A tabletop rotor kit as training platform for fiber optic-based sensing

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ABSTRACT

In order to make aware of the importance that fiber optic sensors have in the modern industry, students in the master´s degree in Telecommunications Engineering at the University of the Basque Country are faced with a practical case of interest that provides a convenient training platform for learning important aspects of fiber-based optical sensing, such as probe design, the calibration curve, data interpretation and management, etc. The hands-on experiment runs around a tabletop rotor kit that includes different rotating parts and custom-designed fiber-based displacement sensors for monitoring the dynamics of the rotation. Practical aspects such as data interpretation and processing are dealt thoroughly, but without neglecting more fundamental aspects involved in the design of the optical probe.

Keywords: Optical metrology, optical fibers, rotor, proximity sensor

1. INTRODUCTION

Optical fibers are well known for their extraordinary properties for transmitting huge amount of data at very long distances in a way never seen before. Fiber optics represents a key enabler technology for modern data transmission to such an extent that current telecommunications networks cannot be understood without its existence. The fiber technology has reached such a high level of maturity, that it has opened the way to many other industrial fields and applications. In the modern industry in particular, fiber optic sensors represent a key trend that responds to the growing demand for safety and monitoring of industrial processes and infrastructures, among others. In order to make aware of it to students pursuing the master's degree in Telecommunications Engineering at the University of the Basque Country (UPV/EHU), a practical activity focused on fiber-based displacement sensing[1] is proposed to be worked out in groups. The hands-on experience develops around a tabletop rotor that allows easy installation of custom-designed fiber-based displacement sensors for monitoring the dynamics of the different rotating parts used throughout the activity. In order to extract the full value from the digital data created during the measurements, students are encouraged to show their skills on signal processing. Important parameters such as blade arrival time or tip clearance -when dealing with rotating compressors and turbines,- are determined experimentally. Students also get a comprehensive understanding of the fundamental aspects behind the fiber-based optical sensor: gaussian optics, geometric optics, the calibration curve, etc.[2] These tools provide students with the skills necessary to design optical probes for each application of interest.

2. MATERIALS AND METHODS

This section describes briefly the different elements that make up the sensing system, as well as the fundamental theoretical aspects necessary to understand and design the optical probe, which is the core element of the sensing system.

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Seventeenth Conference on Education and Training in Optics and Photonics: ETOP 2023,
edited by David J. Hagan, Mike McKee, Proc. of SPIE Vol. 12723, 127231U

2.1 Theoretical modeling of the fiber-based optical probe

The optical probe consists of a bundle of optical fibers arranged hexagonally around a central fiber, the transmitting fiber. The latter operates in a singlemode regime, whereas the fibers around it, organized in a ring-like shape, allow the propagation of many modes and they are aimed at gathering a fraction of the light reflected on the surface of interest, which in our case, is a rotating part.[3–5]

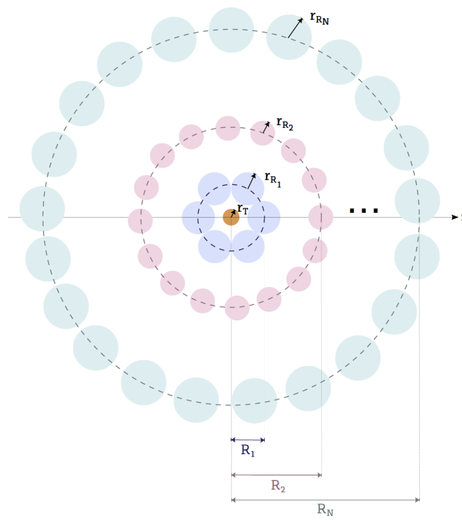

Figure 1. The central fiber is the transmitting fiber. It operates in singlemode regime. The rest of fibers, organized around the central fiber in a ring-like pattern, are multimode in nature and constitute the receiving fibers. Each ring of fibers is connected to a variable gain photodetector.

At this point the students are required to know, for a certain wavelength of light, the different propagation regimes of the fiber, and depending on it, define and implement computationally the strategy to calculate the overall power received as a function of the distance between the sensor head and the surface. This curve — the so called calibration curve,— provides the information that defines the working specifications of the sensor; particularly its linear range of operation and sensitivity.

2.2 Overall view of the optical sensor and the training platform

Apart from the optical head described above, the sensing system also includes the following elements: a laser diode (LD) emitting at 650 nm, two photodetectors of variable gain –each connected to a a different ring of fibers,– an acquisition system with analog inputs and a small software tool developed in LabVIEW for configuration, monitoring and data collection purposes. The working flow of the sensor is as follows (see the left hand side picture in Fig. 2): The light from the LD, after propagating through the transmitting fiber (central fiber), exits the fiber and hits the objetc located at a certain distance (in our case a rotating part several milimiters apart from the bundle endface). Part of the backreflected light is gathered at the endface of the fiber bundle by the receiving fibers (organized in a ring-like fashion). The total optical power collected by each ring of fibers is detected by the corresponding photodetector. In each case, the measured voltage is proportional to the collected optical power due to the high linearity between the optical power incident on the photodiode and the generated photocurrent. For measuring distance, the relevant magnitude will be the ratio of both voltage values, namely the optical power –or voltage– corresponding to the outer ring to the power –or voltage– corresponding to the inner one.

