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APPLICATION OF DISTRIBUTED TEMPERATURE SENSOR FOR FIRE AND CRYOGENIC LEAK DETECTION IN ACCELERATOR TUNNELS

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Abstract

High-energy accelerators like CERN's Large Hadron Collider (LHC) present hazards characterized by temperature variations such as cryogenic leak or fire. Considering that LHC tunnels are large, underground, and radioactive areas, alternatives to traditional systems are explored to improve hazard detection. CERN is investigating the feasibility of installing a large-scale temperature monitoring system in LHC tunnels using Distributed Temperature Sensor (DTS) technology. Based on optical fibre, such a system would be resistant to the LHC radioactive environment and could detect temperature anomalies associated with both fire and cryogenic leak events. This paper presents ongoing studies and a prototype of DTS equipment in the LHC tunnel installed and tested at the beginning of 2025. This publication evaluates the DTS as a safety enhancement tool for accelerator facilities. The potential improvements brought by installing a DTS in LHC tunnels will also be discussed.

LHC FIRE AND CRYOGENIC LEAK DETECTION SYSTEMS

The underground areas of the LHC present occupational hazards related to fire (smoke) and cryogenics leak (oxygen deficiency). The protection strategy is based on automatic detection and protection systems. When a hazard is detected, the CERN Fire and Rescue Service (CFRS) intervenes immediately. The detection systems are designed taking into account the long distances of the tunnels and their radioactive environment:

- Fire detection is carried out by air sampling smoke detectors, limited to specific areas.
- Cryogenics leak detection is performed by oxygen sensors spaced by a maximum of 300 m in the tunnels.

The partial coverage of automatic fire detection systems coupled with fluctuating tunnel ventilation conditions can lead to delays in detecting and notifying the presence of a fire. If the ventilation is stopped, the detection time may increase very significantly. Therefore, depending on the fire location and the ventilation conditions, occupants' evacuation conditions and CFRS operations may be degraded. Furthermore, due to undetected sections of the machine, emergency responders may face difficulties in locating the precise origin of the fire.

OPTICAL FIBRE SENSOR

Optical Fibre Sensor (OFS) refers to the use of optical fibres to measure various physical parameters: temperature, strain, pressure, chemical composition, vibrations, radiation, rotation, shape, EM field, etc. Distributed sensing is a way to obtain spatially continuous, real-time measurements along the entire length of the optical fibre. The result of a distributed measurement is a continuous one-dimensional map. The CERN Fibre Optics Section has developed a technical expertise on two OFS domains:

- Distributed Optical fibre Radiation Sensors (DOFRS): based on Rayleigh scattering phenomena [1, 2].
- Distributed (optical fibre) Temperature Sensors (DTS): based on Raman scattering phenomena [3].

For several years, the DOFRS have been largely used by CERN for radiation dose monitoring over large underground areas. For the DTS domain, the technology "Dual wavelength single-ended Raman DTS"offers inherent radiation resistance [3].

DTS PROTOTYPE

The DTS technology is commonly used in industrial applications, especially for fire detection in road tunnels [4, 5]. In 2023, CERN decided to investigate the radiation resistant DTS technology for fire and cryogenic leak detection purposes [6]. A DTS prototype has been developed and installed in LHC tunnels during the Year End Technical Stop (YETS) 2024/2025, with the following objectives:

- To operate the system in real LHC conditions over the 2025 LHC RUN period and collect tunnel temperature data over a full year.
- To test the DTS capability of detecting a fire.
- To optimize the system design: hardware and software architectures, cable positioning in the tunnel cross section, acquisition parameters, alarm thresholds, faults to be monitored, etc.

The prototype is based of an Optical Time-Domain Reflectometer (OTDR) interrogator from the manufacturer Viavi Solutions, see Fig. 1. The reference product used is FTH-9000 equipped with a DTS module based on the technology "Dual wavelength single-ended Raman DTS".

The main configuration parameters of the interrogator are given in Table 1.

In a portion of the LHC tunnel named "RA43", a radiation resistant cable containing radiation resistant single-mode fibres [7] has been installed and connected to the interrogator, see Fig. 2. The tunnel length monitored with the DTS prototype is about 300 m. The cable was installed at the tunnel ceiling level, at a height of 3.6 m. This position is the highest centered position in the cross section of the tunnel. At this position, the cable is not shielded by other equipment, and

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Figure 1: OTDR interrogator equipped with DTS module.

