From Smart Materials for Space Industry to Soil Temperature Gauges for Climate Change Monitoring: A Review of New Applications of Distributed Optical Fiber Sensors

Łukasz Szostkiewicz*
InPhoTech Sp. z o.o., ul. Poznańska 400, 05-850 Ołtarzew, Poland
**e-mail: lszostkiewicz@inphotech.pl*

ABSTRACT
Distributed optical fiber sensors (DOFS) are usually associated with strain and temperature measurements of long linear constructions. Within this paper we demonstrate how alterations in sensing schemes and application of specialty optical fibers allow to broaden the applications of DOFS's. One of those is an multi line underground temperature monitoring in arctic environment which demonstrates the possibility to remotely interrogate multiple sensing fibers with centimetre spatial resolution. We will also discuss the possibilities of distributed optical fiber sensing embedded in composites and metal alloys.
Keywords: distributed optical fiber sensors, specialty optical fibers.

1. INTRODUCTION

Optical fiber distributed sensors (DOFS) [1] are usually associated with monitoring long linear structures like pipelines [2] or bridges [3]. From economical point of view, it is justified by the fact that the cost of optical interrogator and sensing fiber is by orders of magnitude lower than the structure that is supposed to be monitored. In that scenario the added value of the fiber sensing system vastly exceeds its cost [4]. Such linear applications of DOFS dominate the market due to the maturity of ITU G.652 single mode optical fiber and telecom cables technology. However recent global effort to develop new fiber types [5] allowed to extend the possible applications of optical fiber sensors, for example into antigen detection [6] and bend monitoring [7]. Even DOFS application is extended by a possibility to perform shape sensing [8][9], pressure sensing [10] or even seismic activity monitoring [11]. Apart from the variety of new optical fibers, the emerging new types of fiber components allows to extend the applicability of legacy installed multimode fibers [12][13]. What is more, emergence of novel fiber technologies allows to extend the applicability of DOFS to the areas previously not justified economically or not accessible from technical point of view. To demonstrate some of the recent advancements in applicability of DOFS we show an example of fiber embedding in different materials like metal alloys and Carbon Fiber Reinforced Polymer (CFRP) composite structures typically used in space industry [14]. In both cases fiber allows to measure strain and temperature present inside the material. Another advancements example is a demonstration of multi probe measurement using one interrogator unit to gather high resolution temperature distribution over distant points of permafrost in Svalbard archipelago.

2. MULTIPOINT DISTRIBUTED SENSING IN SVALBARD ARCHIPELAGO

DOFS with centimetre spatial resolution are in most cases constructed using Optical Frequency Domain Reflectometry [15]. The sensing range of this technique is usually limited to tens of meters due to the limited phase noise of the lasers used to build deployable systems. This requires the sensing unit to be placed in vicinity of the sensing area. To overcome that issue InPhoTech elaborated a technique of remote distributed sensing. In such a way one can monitor several fiber links simultaneously with considerable distance from sensing probes to the interrogator. An example of such installation is presented in Fig. 1 where the placement of optical fiber probes is shown.

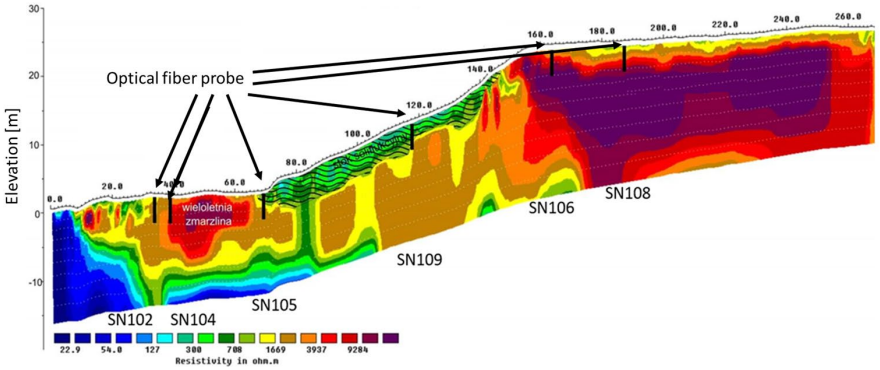

Figure 1. Location of measuring probes in the coastal area of Svalbard archipelago. Localization of probes is indicated in Electrical Resistance Tomography map.