A portable rotor is used as training platform for the hands-on experiments with the fiber-based distance sensor. The rotation speed can be controlled by means of a commercially available electronic proximity probe installed close to the electric motor, in front a a notched wheel. Additionally, the analog signals generated by both the proximity sensor and the optical sensor are made available to the user through the digitization performed in the acquisition system.

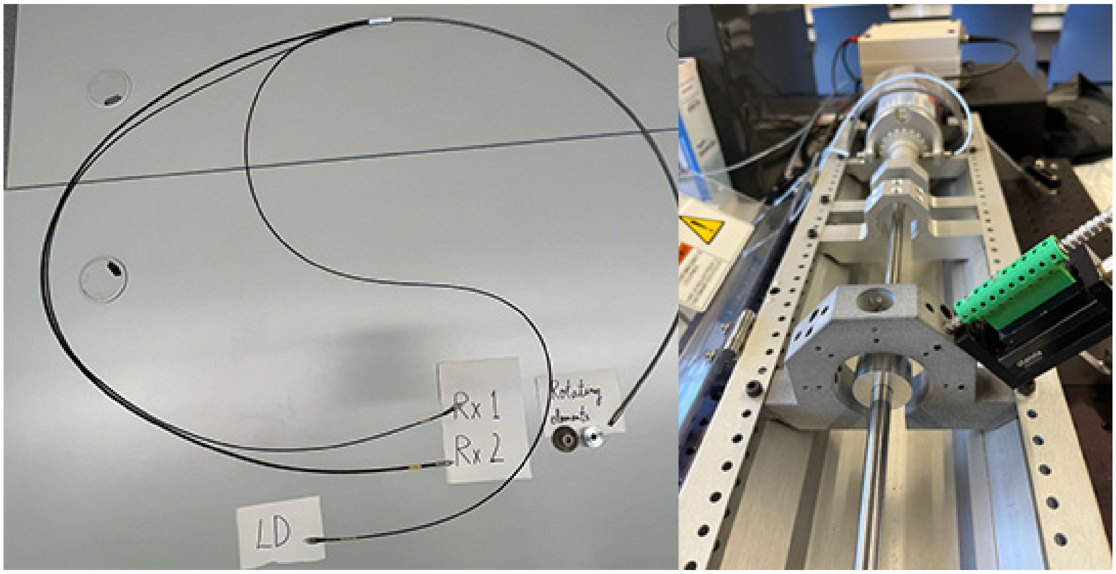

Figure 2. General view of (left hand side) the fiber bundle and (right hand side) the rotor kit platform used for the measurements with the optical sensor. The former shows the different fiber branches and connections to the different optoelectronic elements of the optical sensor, whereas the latter shows a view of the shaft and the spinning element (aluminum disc) used in the calibration measurements, as well as the radial positioning of the optical probe on the platform.

3. EXPERIMENTS AND OUTCOMES

Next we present briefly the most relevant activities that the student must deal with in the practical sessions. They are thought for instructing the students on the general design and use of an optical sensor of great applicability in a wide variety of applications.[6]

3.1 Computational implementation of simple probe model

After providing the students with the most basic bibliography and the corresponding discussion of the contents in order to clarify the most relevants and/or hardest points, they are encouraged to implement a basic model consisting of a transmitting fiber and a receiving fiber placed in parallel along the z axis, and separated by a distance R between centers. The distance, along the z axis, from both fiber's endfaces to the reflecting flat surface is given by d. As the emission of the transmitting fiber is singlemode, the students have to consider the Gaussian beam approach for it, whereas the power collected by the receiving fiber must be calculated taking into account the multimodal nature of the receiving fiber. Therefore, the light distribution does not remain constant across the emitted beam, but decreases exponentially as we move away from the center of the beam. On the other hand, after reflection of the emitted light on the target surface, the amount of optical power coupled to the receiving fiber has to be calculated by integration of the irradiance on the integration surface defined by the cross-section of the receiving fiber at its endface. All in all it allow student to simulate the calibration curve, which represents the optical power received as a function of the distance from the probe tip to the surface. The latter represents, from the practical point of view, the most important curve as it allows to determine the distance by looking up a table of values created from such a curve.

Next, the student are encouraged to extend the model to a ring-like structure of receiving fibers, whereas the singlemode transmitting fiber remains at the center of the structure. Again, the goal is to build the corresponding calibration curve and to analyze the effect that the different design parameters –diameters of receiving fibers, their numerical aperture, radial distance between the central fiber and the ring of fibers, etc.–have on it.

