Using distributed fibre optic sensors for detecting fires and hot rollers on conveyor belts

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ABSTRACT

The use of modern fibre-optic sensors based on DTS (distributed temperature sensing) technology has established itself as a proven method for fire detection and temperature measurement. A passive fibre optic cable provides accurate temperature measurements along the length of the conveyor belt, which enables an effective and cost-effective monitoring of even very long conveyor routes. Fires and overheating, which can occur during operation and lead to serious damage and long downtimes, are quickly detected and localized to within one-meter accuracy. The necessary countermeasures can be quickly activated. Heat detection for hot rollers requires a proper installation of the sensor cable and configuration of the alarm zones and analyses. This paper is based on conveyor belt tests and case studies, and describes the potential of fibre-optic based DTS technology with regard to fire and hot-roller detection along conveyor belts.

Distributed Sensing, Fibre-optic linear heat detection, Conveyors, Smouldering Fires, Hot Roller

1. INTRODUCTION

Linear Heat Detection (LHD) technologies are well-known for decades as a proven method to protect elongated assets such as tunnels, cable trays, conveyors, metros and transportation systems. Simple installation and cost efficiency are the main advantages of conventional LHD’s based on digital, analogue or pressurized tube technologies. Fibre-Optic LHD based on DTS is the latest development and was first installed in the Swiss tunnel “Sachseln” in 1999. After the devastating blaze in the Mont Blanc Tunnel and Tauerntunnel in 1999 introducing FO-LHD was one essential part amongst others to improve the safety of traffic tunnels. The main benefits of FO-LHD are the significantly higher measurement range, the simultaneous detection of multiple fires, the precise localization of every fire event, the flexible zone configuration and very low false alarm rate, to name just a few. These characteristics make FO-LHD superior to any other LHD technology and hence this technology has spread quickly to other typical LHD areas such as conveyors – notwithstanding the significant higher CAPEX. Robustness and reliability make fibre optic technology suitable for conveyors, even with the rather harsh environmental conditions. Thousands of FO-LHD systems have been installed in the past with predominantly satisfying results and consequently this technology is now solidly established in fire protection. A new and fascinating distributed sensing technology has appeared on the horizon which may improve the protection of assets in conjunction with FO-LHD. This technology utilizes the optical fibre as a distributed microphone - means one measures not only the temperature but also the acoustics along the asset with the same fibre optic cable. Adding another level of information helps identify potential sources of danger and to achieve the overall goal of fire prevention. Particular on conveyors this new technology is gaining interest for detecting hot rollers – one of the major causes of conveyor fires.

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2. DISTRIBUTED SENSING TECHNOLOGIES

2.1 RAMAN OTDR

Most commercially available FO-LHD systems are based on Raman-DTS, which utilizes the OTDR (Optical Time Domain Reflectometry)- method. Light pulses are coupled into the fibre of the sensing cable. The backscattered light contains information about the temperature of the optical waveguide and thus the surroundings. The backscatter spectrum consists of the so called RAMAN Stokes and Anti-Stokes lines, which are shifted to the lower (Stokes) or higher wavelength (Anti-Stokes) due to an inelastic collision of photons with atoms that form a temperature- dependent electromagnetic oscillator. While the intensity of the Stokes line is nearly independent of the temperature, the Anti-Stokes line shows a temperature dependence (Fig. 1). The quotient of both intensities constitutes an obvious measure of temperature in the optical waveguide. Measuring the backscattered signals as a function of time together with the information of the speed of the light, one can calculate the distance and thus a temperature profile along the optical fibre (radar principle). Several advances have been made to improve the S/N ratio of DTS systems as the RAMAN signals are measured in pico-watts. The most promising is the code-correlation concept, improving the S/N ratio by ten times compared to conventional OTDR/OFDR measurement concepts, which results in higher life-time and better suitability in harsh environments.

