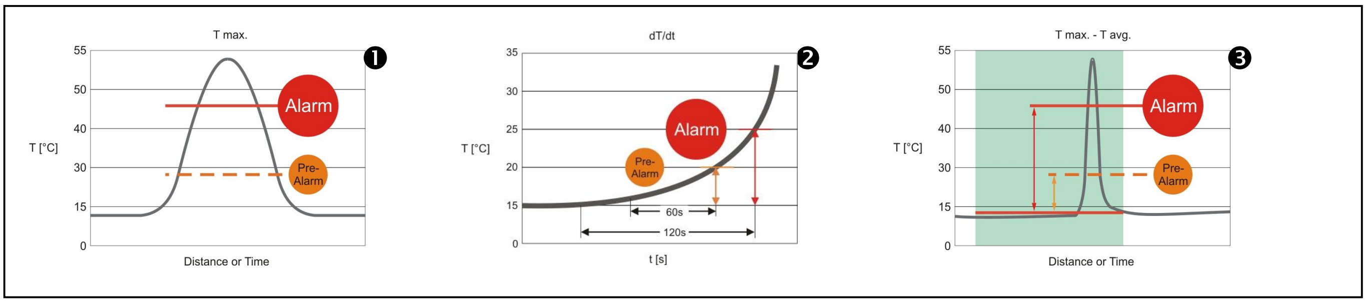

Fig. 5 Alarm criteria

These settings can be individually adapted to the conditions prevailing at each monitored zone.

Alarming

The system's behavior in the event of an alarm or pre-alarm can be very flexibly adapted to the prevailing conditions or legal provisions. It is e.g. possible to define specific outputs for different events, for the hardware transmission of pre-alarms or alarms. In addition, the events can be forwarded to a superordinate system via one of the ports.

In case of alarm, the optical alarm indicator on the device (red LED "ALARM") and the output "Collective alarm", which is automatically activated, cannot be influenced.

If a pre-alarm criterion has already been defined during commissioning, this is automatically indicated on the device in the event of a pre-alarm (orange LED "Pre-Alarm").

Alarm Reset

Alarms must be actively reset, which is possible with an input contact, with a key switch on the controller front plate or, on the software side, via an interface.

Pre-alarms need only be actively reset if this has been parameterized during the system commissioning.

4.3 Position Indication

The accuracy of the position indication of a fire or overheating can be influenced by selecting the spatial resolution, which can be chosen between 0.25 m and 3 m for continuous measuring, depending on the project.

The longer the sensor cable and the shorter the spatial resolution, the more measuring points must be polled and the longer is a measuring cycle.

With the OTS, the desired spatial resolution and the measuring cycle are defined during commissioning by selecting the corresponding measurement parameter set.

4.4 Fire Size

For an optimum fire fighting planning it is of utmost importance for the intervention forces to have sufficient information on the temperature, fire location, fire size and fire spread.

The system provides this information as fire classes. Each fire is classified accordingly:

- Class 1: Fire spread up to 3 m
- Class 2: Fire spread up to 10 m
- Class 3: Fire spread up to 30 m
- Class 4: Fire spread up to 100 m
- Class 5: Fire spread up to 300 m

The fire class relating to the specific fire situation can then be forwarded to a superordinate system.

4.5 Direction of Fire Spread

Most fires have a dominant direction of spread, which results from the expanding, hot fire gases and the wind flow. Knowing this direction of spread, the intervention forces (fire brigade, ambulance, etc.) can direct their attack to the less dangerous side of the fire.

The system signals one of three possible directions of fire spread:

- No direction of spread (stationary)
- Towards the OTS controller (beginning of sensor cable)
- In the opposite direction of the OTS controller (end of sensor cable)

The direction determined for the current fire situation can be forwarded to a superordinate system.

4.6 Controls

The control of video, ventilation or lighting is a central function supported by the system.

To optimize the various controls, the entire cable length is subdivided into different zones, depending on the project. A zone is an uninterrupted sensor cable section, to which the controls required for this zone are allocated.

At maximum 1000 freely definable zones are available; these zones may overlap.

