Calibration of a Distributed Temperature Sensor in Optical Fiber Based on OFDR

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Optical Frequency Domain Reflectometry (OFDR) is a distributed sensing technique that uses a laser to sweep the frequency of light and record the backscattered signal along an optical fiber. Equipment such as the ODISI 6101 by LUNA employs this method for strain and temperature measurement. The present work aims to present a calibration method for an optical fiber distributed temperature sensor based on OFDR, through experimental bench tests, resulting in an equation describing the relationship between temperature and spectral shift for temperature measurement.

Keywords: Optical Fiber. OFDR. Calibration. Temperature Sensing.

OFDR is a distributed sensing technique that employs a laser to sweep the frequency of light and record the backscattered signal along an optical fiber. Using Fourier transforms, the signal is converted into a spatial profile, allowing distributed mapping of variations along the fiber. According to the studies of Wegmuller and colleagues [1] and Eickhoff and colleagues [2], OFDR can be used to analyze wavelength shifts and changes in the refractive index resulting from Rayleigh scattering, as well as the spatial distribution of scattering and attenuation characteristics.

From these signals, information about the internal expansion of the fiber and temperature can be extracted. This is achieved through analysis of the wavelength shift relative to the initial wavelength profile. In the case of temperature, the wavelength deviation occurs due to fiber expansion and changes in the refractive index of its core.

The potential of OFDR to provide accurate, distributed measurements with high spatial resolution has been widely demonstrated in the literature, including works by Kreger and colleagues [3] and Wegmuller and colleagues [1], which highlight its applicability in thermal sensing and structural strain measurement [3-4].

In this work, we propose a fiber calibration method that involves determining the relationship between wavelength shift and temperature, enabling distributed temperature measurement along the optical fiber by utilizing the fiber itself as the sensing element. The proposed approach not only validates the calibration methodology but also expands the applicability of OFDR in advanced distributed sensing systems.

Materials and Methods

The measurement and calibration of the optical fiber were performed by acquiring the spectral shift of a trace generated by the OFDR interrogator. The fiber was placed on a heating plate, and the experimental tests were repeated three times to ensure reproducibility of the results.

The equipment used included an Allerbest heating plate, Corning ClearCurve optical fiber (which has lower optical power loss due to micro- and macro-bending), a Fluke True-RMS 289 multimeter with a thermocouple for monitoring plate temperature, and a LUNA ODISI 6101 system, which operates using reflectometry techniques based on Rayleigh backscattering to determine a reference trace of the fiber. The ODISI saves this trace, and subsequent traces are measured and compared to it. The difference

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between the traces can be correlated with strain and temperature in the fiber core.

The experimental setup consisted of arranging the ClearCurve optical fiber into a coil with six turns placed on the heating plate, as shown in Figures 1 and 2. The fiber was connected to the ODISI, and using the LUNA OD6 software, fiber sensing data were collected. The temperature was recorded at 2.6 mm intervals, corresponding to the spatial resolution configured on the equipment.

A Python code was developed to identify the initial and final indices of the vector shared by ODISI where the fiber position was located.The code scans the vector and locates the highest deformation peak, corresponding to the intentional strain applied to the fiber, allowing for the precise identification of the segment under analysis. The data collection width was set to 96 points, corresponding to a fiber length of 252.2 mm in contact with the heating plate.

Spectral data acquisition was performed at temperatures ranging from 20°C to 100°C in 10°C increments. A second Python code was developed to collect and store the spectral shift data in text files.

Ninety-six spectral shift data points were collected for each of the nine temperature levels. The first plot displays the average of the 96 shift values for each temperature, yielding nine averages for each of the three tests. The second plot displays the average of the means of each test, resulting in nine final average values. Finally, a linear regression was applied to the mean data, producing the sensor's calibration curve.

Results and Discussion

Figures 3 and 4 present the relationship between temperature and spectral shift, along with their respective linear regressions. These results quantify the dependence between wavelength displacement and thermal variation, allowing calibration of the optical sensor. Figure 3 shows the experimental data obtained in each of the three tests, represented by different colors (blue for the first test, red for the second, and yellow for the third). The linear regressions associated with each dataset enable comparative analysis, demonstrating measurement reproducibility and spectral shift variation as a function of temperature. The average values obtained in the three tests, along with the corresponding linear regression, are illustrated in Figure 4. The equation resulting from the linear regression defines the sensor's calibration curve, serving as a reference for future measurements. The good correlation observed between the experimental data and the linear model reinforces the reliability of the proposed

Figure 1. Optical fiber attached to the heating plate.