2.2. Brillouin – OTDR

Brillouin DTS are barely known in the fire protection industry and finds some applications in other markets. Here a light-pulse travels through the fibre and backscattering is caused by the lattice vibration of the quartz glass. Also here an OTDR procedure allows the detection of signals as a function of the distance resulting in a measurement profile along the fibre. As the lattice vibration is a function of the temperature and elasticity of the fibre the Brillouin DTS measures fibre temperature and strain at once which does not qualify this technology for reliable fire detection. However, this technology is characterized by a higher measurement performance due to a better S/N ratio of the Brillouin signals.

2.3. Distributed Acoustic Sensing (DAS); Distributed Vibration Sensing (DVS)

A rather new technology of fibre optic sensing employs the Rayleigh backscattering to measure the acoustic information. A very coherent laser source sends a laser pulse through the optical fibre. Light is scattered at density fluctuations. Distance (optical path length) between these scattering centres varies with sound waves penetrating the fibre. As a result, the measured interferometric backscattering signal varies synchronously. A conventional OTDR procedure enables to the measurement of the backscatter signal as a function of the distance. The concept described above is known as Coherent *Optical Time Domain Reflectometry,* or C-OTDR. Another rather unknown technology combines a Mach-Zehnder and Michaelson Interferometer to detect critical acoustic events along the fibre (Hybrid Interferometer). One difference to DTS technology: well-developed software algorithms are key for the automatic detection of critical acoustic events and hence DAS/DVS systems are prone to nuisance alarms particularly in noisy environments.

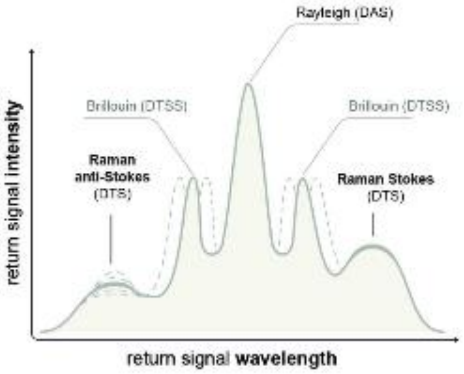

Figure 1: Optical spectrum of backscattered lines used by distributed sensing technologies

3. ENABLING DTS TECHNOLOGY TO BE USED AS A LINEAR HEAT DETECTOR

All commercially available FO-LHD products are based on DTS but not all DTS products can be used as a linear heat detector, especially for conveyors. Special requirements have been established with regard to robustness, reliability and performance to meet international safety standards. Users are well advised to look into all aspects before making any decisions.

3.1. Certifications

There are many standards according to which fire safety products are tested and certified. But a few enjoy international reputation, namely *Factory Mutual* (FM), *Underwriter Laboratories* (UL) and *Verband der Schadensversicherer* (VdS). Certification according to these standards gives certainty in the quality and functionality of any fire safety product and should be a non-negotiable requirement when considering the use of any LHD systems including fibre optics. Linear heat detectors are special detectors and sometimes not covered by standards in particular. Nevertheless, it is possible to certify fibre optic LHD according to these international standards – some FO-LHD already have them. The EU has recently issued a new standard for the first time which is dealing with *addressable linear heat detectors* (EN54-22). DAS/DVS systems are not subject to certification yet – they are not fire safety products.

3.2. ATEX/IECEX

Fibre optic sensing products and particular FO-LHD are not necessarily intrinsically safe in areas containing explosive atmospheres due to gas or dust. This is highly dependent on the output power of the laser. A cable and fibre break will lead to an uncontrolled release of laser light. As the typical wavelength of a DTS interrogator is in the near IR – laser light may heat up surfaces at which flammable gas or dust particle are ignited. As a rule, optical power of below 35mW are considered to be inherently safe. This is a necessary but not sufficient condition for the deployment of FO-LHD systems in ATEX environments. Particularly in areas with permanent explosive atmospheres, safety measures must be in place ensuring that the optical power remains below the critical level even if the system has one (category 2 system) or two faults (category 1 system). This is usually managed by safety circuits which are subject to certification at a n authorized body. Also here users are well advised to look for the respective ATEX / IECEX certification of the FO-LHD system when considering to deploy it on a conveyor.