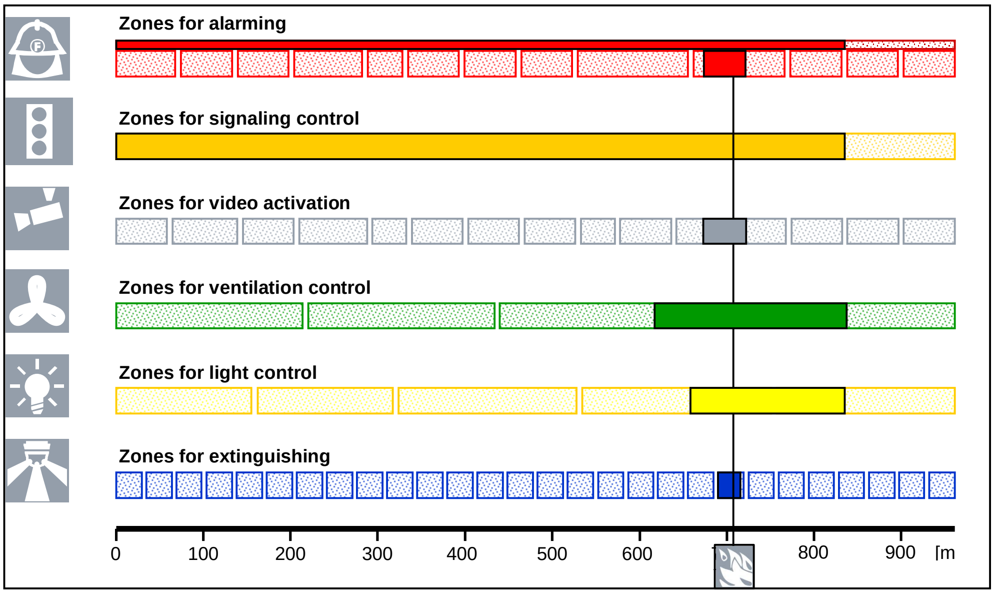

Fig. 6 Activated controls based on zones and fire location

The figure above shows that in this example an alarm is triggered and a tunnel is blocked – entirely independent from the fire location. In addition, a zone alarm is generated and the video, ventilation, lighting and extinguishing control is activated in the fire zone.

5 Planning

5.1 General Information

Before the planning of a FibroLaser project it is necessary to acquire information on the dimensions of the area to be monitored, on possible external influences and the special customer requirements.

5.1.1 Dimensions

The dimensions of the area to be monitored serve as a basis for the selection of the controller and the required sensor cable length.

If e.g. a tunnel shall be protected, the following parameters must be defined:

– Tunnel length
– Tunnel section profile incl. width and height
– Number of tunnel sections
– Number of traffic lanes, incl. emergency lane
– Special areas in the tunnel such as emergency bays, additional tunnel entrances and exits or special construction forms including the tunnel cross section at these sports

5.1.2 Environmental Conditions

Environmental conditions such as temperature, humidity, dust or corrosive gases affect the long-term quality of any product. These aspects must be taken into consideration when planning a FibroLaser system.

Regarding the positioning of the controllers, this means that they have to be placed in a clean area in which the maximum admissible ambient temperature and humidity values will not be exceeded.

The sensor cables used in the FibroLaser system are extremely robust against external influences such as humidity, dust, dirt or corrosive vapor and can also be applied in very rough ambient conditions.

For the selection of the optimum alarm parameters it is equally important to acquire information on the temperature development of the different areas throughout the year (e.g. tunnel entrance and exit areas).

5.1.3 Customer Requirements

It is substantial to clarify the customer requirements before beginning with the planning. Some aspects that require special consideration are:

– Does the customer expect a redundant installation?
– What guidelines and standards must be observed?
– Will the customer carry out an acceptance test after the installation (possibly with test fire)? If yes, what are the test parameters?
– Where can the controllers be installed; i.e. are there any appropriate technical rooms with appropriate ambient conditions?
– Are there any limits or obstacles affecting cabling?
– How shall the FibroLaser system be integrated into a superordinate system?

5.2 Cable Placement

5.2.1 General

The cable position depends on the geography of the area to be monitored, and on the installation limitations defined by the customer.

In general, the sensor cable should be mounted at the highest point of the room, at a distance of 5 - 20 cm from the ceiling. For safe fire detection, it is critical that the cable can "see" a fire. This must be specially considered with ceiling hoists, obstacles, but also with ventilation ducts and lighting fixtures near the sensor cable mounting area.

If an unambiguous mapping of events within fire compartments is required, we recommend using an extra length of at least six times the spatial resolution sensor cable in between the alarm zones of the fire compartments.

The sensor cable shall be placed in one piece. Splicing of several sensor cable pieces is only permissible in special exceptional cases. As every splice leads to attenuation, additional splicing of the pigtail is only admissible if the optical attenuation of the sensor cable does not exceed the admissible maximum value!

Regarding the installation of the sensor cable, possible mounting techniques, lighting, cable channels, etc. must be taken into consideration. The sensor cable must not be placed in the immediate vicinity of lighting fixtures constituting significant heat sources, as this may lead to false alarms.

