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Fire Monitoring System Using SMA and Fiber-optic Cable

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ABSTRACT

This study presents a fire monitoring system using SMA (shape memory alloy) and fiber optic cables. As the sensing points in one cable are connected in series, installation is less costly and less cumbersome than wiring dozens of separate electronic gage networks. In side-by-side comparisons with conventional thermocouples, this system has no EMI issues, while providing for faster response, with no need for calibration. This system is applicable to harsh conditions and delivers many advantages of all fiber-optic sensors.

1. INTRODUCTION

Complex living conditions in modern societies force shared living units, plant production facilities and other hazardous facilities into being densely distributed in predefined districts, where power, communication, gas, district heating and plumbing systems are installed en bloc in underground culverts. Also, road tunnels architecturally similar to underground culverts have been increasing due to the geological structure of the country to cope with such issues as reduction of logistics cost and conservation of nature. These structures house a range of hazardous articles and constitute highly important public facilities, which is why it is foreseeable that a series of disasters could be immensely damaging for the entire community. Nonetheless, automated disaster detection systems have not been installed in such structures regardless of their importance as it is considered difficult to gain efficiency in maintenance on account of excessive moisture or dust, variation in air flows and above all uneasiness of accessing the sites. To resolve such issues, fire monitoring systems using heat or smoke detection sensors have been designed for such structures as buildings or tunnels. Yet, as heat or smoke detection sensors are far from reaching broad ranges, it is necessary to install a number of sensors to monitor wide areas including tunnels, which incurs excessive costs for installation, maintenance and replacement in case of sensor

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failures resulting from the moisture and dust in underground culverts or road tunnels. Recently, to make up for such drawbacks, the Raman-OTDR (Raman-Optical Time-Domain Reflectormeter) system is often used as the fire monitoring system for industrial infrastructure facilities. The Raman-OTDR system injects laser pulses into the optical cables and measures temperature based on the optical intensity ratios of stokes to anti-stokes of the Raman scattering lights among the back-scattering lights. Despite the accuracy of the Raman OTDR system, it is costly and inapplicable to fire incidents calling for prompt responses together with rapid data analysis within dozens of seconds or a few minutes for temperature measurement. Also, the system can cover just a few, not dozens of, kilometers.

Table 1. Specifications of conventional Raman OTDR fire monitoring systems

Company/ Country	QOREX/US	LIOS Technology GmbH/Germany
Model		OTS20P 
Specifications	. Distance coverage: 2km (option 10km) . Temperature coverage: 0~300℃ . Temperature Accuracy: 0.8℃ . Temperature Resolution: 0.2℃ . Spatial Resolution: 1.5m	. Distance coverage: 2km, 4km . Spatial resolution: 3m; 1.5m, 1m . Spatial resolution(option): 0.5m . Temperature Accuracy: depends on distance

This study presents a system using fiber-optic cables and SMA (shape-memory alloys) to solve the problems found in the Raman-OTDR system. The proposed fire monitoring system is capable of detecting temperature rise in real time, requires no wire and wireless connections of each sensor with communication devices and provides a fire detection unit and method using less costly optical fibers.

2. BASIC CONCEPT

The proposed fire monitoring system consists largely of three components, i.e. the optical fiber, the OTDR and the fire-detection deformer. This section describes the basic concepts of each component.

2.1 Optical fiber cable

The optical fiber is comprised of a highly refractive core and a relatively less refractive cladding. The fiber serves as a transmission path through which the light injected into the core proceeds by total reflection. Optical fibers use silica, which is used as the primary material for glass, suffers no external EMI (electromagnetic interference) and sends lights over long distances with low loss. As ordinary optical fibers are vulnerable to shocks, however, the proposed system employs a stainless steel flexible tube helically installed on an ordinary bare optical fiber together with the stainless steel braiding applied to the external cover, which allows easiness of bending and handling. In addition, as our optical fiber cables used in the system has no polymeric external covering, no toxic effects arise from harmful gases in case of a fire.