4. USING DISTRIBUTED SENSING ON CONVEYORS

Nearly all open fires in mines are caused by external supplied ignition. The most frequent sources of a fire are disturbances in active conveyor belt systems and thus most fires develop in the proximity of conveyors. A few examples of these faults include stuck or defective rollers, graters, grinding of the belt and slip of the belt or belt misalignment. Self-ignition of coal dust accumulated below the conveyor is another source of fire. The initial smouldering stage is difficult to detect with conventional technologies and requires very tuned alarm algorithms. Smoke/Gas detectors does not work properly because of high air currents.

4.1. Fire Detection

FO-LHD appears to be an ideal solution for detecting fires in an early stage in the proximity of conveyors. A fibre-optic based distributed temperature sensing system has several advantages during normal operation and in case of a hazardous situation:

- Cable design is robust and resistant against dirt and dust.
- Fully certified systems (FM, UL, VdS and ATEX/IECEX).
- Long range up to 10km and up to 4 measurement channels let you monitor multiple conveyors with one system.
- Virtually maintenance-free: no down time due to maintenance activities.
- Mechanically robust cable design.
- Precise localization of fires/hot rollers enables targeted intervention.
- Reliable fire detection despite unfavourable environmental conditions.

4.2. Smouldering Fires

In spite of all the security technology currently used in conveyors, it is still not possible to prevent the ignition of all coal smouldering fire in close proximity to conveyors.
Thermal radiation from a smouldering fire spreads out independently of the ambient and therefore independent of the speed of the air current. For this reason, a monitoring system is required which is able to detect the thermal radiation of a smouldering fire and which can permanently monitor the area and allows hot spot detection at an early stage.

A good example of an advanced fibre optical temperature sensing system for early detection of smouldering fires at conveyors has been installed in the mine *Prosper Haniel* in Bottrop, Germany. This installation shows above all that it is possible to install fibre cable at a conveyer and permanent operation under practical conditions. A fibre optical sensing cable about 3500m long was mounted on the lower left side of the conveyor.

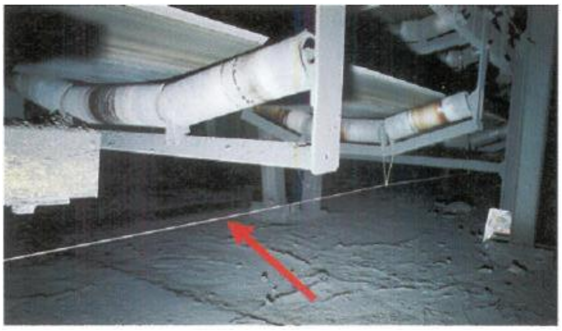

Figure 2: Installation of a sensor cable for detecting smouldering fires

The coal dust smouldering fire was inflamed by lab hot plates. During the test the smouldering fire had been controlled by a thermographic camera. The electric heat was turned off after the coal dust had reached a surface temperature of 270 °C and visible smoke with first zones of smouldering fire showed. Then the smouldering fire progressed until the whole area was completely covered. The temperature of the smouldering fire rose to about 450 to 500°C. The temperature in all five fibre cable positions with weather speeds of 1,2m/s, 3,0m/s and 4,5m/s was acquired.