With obstacles such as lamps or fans, the cable shall be placed as shown in the figures below:

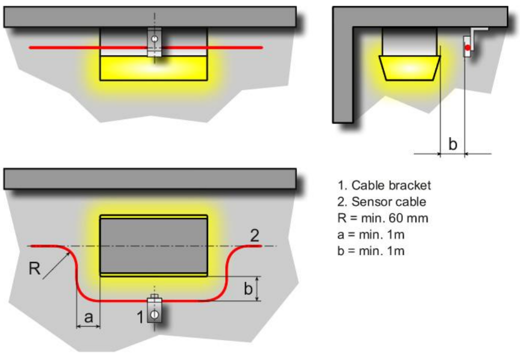

Fig. 7 Installation around lamps

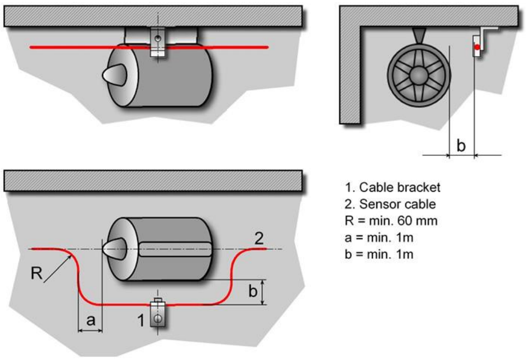

Fig. 8 Installation around fans

5.2.2 Placement in Road Tunnels

In road tunnels, it is recommended to install the cable in the tunnel ceiling area above the traffic lanes. The exact position must be agreed upon with the customer.

At tunnel entrances large temperature differences may occur, depending on the weather, season, time of day and traffic volume. For this reason, no sensor cables should be placed within a distance of 20 m from the tunnel entrance. Alternatively, a special alarm parameter that is adapted to the situation can be used for these entrance zones.

Normally, in a tunnel with a maximum width of 10 m only one sensor cable is placed. In tunnels with widths > 10m, two or more sensor cables shall be placed to ensure early fire detection.

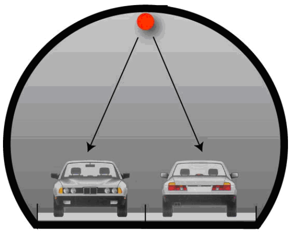

Fig. 9 Tunnel with a width < 10 m and one sensor cable

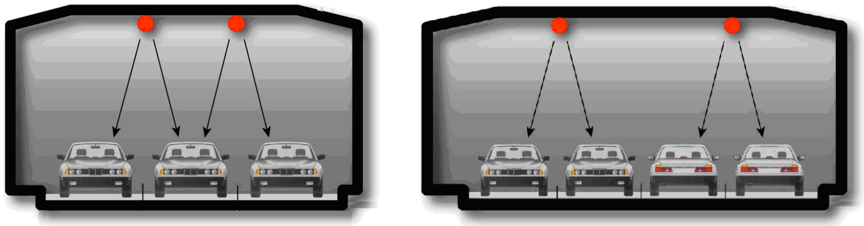

Fig. 10 Tunnel with a width > 10 m and two sensor cables

The cable is not always placed directly above the traffic lane throughout the tunnel. If there are special emergency bays or exits in the tunnel, it may be advisable to modify the installation method.

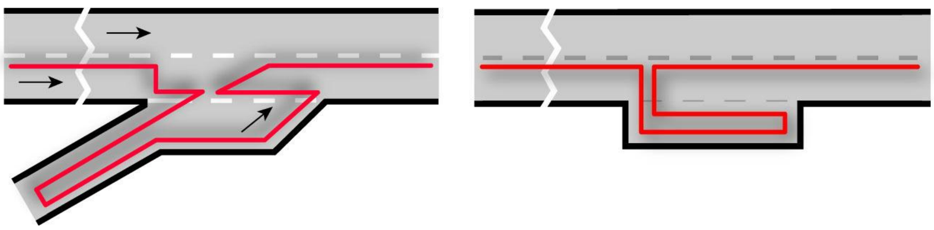

Fig. 11 Cabling in entrances and emergency bays

In multi-lane city tunnels, there may be additional entrance or exit areas, in addition to the transit lanes. These tunnel sections must be protected if they are longer than 400 m.

5.2.3 Placement in Railway Tunnels

The exact cable position in a railway tunnel depends on the geography of the tunnel cross-section and the installation restrictions defined by the customer.

Like in a road tunnel, it is recommendable to install the cable in the tunnel ceiling area above the traffic lanes. However, in many cases a cable placement on the ceiling is unfavorable. In these cases, the cable should be preferably installed on the walls, as:

- otherwise the cable would be in conflict with the overhead contact line;
- train fires often occur near the gear sets, where overheating may occur;
- fires inside passenger trains can be detected through the heat radiated through the windows;
- wagon roofs often constitute heat sources, which may lead to false alarms.