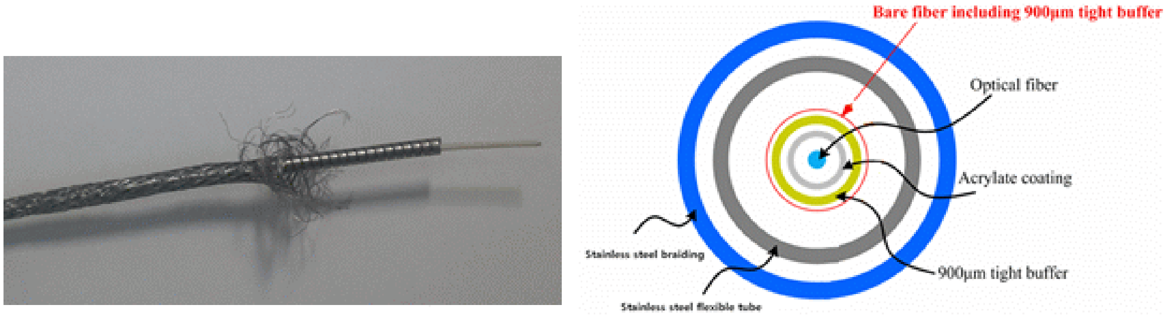

Figure 1. Optical fiber cable for fire measurement

2.2 OTDR (Optical Time-Domain Reflectormeter)

The OTDR is an instrument used for time-domain analysis of the optical loss distribution of the backscattering light generated when laser pulse beams are injected into the optical fiber, and widely used in the field of optical communication for measuring the loss of optical fiber cables per unit distance, locating the bending of optical fibers and checking the splicing of optical fibers. The abovementioned Raman-OTDR (ROTDR) uses the Raman scattered light, while the OTDR uses the Rayleigh scattered light. Here, as the larger Rayleigh scattered light is more easily applicable than the smaller and thus harder-to-detect Raman scattered light, the OTDR is less costly than the RDTDR and capable of measuring long distances.

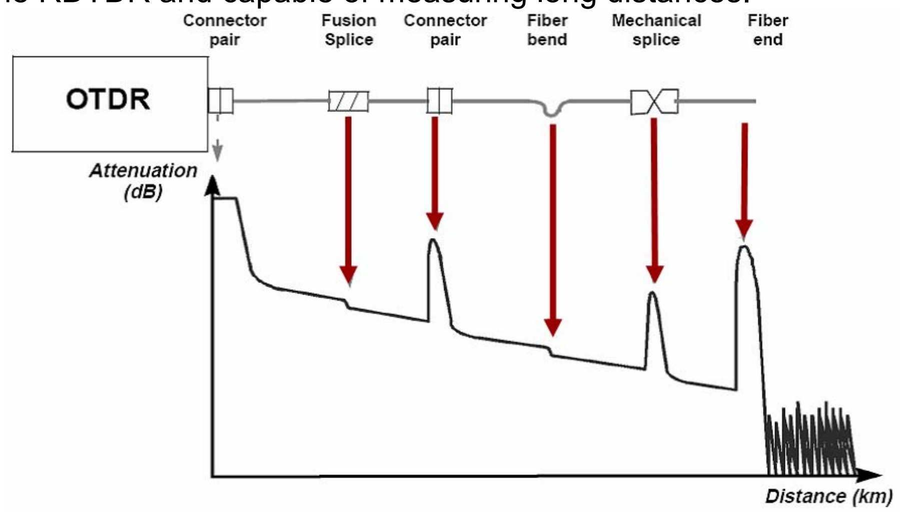

Figure 2. Measurements with an OTDR per loss factor

2.3 Fire-detection deformer

The fire-detection deformer developed here is composed of a shape memory alloy and an optical fiber cable. The shape memory alloy remains stretched or pulled at room temperature, whereas it shrinks to its original state upon being heated at 70℃ or higher in case of a fire. The optical fiber cable attached to the shrinkable shape memory alloy bends measurably. Then, the OTDR system detects the bending.