Each probe has length of 2.8m and allows to measure temperature distribution with 5 cm spatial resolution and 0.05 °C temperature measurement resolution. The whole installation was designed to measure 32 probes each installed over 100 m from active interrogator unit.

Each probe could measure temperature distribution changes in the permafrost soil. An exemplary result in presented in Fig. 2 where one can see temperature distribution changes over 3 weeks. Daily patterns of temperature variation are clearly visible especially at the soil surface. Using such technique one can determine the level of permafrost temperature variations over 100s of meters from interrogator unit.

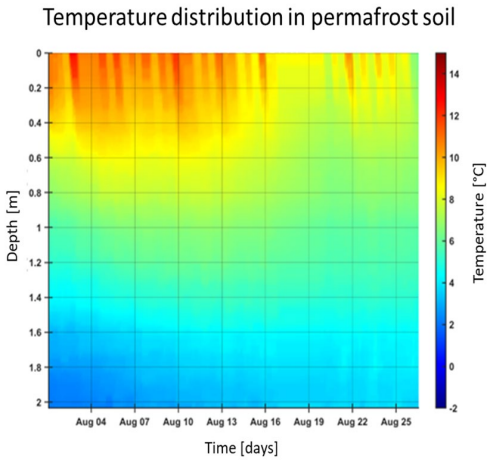

Figure 2. Temperature distribution in one of the probes installed in Svalbard recorded over 3 weeks.

The demonstration of multipoint high resolution sensing technology allows to broaden the applications of DOFS where multiple areas need to be monitored closely with shared interrogator unit and thus greatly reduced cost calculated per measurement point.

3. FIBER EMBEDDING IN ADVANCED MATERIALS

Another example of recent advances in optical fibers application is coating technology [16] that allows to incorporate optical fibers into various materials including metal alloys and CFRP composite. Specially developed coatings like nickel or copper allows to extend the durability of fibers in high temperature environments typical for production process of additive manufacturing or CFRP autoclave processing. Examples of fibers embedded in such material are presented in Fig. 3.

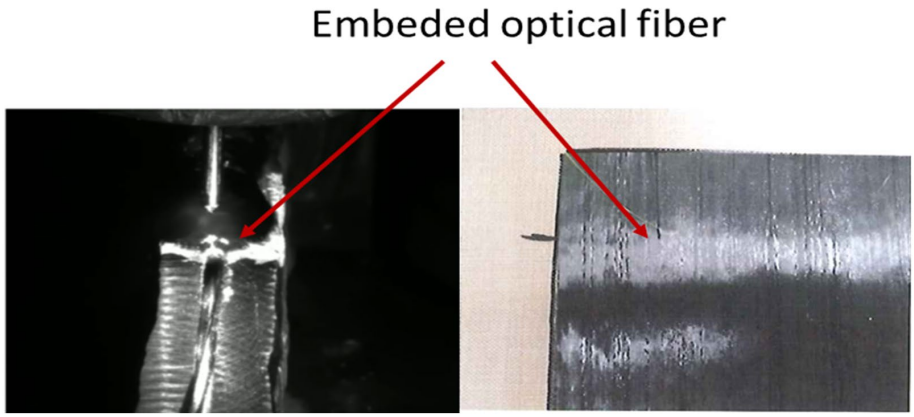

Figure 3: Left side– optical fiber embedded in metal during additive manufacturing. Right side optical fiber embedded in CFRP material with face ingress/egress.

Embedded fibers remain their structural integrity which allows to use DOFS to monitor strain and temperature during element lifetime.

4. CONCLUSION

Although most applications of optical fibers are still focused on long linear civil structures, the emerging technologies allows to extend their applicability to new areas.

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