The exact position must be agreed upon with the customer.

If a cable is installed at the tunnel wall, a height of 2 m is recommendable.

If an overhead contact line is installed in the tunnel, we recommend the metal-free cable type MFLT4, as electromagnetic interferences can be ruled out with this cable type. If the tunnels are only used by Diesel trains, or if power supply is ensured with a power rail, the metalliferous cable SWLT4 may as well be used; however, earthing is mandatory in that case.

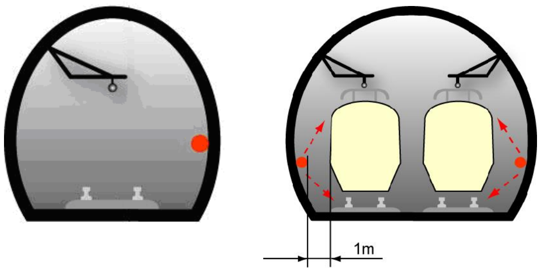

Fig. 12 Single-tracked and double-tracked tunnels

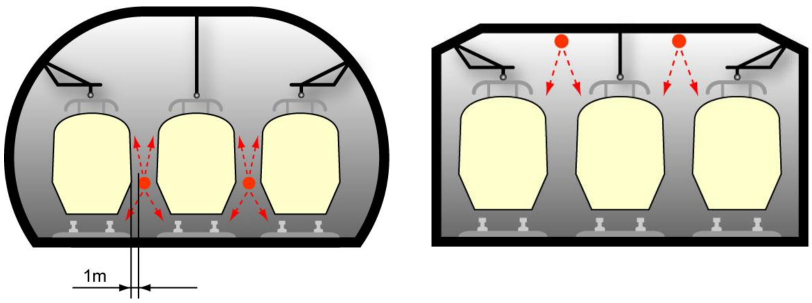

Fig. 13 Tunnel with three tracks

Cable placement in stations

Even if only one station area, e.g. in a subway train, is protected, the cable position must be agreed upon with the customer. The same installation restrictions apply as for entire tunnels.

As stations areas are usually relatively small, combined protection of ceiling and wall areas is recommendable, provided that the customer agrees to a ceiling installation.

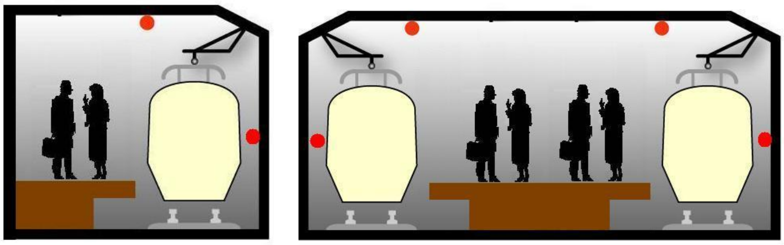

Fig. 14 Single-tracked station / Double-tracked station with central platform

An installation at approx. 2 m wall height is not always possible with double-tracked stations. Alternatively, the cable can be placed at the side of the platform.

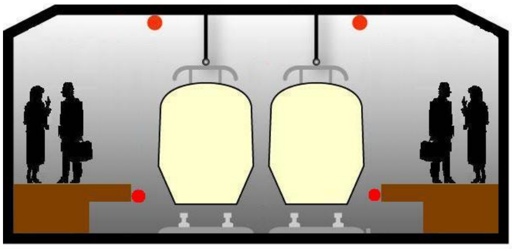

Fig. 15 Double-tracked station with lateral platform

5.2.4 Placement in Buildings

In general, the sensor cable should be mounted at the highest point of the room, at a distance of 5 - 20 cm from the ceiling. If the installation has to fulfill a specific standard or regulation a detailed analysis of the instructions given in the related documents is required.

For example; DIN VDE 0833-2 specifies the maximum height for mounting the sensor cable of an EN 54-22 approved linear heat detector with response to class A1 is 9 m and 7.5 m for a class A2 system.

5.2.5 Placement in Other Applications

If the system is intended to monitor a production area (e.g. conveyor belt), the cable must be positioned in such a way that the distance between the cables to the objects (e.g. rolls) on which the system shall detect an abnormal temperature increase is as short as possible.

5.2.6 Test Sections

Test sections permit to periodically check the FibroLaser system using the testing device “FibroTester” without the need to block or necessarily enter the protected area. The FibroLaser system can continue working. Test sections can be established at easily accessible locations outside the danger area (e.g. in recesses in case of tunnels) outside the danger area. To make testing possible without a ladder, the sensor cable is mounted at 2 m in height over a length of approx. 6 m.