Therefore, the main goals of this activity may be summarized in the following points:

1. Gaussian approach implementation in transmitting fiber.

2. Geometric optics implementation in receiving fiber.
3. Calculus of the power guided in the receiving fiber.
4. Extension of the model to a fiber bundle design of interest —hexagonal arrangement of receiving fibers.

3.2 Calibration curve on rotor kit

The rotor kit itself servers as a platform for carrying out dynamic calibrations of the sensor. A simple micrometric stage allows precise radial movement of the optical probe with respect to the rotating surface (see Fig. 3). The latter consists of a rotating donut-like aluminum disc. The students measure the voltage values V_1 and V_2 as a function of the distance d to the surface and they plot the ratio V_2/V_1 as a function of the distance. This activity is aimed at making the students aware of the importance of calibrating conveniently the sensor for reliable and confident experimental distance measurements. As an additional activity, students are encouraged to compare the measured calibration curve with that obtained from the numerical simulations for the specifications given by the fiber bundle used in the experimental sessions.

To summarize, the main goals of this activity are the following:

1. General use of the rotor kit (ramping up and down, speed control, speed control probes, installation of rotating parts).
2. Setting-up the optical probe on the measuring platform.
3. Carrying out calibration measurements.
4. Comparison of theoretical and experimental curves.

3.3 Measurements on rotor kit

Next the students are encouraged to perform several demonstrations on the rotor kit to generate several cases of interest. After carrying out the measurements, the students observe and analyze the data in order to obtain valuable information about the spinning condition of the rotor kit. After all, signal processing and data generation from sensors are two activities that go hand in hand. For this activity a bladed disc is mounted on the shaft (see picture on the right hand side of Fig. 3). It consist of 27 blades and although the reflective surface is far from being shiny, the activity provides satisfactory results and a nice experience to the student. Amongst others, they have to check the shape of the optical pulses obtained as a result of the blades going past the sensor, the signal to noise ratio of the optical signal, or compare it with the pulse shape of the electronic proximity sensor used to control the speed of the rotor. Other activities that are included in this section are the following:

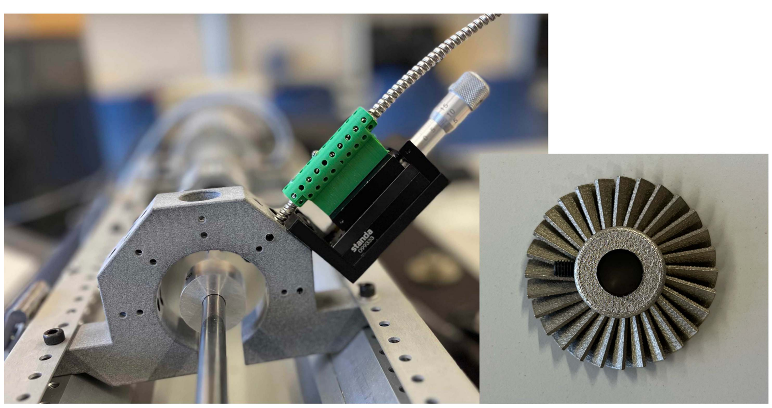

Figure 3. The micrometric linear stage allows a precise positioning of the optical probe on the rotor kit. The aluminum disc on the shaft is used for the dynamic calibration of the optical probe The bladed disc on the right hand side is used for the rest of measurements.

1. Determination of the arrival time of each blade (for every revolution). From there, instantaneous speed (27 speed values per each revolution) may be known, or the arrival time deviation of every blade with respect to the expected theoretical value.
2. Determination of every peak-value (blade) and its time/sample position. It has great relevance when precise distance to every blade going past the sensor is to be determined. At this point the calibration curve is required.
3. Determination of the Fourier Transform of the time signal, its interpretation and extraction of valuable information.

4. CONCLUSIONS

In a world where the trend is to monitor everything (from infraestructures to every kind of processes), optical sensors undoubtedly represent the key element in the generation of data which will be processed later on for its correct interpretation. In order to make aware of the importance of it to students in the master's degree in Telecommunications Engineering at the University of the Basque Country, a project is proposed to them where they participate in the design, calibration and general use of an optical fiber-based distance sensor in a rotating machine that simulates several cases of practical interest. Each student goes through the different project stages and must show skills in fundamental aspects of light propagation in optical fibers, in programming using a language of their choice, in setting up the optical sensor and rotor kit according to the measurements to be made, and in signal processing for extracting valuable information from the huge amoung of raw data provided by the optical sensor. All in all the main goal of the project is to put working together a group of students in their final stage of their studies around a specific topic of great practical interest within the framework set by photonics and industry.

ACKNOWLEDGMENTS

These results are funded in part by the Ministerio de Ciencia e Innovación -under projects RTC2019-007194-4, PID2021-122505OB- C31 and TED2021-129959B-C21,- and in part by Gobierno Vasco/Eusko Jaurlaritza under project IT1452-22.

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