Table 1: Interrogator Configuration

Parameter	Value
Wavelength	[1550 nm, 1625 nm]
Spatial resolution	3 m
Acquisition cycle	[29 s, 31 s]
Noise amplitude	+/- 2 °C

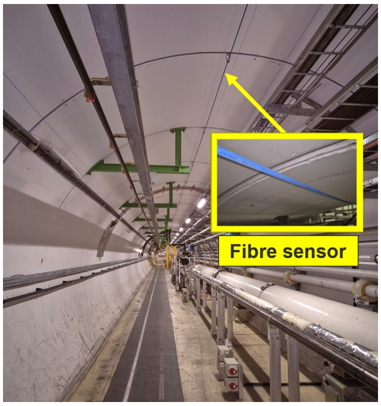

Figure 2: Optical fibre installed in LHC tunnel.

both events will induce a significant temperature change. It offers the best configuration for both fire and helium leak detection performance.

FIRE TEST

To assess the performance of the DTS prototype, a pool fire test was conducted in real LHC conditions in January 2025. The fire test was performed in the RA43 tunnel, with a measured average ventilation speed of 0.55 m/s. The fire was set up using a metallic bin with dimensions of 25 cm by 65 cm, filled with 0.9 L of ethyl alcohol. The power produced by this fire is estimated at about 50 kW, which corresponds to a waste paper basket fire. Sensitive equipment of the machine were protected against thermal radiation from the fire with fire protection covers. The duration of the fire was 9 min 9 s. The DTS allows to display the temperature as a function of the Distance CUMulated (DCUM) along the machine, with a fire located at DCUM 9790 m, see Fig. 3. The curves are collected according to the DTS acquisition cycle. It shows the temperature distribution along the tunnel with a peak at the location of the fire.

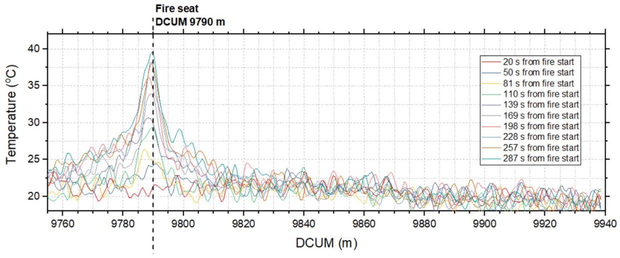

Figure 3: Fire test temperature as a function of distance.

In addition to the DTS cable, 35 PT100 temperature sensors were installed to monitor the test and compare the data collected by the DTS. The weight of ethyl alcohol consumed as well as the air velocity in the tunnel were also collected. The DTS allows to display the temperature as a function of time. Data collected close to the fire location are presented in Fig. 4. The temperature measured by the PT100 sensor could be considered as the reference temperature. The temperature collected by the DTS follows the reference with a latency in the measurement. This thermal latency is related to the cable construction.

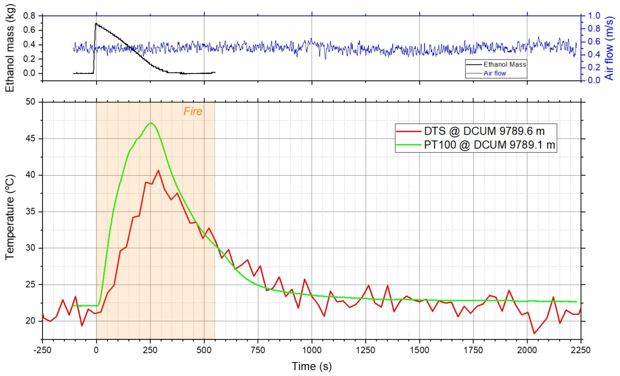

Figure 4: Fire test temperature, mass of ethyl alcohol consumed, and air velocity, as a function of time.

The fire test provides a demonstration that a DTS can detect, localize, and monitor the evolution of a fire in real LHC conditions. With an alarm threshold set at 10 °C above the ambient temperature, a DTS can effectively detect a very small flaming fire in LHC tunnel within less than 3 min. Nevertheless, in the event of a fire producing smoke, the DTS detection time would be longer. For this type of fire, smoke detection technology will always be more efficient than thermal detection technology.

CRYOGENIC LEAK TEST

During CERN Long Shutdown 1 (LS1) in February 2014, controlled liquid helium spill tests were conducted in LHC tunnels [8–10]. It was concluded that a liquid helium leak of 100 g/s is the limit threshold below which a leak is considered as non-dangerous for personnel. For the 100 g/s leak, a temperature drop of about −48 °C was measured at the tunnel ceiling level, in standard ventilation conditions.