A test section is normally set up at the beginning and at the end of the sensor cable. With larger monitoring lengths, it is possible to set up more than 2 test sections; this must be agreed upon with the customer.

5.2.7 Reversal Point

If the direction of spread is supposed to be indicated on the control panel, the reversal point must be defined at the correct position and tested after commissioning.

Fig. 16 Monitoring of two tunnel tubes with one sensor cable

5.3 Controller Placement

5.3.1 General

The positioning of the controller strongly depends on the infrastructure of the object to be monitored. It is important that the controller be installed in a clean room in which the admissible ambient conditions regarding temperature and humidity are not exceeded. In most cases the controller is placed in a technical room.

If several rooms are available, a room should be preferably chosen in which the required coverage area can be monitored by a possibly short sensor cable length.

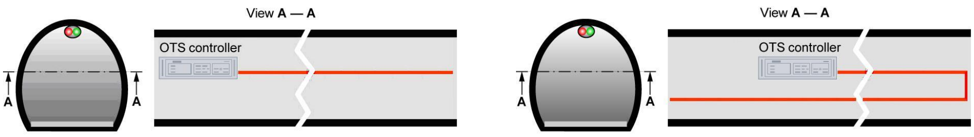

Fig. 17 Optimally vs. not optimally suited controller position

5.3.2 Redundant System

With a FibroLaser system it is possible to realize different levels of redundancy.

The figure below shows the standard, redundant setup, in which two controllers are connected to one sensor cable. This is possible with one sensor cable, as each cable contains two glass fibers (red and green).

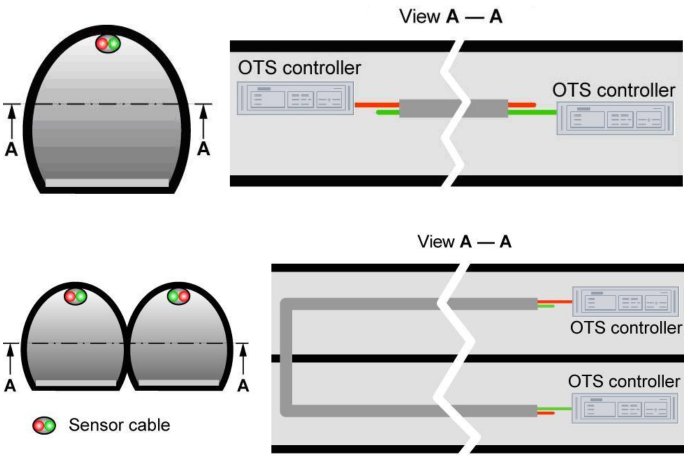

Fig. 18 Redundant system with one sensor cable

With this setup, redundancy is possible regarding controller failure or fiber interruption.

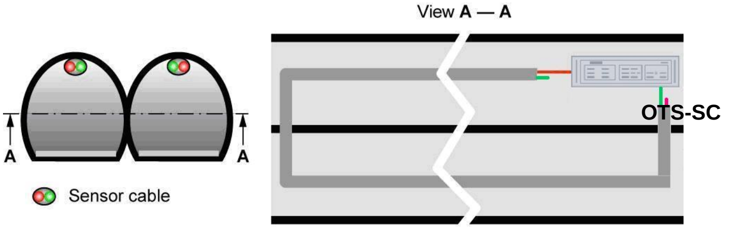

Fig. 19 Partial-redundant installation with one Switch-Controller

With this setup, redundancy is possible regarding fiber interruption.

With a redundant installation in a tunnel, the controllers are preferably installed at the tunnel entrance and exit.

5.4 Supply

As FibroLaser is a safety-relevant system, the energy supply must be designed in such a way that a redundant energy source is available in case of a failure of the main energy source.

The main energy source must be set up in such a way that it can be operated by the generally available public electric power system or any equivalent power system.

The redundant energy source for the 24VDC devices must be a rechargeable battery. It must be ensured that the battery is permanently connected to a battery recharger, so that the battery will always remain fully charged.

An uninterrupted power supply must be available as redundant energy supply source for the 115/230VAC devices.

The energy supply must be designed in such a way that in case of failure of the main energy source the system automatically switches over to the redundant energy source. As soon as the main energy source is again available, the system must switch back automatically.

5.5 Network Connection

The linear heat detection system is usually a part of an overall system and must be able to communicate with various superordinate network components.

The easiest way is the direct connection with a fire detection control panel, which in turn communicates with the superordinate systems.