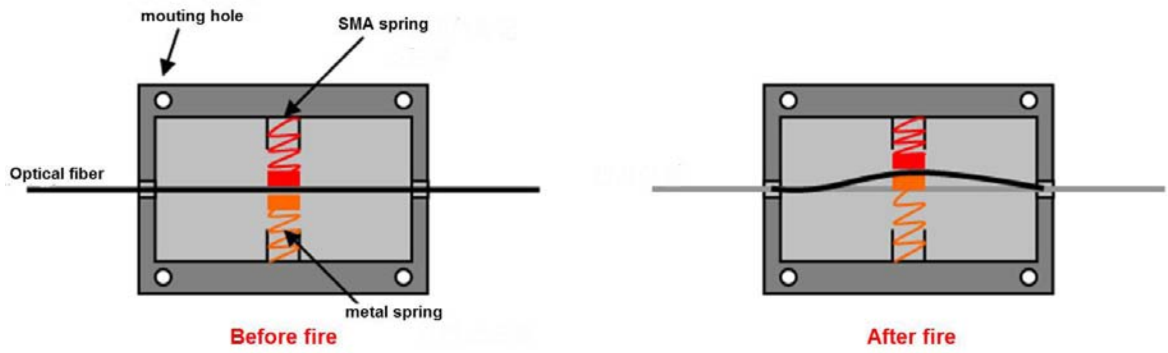

Figure 3. Conceptual diagram of the fire-detection deformer

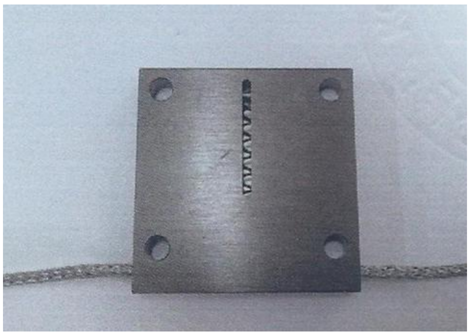

Figure 4. The SMA fire-detection deformer

3. EXPERIMENTAL RESULT

To experimentally verify how the fire-detection deformer operates by distance, the length of the optical fiber cable between the OTDR and the fire-detection deformer was varied in the experiment. First, for a short-distance test, a 4.15 km optical fiber was installed between the OTDR and the fire-detection deformer. As in Figure 7, the difference in optical power before and after the application of the fire-detection deformer measured approximately 1.1 dB.

