EPJ Web of Conferences **266**, 13003 (2022)
EOSAM 2022
https://doi.org/10.1051/epjconf/202226613003

A ϕ-Shaped Bending-Optical Fiber Sensor for the Measurement of Radial variation in Cylindrical Structures

Victor Cardoso[1,4,6], *Paulo* Caldas[4,5], *M. Thereza* R. Giraldi[2], *Orlando* Frazão[3,4], *João* Costa[1], and *José* L. Santos[3,4]

[1]Federal University of Pará, Applied Electromagnetism Laboratory, Rua Augusto Corrêa, 01, 66075-110, Belém, Pará, Brazil
[2]Military Institute of Engineering, Laboratory of Photonics, Praça Gen. Tibúrcio, 80,22290-270, Rio de Janeiro, Brazil
[3]Department of Physics and Astronomy, Faculty of Sciences of University of Porto, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal
[4]Institute for Systems and Computer Engineering, Technology and Science, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal
[5]Polytechnic Institute of Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, 4900-347, Viana do Castelo, Portugal
[6]victorcard@ufpa.br

Abstract. This work presents preliminary results of the ϕ -shaped sensor mounted on support designed by additive manufacturing (AM). This sensor is proposed and experimentally demonstrated to measure the radial variation of cylindrical structures. The sensor presents an easy fabrication. The support was developed to work using the principle of leverage. The sensing head is curled between two points so that the dimension associated with the macro bend is changed when there is a radial variation. The results indicate that the proposed sensor structure can monitor radial variation in applications such as pipelines and trees.

1 Introduction

Compared to traditional methods of monitoring diameter variation, fiber-based sensors have several advantages: high sensitivity, immunity to electromagnetic interference, compact size and low weight, multiplexed measurement possibility, fast response, and ability to communicate over long distances [1, 2]. On the other hand, there is an increasing demand for developing sensors and instrumentation to reduce costs, optimize processes, and increase production through technological advances in Industry 4.0. In this scope additive manufacturing(AM), or 3D printing, is gaining applicability in industries and is used to manufacture structures using digital models [3].

The search for sensors with the above mentioned characteristics has been the research object in several works. Among them, we can mention Sienkiewicz *et al*[1] that uses a sensor based on an optical fiber in ϕ-shape for displacement measurement over large ranges associated with optical power loss as a function of the macro bend. The sensor has an extremely simple design. This same configuration was used years later in respiratory monitoring [2].

This work presents preliminary results where we investigate a designed setup for radial variation monitoring using a simple sensor based on ϕ-shaped with 3D printer support. It was possible to analyze the radial variation of cylindrical structures, typical of some kind of trees and pipelines.

*This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – (CAPES) – Finance code 001, the Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPq) from Brazil, Institute for Systems and Computer Engineering, Technology and Science (INESC TEC) and the Department of Physics and Astronomy, Faculty of Sciences of University of Porto from Portugal)

2 Sensor Operation and Preliminary Experimental Setup

The proposed sensor is formed by a piece of a singlemode fiber (SMF-28, Corning Inc.) in ϕ-shaped, as depicted in Fig. 1. When submitted to strain or displacement, this device acts as an intensity optical fiber sensor. The fiber is glued to the support at two points, one on each side of the loops [1]. Due to it, the radius of curvature of the sensor loops changes when subjected to an extension. This results in the stretching of the sensor loops and optical power loss in this setup. Contrariwise, a compressive strain would shorten the loops and increase intensity at the detector. These deformations take place in the plane of the loops. It is a simple optical sensor. These deformations take place in the plane of the loops. It is a simple optical sensor.

This structure was evaluated to use the lever principle, observed in several examples of everyday life as in pliers and scissors. The material used is Polyethylene Terephthalate Glycol (PET-G). This is a thermoplastic copolyester material, highly resistant and durable, chemical resistant, which is used commercially in desktop 3D printers [4]. It is an excellent material for various applications. Its use was intensified in 2020 in face shields production for the pandemic crisis caused by the SARS-CoV-2 virus, responsible for Covid-19 [5]. PET-G is a tough material, between 2.01 GPa and 2.11 GPa for Young's modulus and between 60 and 66 MPa for tensile strength [6, 7]. These char-

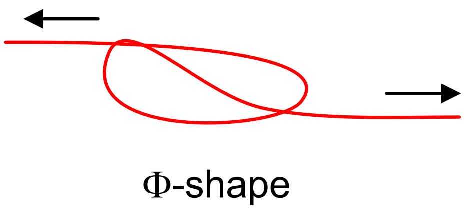

Figure 1. Schematic of the proposed sensor.