The FibroLaser system also offers the possibility of a connection to a superordinate system, to which all relevant information such as temperature values or the status of outputs is transmitted. Such a connection also enables the superordinate system to control and poll different data from the controller.

It is important to exactly define the requirements concerning network connection and the relevant information as well as control possibilities before beginning with any detailed planning.

6 Annex

6.1 Raman Principle

Raman Scatter

Optical fibers are made from doped quartz glass. Quartz glass is a form of silicon dioxide (SiO_2) with amorphous solid structure. Thermal effects induce lattice oscillations within the solid. When light falls onto these thermally excited molecular oscillations, an interaction occurs between the light particles (photons) and the electrons of the molecule. Light scatter, also known as Raman scatter, occurs in the optical fiber. Unlike incident light, this scattered light undergoes a spectral shift by an amount equivalent to the resonance frequency of the lattice oscillation.

The light scattered back from the fiber optic therefore contains three different spectral shares:

– the Rayleigh scatter with the wavelength of the laser source used;
– the Stokes components with the higher wavelength in which photons are generated, and;
– the anti-Stokes components with a lower wavelength than the Rayleigh scatter, in which photons are destroyed.

The figure shows the spectral location of the newly created Raman bands. The intensity of the so-called anti-Stokes band is temperature-dependent, while the so-called Stokes band is practically independent of the temperature. The local temperature of the optical fiber is derived from the ratio of the anti-Stokes and Stokes light intensities.

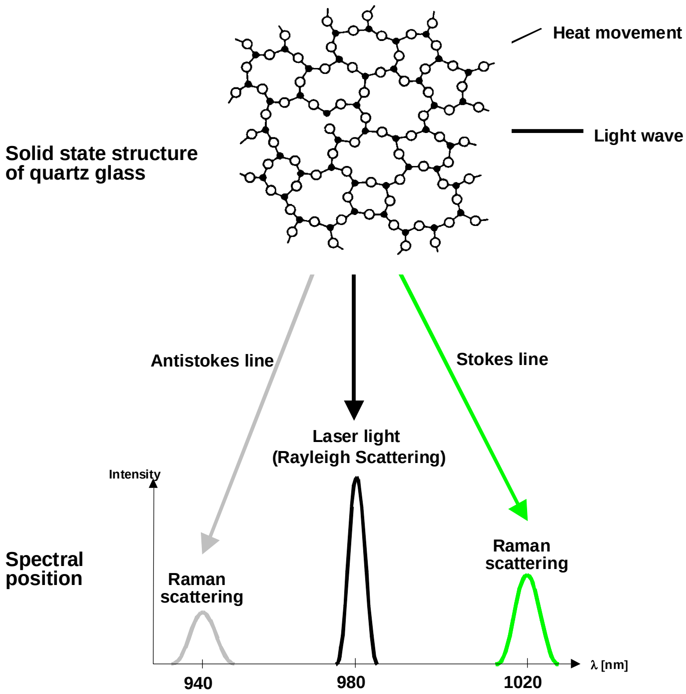

Fig. 20 Raman scatter

Measurement and Evaluation Method

With FibroLaser the **O**ptical **F**requency **D**omain **R**eflection (OFDR) method is used.

The OFDR system provides information on the local characteristic only when the back scatter signal detected during the entire measurement period is measured as a function of frequency, and then subjected to Fourier transformation. The essential benefits of OFDR technology are the continuous wave mode employed by the laser and the narrow-band detection of the optical backscatter signal, whereby a significantly higher signal to noise ratio is achieved than with the conventional pulse system. This technical benefit allows the use of affordable semiconductor laser diodes and electronic assemblies for signal averaging. This is offset by the technically difficult measurement of the Raman scatter light and expensive signal processing, due to the FFT calculation (FFT, Fast Fourier Transformation) with higher linearity requirements for the electronic components

The optical frequency range reflectometry has been developed as a high-resolution measurement process to characterize optical waveguides with length dimensions of just a few millimeters.

The figure below shows the schematic design of the OFDR Raman temperature measurement system.