Under these test conditions the FO -LHD system successfully monitored the detection of a coal dust smouldering fire with an area of 0,5 x 0,5m (=0,25m²) and a distance of 1,8m (distance between surface of smouldering fire and sensing cable) at a weather speed of up to 4,5m/s.
In the report of the DMT (Deutsche Montan Technologie) was finally stated:

"*Due to the results it is assumed that the presented fibre optical linear heat detector, in view of its measurement parameters for early detection of fire, is applicable for conveyers in coal mines. It must be assumed that if the fibre cable is fixed right below the supporting structure of the conveyer system, the source of smouldering fire at all regular weather speeds is surely detected."*

4.3. Hot Roller detection

Rollers on conveyor belts can become overheated and a source of danger when bearings suffer enhanced friction due to usage over time. Conveyor systems that transport heavy loads and/or work at high speeds are more likely to overheat. These systems are often used in harsh environments where hazardous materials, dirt, dust, and vibration are present. Apart from the danger of personal injury and asset damage should a fire occur, the down-time of the line represents a significant financial risk. Extensive laboratory and field tests have been carried out for hot roller testing, in addition to experience gathered from a wide range of conveyor belt system installations.

When a DTS solution is used to detect hot rollers on the conveyor belt, the placement of the sensor cable becomes crucial. A solution has been developed to mount the sensor cables with a special clip that ensures a simple and secure installation but also improves heat detection of small hot spots. Once installed, rollers can still be accessed for maintenance or exchange without affecting the sensor cables (patent pending).

Figure 3: Sensor cable installation for detecting hot rollers

Field tests have been conducted to verify the suitability of the mounting concept. In this test a mock-up idler frame has been heated to simulate a hot roller. The thermal camera shows that when heat originates from the outside of the roller (left), the inside of the roller (where the sensor cable is located) becomes hot enough within minutes to detect the change, as shown in the DTS trace below:

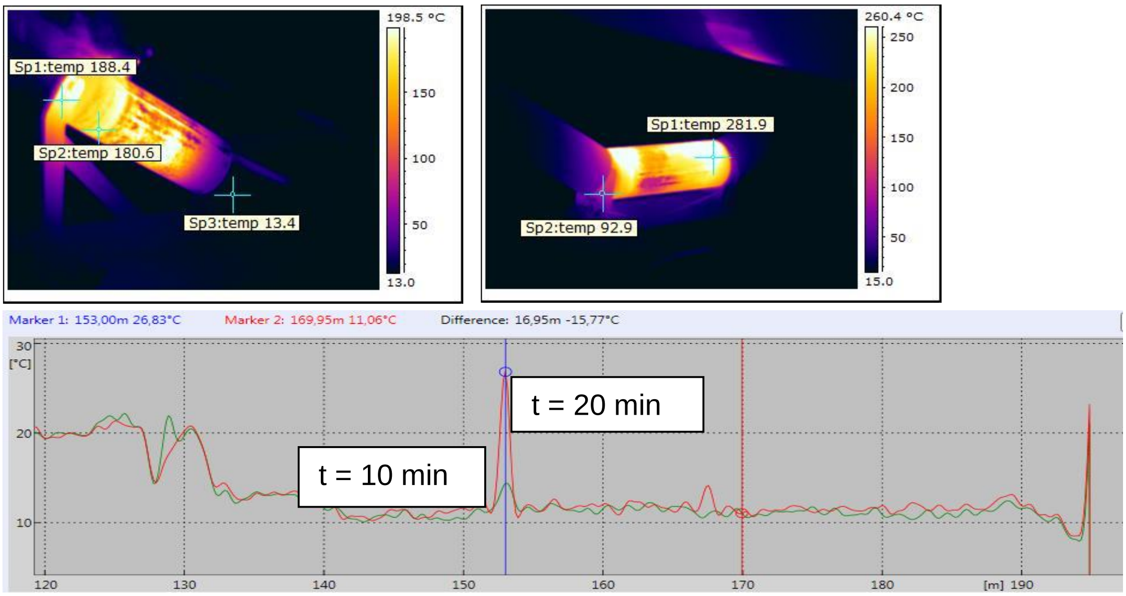

Figure 4: Temperature and DTS response of hot rollers

Another method to detect hot rollers is to install the sensor cable as close as possible along the roller. In doing so, along the conveyor system, the sensor cable is installed close to the idler roller by a customized mounting frame. The frame keeps the fibre near to the surface of the idler to ensure that the sensor cables are securely mounted, the cables are mechanically protected and thermal radiation of a hot roller is concentrated at the sensor cable. With this an early detection of overheated rollers at temperatures of 100-150°C is possible.