In March 2025, a cryogenic test was performed at the CERN Cryolab to reproduce −48 °C and assess the performance of the DTS. A cryogenic dewar was partially filled with liquid nitrogen (−196 °C) creating an air temperature gradient inside: see Fig. 5. The DTS optical fibre cable along with PT100 temperature sensors were attached to a basket and lowered into the dewar using a crane. The temperature decrease was controlled by adjusting the speed and amplitude at which the basket was lowered. Data collected during this test are given in Fig. 6. The temperature data collected by the DTS and PT100 sensors are plotted as a function of time. The air temperature amplitude measured during the test (−63 °C) was slightly larger than the one observed at the LHC tunnel ceiling during the 100 g/s liquid helium spill test (−48 °C). The temperature measured by the PT100 sensors could be considered as the reference temperature. As with the fire test, the temperature collected by the DTS follows the reference temperature with a latency introduced by the cable construction.

Figure 5: Dewar partially filled with liquid nitrogen.

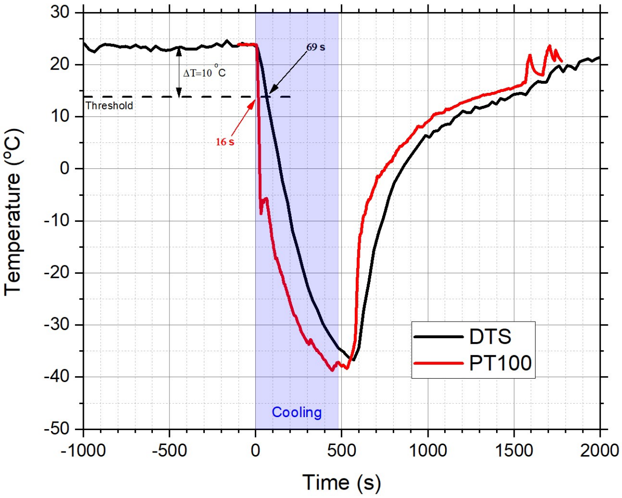

Figure 6: Cooling test temperature as a function of time.

The test representing a cryogenic leak in LHC provides a demonstration that a DTS can detect, localize, and monitor the evolution of a cryogenic leak in real LHC conditions. With an alarm threshold set at 10 °C below the ambient temperature, a DTS can effectively detect the personnel safety threshold of 100 g/s liquid helium spill in LHC tunnel within 2 min. Nevertheless in the event of a cryogenic leak producing an oxygen deficiency without dropping the temperature, a DTS would not be able to detect the leak. For this type of event, oxygen detection technology will always be more efficient than thermal detection technology.

POTENTIAL IMPROVEMENT OF THE LHC PROTECTION STRATEGY

In complement of existing fire and oxygen deficiency detection systems, the implementation of a DTS in the LHC tunnels would represent a significant enhancement of both fire and cryogenic leak protection strategies. Unlike conventional smoke or oxygen sensors, a DTS system can offer continuous temperature monitoring over 100% of the tunnel length, independently of ventilation conditions. This enables faster and more reliable detection of hazards, with a 50 kW flaming fire detected within 3 min, and a helium release of 100 g/s within 2 min.

DTS also enables precise localization of events, supporting the use of location-specific voice alarms, and allowing optimized CFRS intervention. Real-time thermal data enhances situational awareness and supports critical decision-making. This includes selecting appropriate firefighting strategies, such as choosing the most suitable tunnel entrance, determining whether ventilation should be activated or halted, identifying the initial actions to take, and deciding which equipment to bring. Moreover, DTS increases safety during periods where conventional sensors are disabled (e.g., during works generating dust), and limits unnecessary machine interruptions required to validate alarms.

By reducing unprotected tunnel segments, accelerating emergency response, and potentially minimizing damage to LHC infrastructure, DTS contributes to personnel safety, property protection, and operational continuity.

CONCLUSION

The study and tests performed have demonstrated the ability of a DTS to detect, localize, and monitor the evolution of both fire and cryogenic leak events quickly and accurately, with performance not significantly affected by ventilation conditions. The integration of a DTS in the LHC tunnels in complement of existing safety systems could significantly enhance the LHC safety strategy. Its scalability, cost effectiveness, and radiation resistance make it a strong candidate for deployment across existing and future CERN underground facilities. Ongoing data collection during the 2025 LHC run will further support the validation and optimization of the system for large-scale implementation.

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