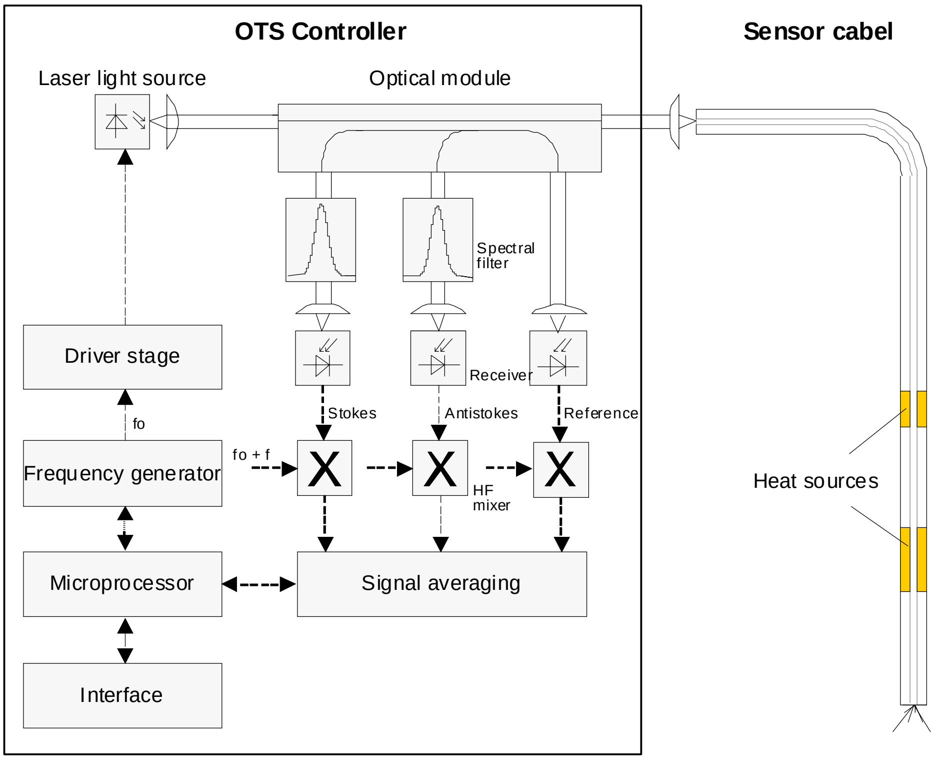

Fig. 21 OFDR- Raman temperature measurement system

The temperature measuring system consists of a controller (frequency generator, laser source, optical module, HF mixer, receiver, and microprocessor unit) and a quartz glass fiber (fiber optic) as line-shaped temperature sensor.

The system is set up with three channels, since an additional reference channel is required in addition to the two measurement channels (anti-Stokes and Stokes). Corresponding to the OFDR system, the power output of the laser runs through the sinus-shaped frequency with the help of the HF modulator, beginning with a starting frequency in the kilohertz range up to the end frequency in the high megahertz range within a measurement time interval. The resulting frequency shift is a direct expression of the local resolution of the reflectometer. The frequency-modulated laser light is connected to the fiber optic sensor via the optical module.

The continuously backscattered Raman light is spectrally filtered in the optical module and converted to electrical signals by means of photo detectors. The measurement signals are then reinforced and mixed in the low-frequency spectral range (NF range). The Fourier transformation of the averaged NF signals results in the two Raman backscatter curves.

The amplitudes of these backscatter curves are proportional to the intensity of the Raman scatter of the location in account. The fiber temperature along the sensor cable results from the amplitude ratio of the two measuring channels.

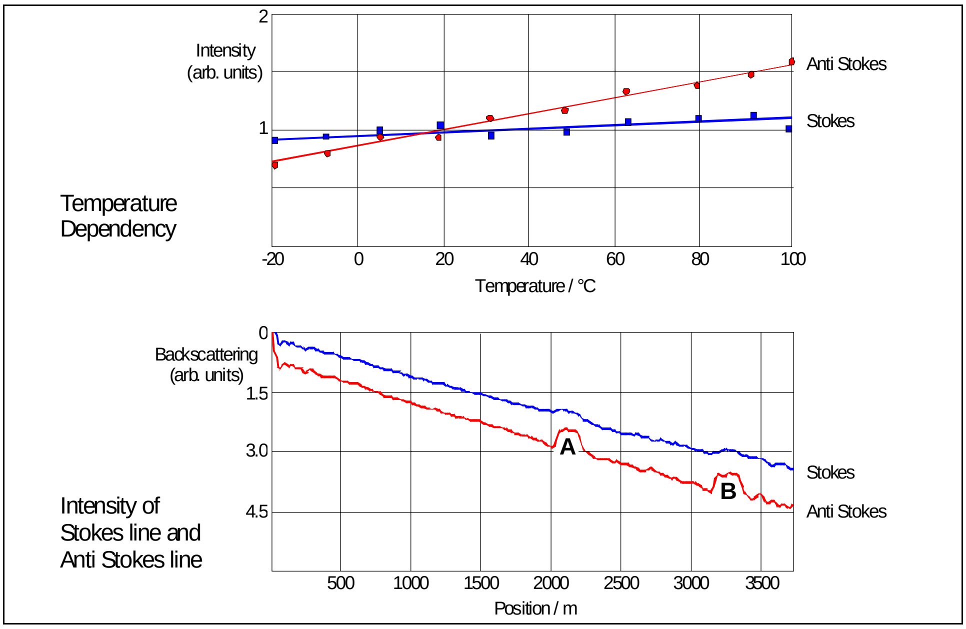

Fig. 22 Raman backscatter curves

The first diagram shows the temperature dependency of the Raman bands. It is obvious that the anti-Stoke signal is clearly temperature-dependent, while the Stoke signal is only marginally influenced by the temperature.