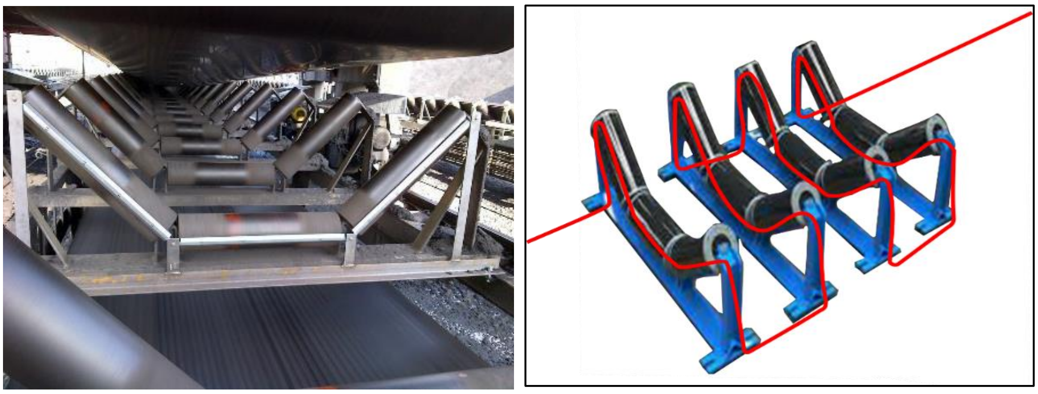

Figure 5: Mounting frame on an idler station and cable setup

Distributed Acoustic Sensing (DAS) seems to be a very promising solution for detecting defective roller in idler stations. Wear-out of bearings cause high friction and thus an intensified rolling noise which is detected and localized by the DAS system. Background noise caused by the operation of the conveyor as well as from the working environment is a challenge for a trouble-free utilization of acoustic sensing. Specialized algorithms and analysing acoustic patterns, frequencies and amplitudes are required to minimize nuisance alarm rate.

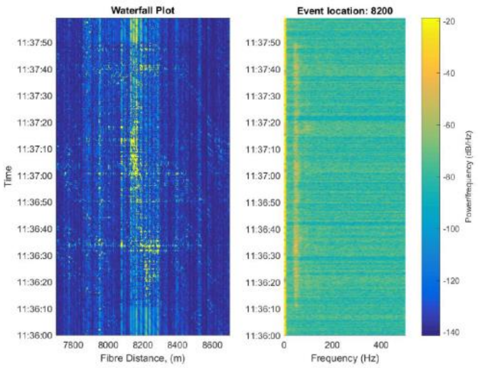

Figure 6: Acoustic response recorded by a distributed acoustic sensing system

5. CONCLUSION

Distributed Sensing Technologies are widely and successfully used to protect transportation systems. The characteristics of FO-LHD are ideal to significantly improve the safe operation of any conveyor. One system can cover multiple long-distance conveyors, the sensor cable is robust, passive and easy to install – no additional wiring is required. Fires and overheating are detected quickly in early stages and are localized precisely with accuracy down to 1 meter. Furthermore, it has been shown that FO-LHD is capable to detect and localize hot rollers. Different methods have been developed and tested. For safe operation of FO-LHD it is recommended to use systems which are certified according to internationally recognized standards and are safe in explosive atmospheres even when the system is compromised.

Distributed Acoustic Sensing can contribute to the safety of a conveyor by detecting defective rollers before any overheating may cause a fire. More experience is needed to assess the capability and to develop reliable detection algorithms.