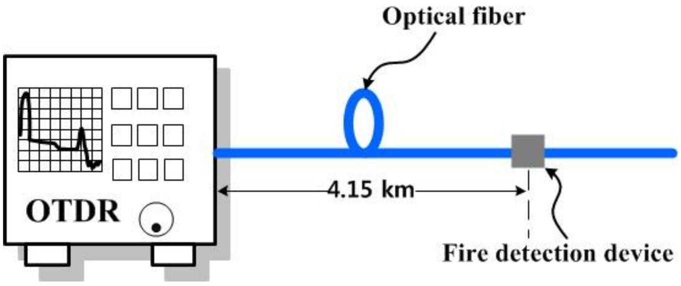

Figure 5. Set-up of the short-distance measurement test

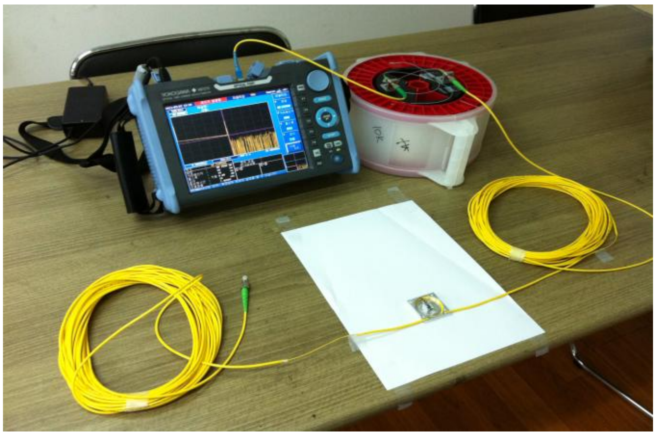

Figure 6. The short-distance measurement test

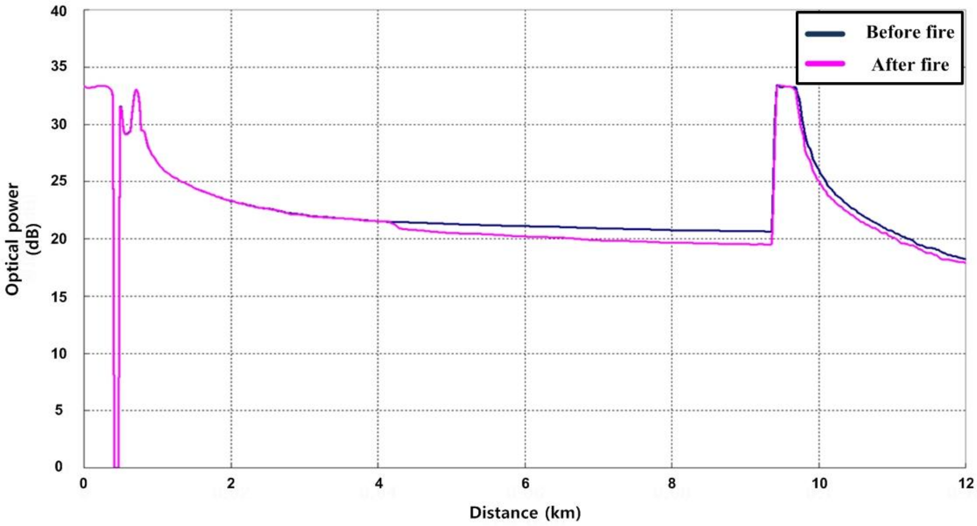

Figure 7. Result of the short-distance test

The long-distance measurement test was referred to a qualified office (KTL, Korea Testing Laboratory). As for the experimental set-up, an optical fiber cable measuring about 83km was installed between the OTDR and the fire-detection deformer. Then, the fire-detection deformer was heated until the optical fiber bent. As in Table 2, within 10 seconds as from the moment of heat application, the difference in optical power measured about 3.2 dB.

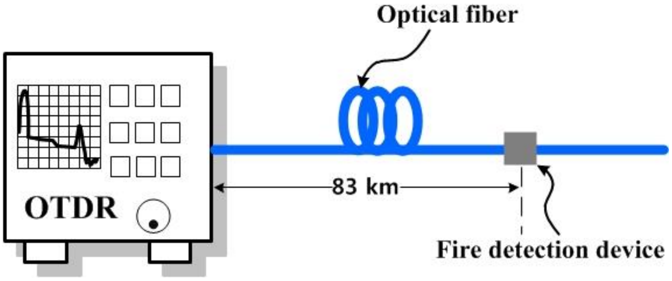

Figure 8. Set-up of the long-distance measurement test

Table 2. Results of the long-distance test

Items	Results
Response time	Within 10 seconds
Difference in optical power	3.2 dB

4. CONCLUSIONS

Based on the extensive test results, the optical loss of 1.0 ~ 1.5 dB was optimally designed to occur at 70±10℃, which was a performance indicator in this study. The in-house experimental test found the design met the performance levels required. The quantitative results obtained from a qualified office indicated that the fire monitoring system developed here was capable of detecting a fire occurring in a long-distance section in real time. Based on the findings, the fire monitoring system is considered good enough to replace the existing commercial fire detection systems.

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