The second diagram shows the situation of both signals at a significant temperature increase in the sections A (at approx. 2100 m) and B (at approx. 3200 m).

6.2 Glossary

Anti-Stokes
Light of a newly generated wavelength caused by the Raman effect. The anti-Stokes band is temperature-dependent, in contrast to the Stokes band. This signal contains the location-dependent temperature information of the sensor length.

FFT
Abbreviation of **F**ast **F**ourier **T**ransformation.
This mathematical transformation is used in signal processing for transforming time period signals into frequency range signals and in the opposite direction.

FRNC
Abbreviation of **F**lame **R**etardant **N**on **C**orrosive.
Characteristic of the sensor cable isolation material.

HF
Abbreviation of **H**igh **F**requency.

LF
Abbreviation of **L**ow **F**requency.

OF
Abbreviation of **O**ptical **F**iber, glass fiber.

OFDR
Abbreviation of **O**ptical **F**requency **D**omain **R**eflectometry.
This principle is used in the OTS temperature measurement system. The measurement procedure does not work in the time range, as with OTDR, but in the frequency range. The backscatter signal of a sinus-shaped modular frequency ramp is detected as a complex frequency spectrum. With OFDR, the backscatter curve recorded directly by the OTDR process is obtained after a Fourier transformation of the spectrum in the time/location range.

OTDR
Abbreviation of **O**ptical **T**ime **D**omain **R**eflectometry.
A measurement procedure widely used in optical signal engineering for verification of optical fiber lines. A backscatter measurement process mainly used in connection with detection of Rayleigh scatter for evaluation of the local fiber attenuation. The measurement system works according to the pulse echo principle; in addition to the scatter level, the location of the scatter is determined from the runtime difference between transmission and detection of the light pulse.

OTS
Abbreviation for **O**ptical **T**emperature **S**ystem,
OTS linear heat detector system.

Raman effect
Physical effect that forms the basis of the fiber-optic temperature measurement technology. When coupled light falls in the glass fiber onto thermally excited molecular structures, an interaction occurs between the light particles (photons) and the electrons of the molecule. Then there is an emission of light of new wavelengths. The Raman effect creates the so-called stokes and anti-stokes bands, which show a displaced optical wavelength compared to the incident light.

Backscatter measurement process / scatter

The density in liquids fluctuates due to thermal disorder. Since quartz glass (the material of the glass fibers) is a sub cooled liquid, the irregularities remain after solidification from the molten mass. A portion of the transferred light is scattered at these microscopic density fluctuations that is, diverted from the original direction of spread. Light carried in a glass fiber is subject to attenuation through scattering at every location in the fiber (Rayleigh scatter). The scatter light arising at a location is sent in all directions, a part of it also in the reverse direction. This scatter light sent in the reverse direction is transported by the glass fiber back to the coupling spot and picked up by the evaluation unit. Light from a very distant location needs a longer time to go back to the evaluation unit than light that is sent back from a location near the coupling spot. Through the known spreading speed of the light in the fiber, the location of the back-scatter signals can be determined.

Besides the Rayleigh back-scatter measurement process used in optical signal engineering to evaluate glass fiber lines and localize disturbances, the simultaneously arising Raman scatter is detected with optical temperature measurement technology.

Splicing

Connection technique for optical fibers. After the glass fiber end surfaces are properly prepared, they are exactly aligned with each other in a special device. Then a triggered arc welds the two fiber end surfaces almost without loss. After splicing, the splice spot is given mechanical protection.

Stokes

Light of a newly created wavelength generated by the Raman effect.. The stokes band is not temperature-dependent, in contrast to the anti-stokes band. It is used in the optical temperature measuring system as a line reference to achieve line neutrality, that is, splice locations in the sensor line that result in a local increase in dampening do not influence the temperature profile.

Siemens Switzerland Ltd
Infrastructure & Cities Sector
Building Technologies Division
International Headquarters
CPS Fire Safety
Gubelstrasse 22
CH-6301 Zug
Tel. +41 41 724 24 24
www.siemens.com/buildingtechnologies