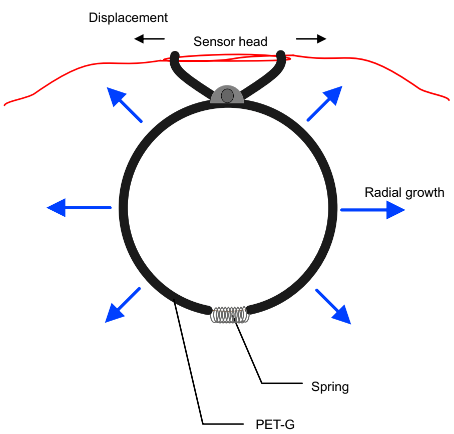

Figure 2. Schematic of the experimental piece.

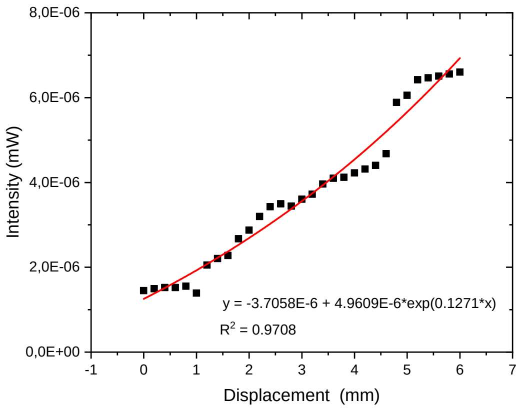

Figure 3. Gain intensity caused by the diameter variation.

acteristics make it an excellent material for the proposed application.

The schematic of the experimental piece is illustrated in Fig. 2. The support diameter is 90 mm, and it can be placed around the plant specimen or pipeline. The structure expands from the radial growth, changing a macro bend in the sensor, thus producing a variation in the optical power. The advantage of this design is the gap between the sensor head and the cylindrical structure because the sensor is free from possible transverse deformations. A spring was placed in the piece to be adjusted along with the radial variation.

3 Results and discussion

The preliminary results obtained from the experiments are depicted in Fig. 3. It is possible to observe that the results presented good behavior using the ϕ-shaped sensor when increasing the radius piece. This sensor allows greater control of the optical power for the dynamic range from 0 to 6 mm with a gain of the $\approx$ 11.8 dB. For this setup, the sensor has given good responses with R^2= 0.9708, and the sensitivity obtained was 1E-6 mW/mm.

4 Conclusion

In conclusion, we presented an experimental investigation to measure the cylindrical structures' radial variation using a ϕ-shaped sensor mounted on a 3D printer piece designed to support it. The setup is very simple and repeatable. The results showed that it is possible with the designed sensor to monitor the radial variation from 0 to 6 mm with good sensitivity and R^2=0.9708. This dynamic range can be used in many applications, such as obtaining the irrigation levels in agriculture by measuring variation of the stem of trees. The next step in this investigation will be to perform measurements using other kinds of optical sensors and optimized 3D printer structures.

References

[1] F. Sienkiewicz, A. Shukla, Optics and Lasers in Engineering **28**, 293–304 (1997)
[2] A.T. Augousti, F.X. Maletras, J. Mason, Physiological Measurement **26**, 585 (2005)
[3] H. Lasi, P. Fettke, H.e.a. Kemper, Bus Inf Syst Eng **6**, 239 (2014)
[4] J. Kechagias, N. Fountas, K. Ninikas, M. Petousis, N. Vidakis, N. Vaxevanidis, Materials and Manufacturing Processes (2021)
[5] K. Grzelak, J. laszcz, P.M. Jakub Polkowsk and, J. Kluczynski, J. Luszczek, J. Torzewski, I. Szachogluchowicz, R. Szymaniuk, Materials **14**, 4823 (2021)
[6] S. Guessasma, S. Belhabib, H. Nouri, Polymers **11**, 1220 (2019)
[7] C. Cianci, G. Pappalettera, G. Renna, C. Casavola, M. Laurenziello, G. Battista, C. Pappalettere, D. Ciavarella, Front. Mater. **7**, 104 (2020)