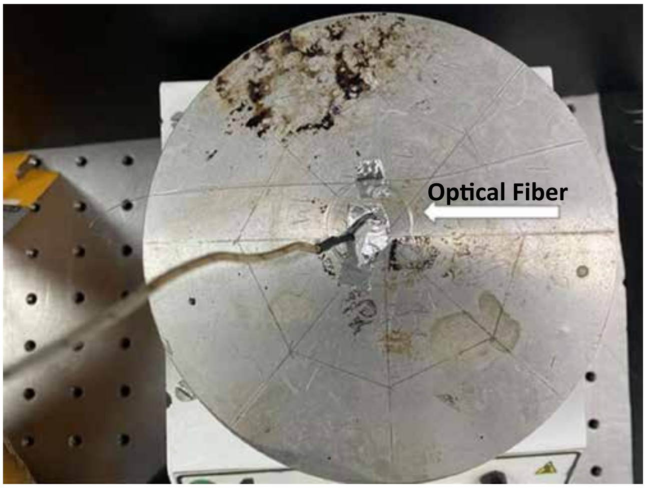


Figure 2. Composition of the experiment.

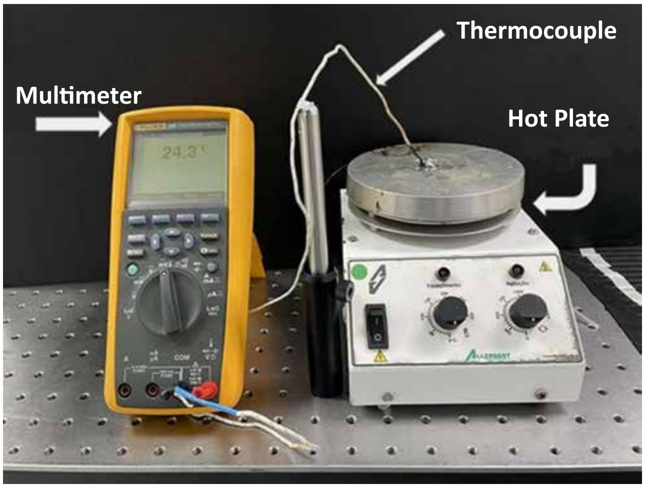


Figure 3. Three-test comparison graph.

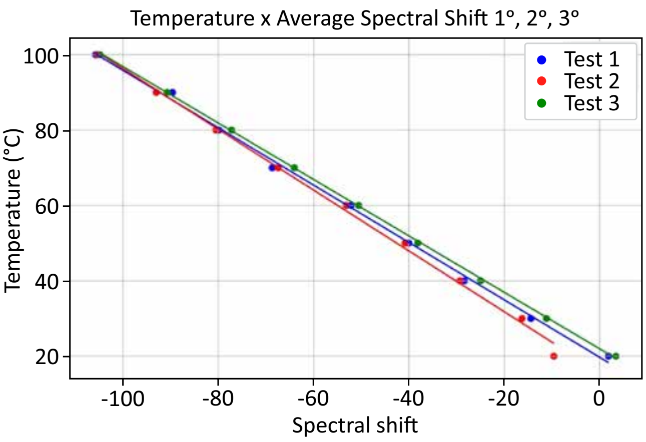
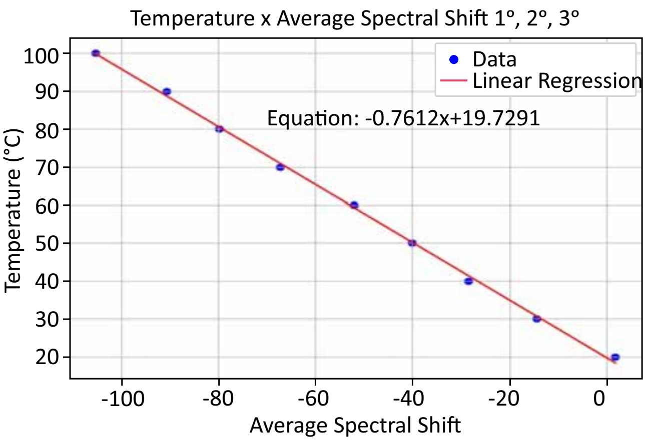


Figure 4. Temperature *vs*. spectral shift graph.



method, confirming the feasibility of using optical fiber as a sensing element for precise distributed temperature monitoring.

Conclusion

For temperature measurement using OFDR and fiber calibration, the relationship between wavelength shift and temperature was utilized.

According to the Figure 4, after performing linear regression, the calibration curve equation for the OFDR sensor was obtained as:
$-0.761x + 19.7$, which is used for temperature calibration based on the relationship between spectral shift and temperature along the optical fiber.These results demonstrate the precision and effectiveness of the applied method, making a significant contribution to the development and advancement of distributed temperature monitoring research. The proposed approach not only validates the calibration technique but also lays the groundwork for future applications and enhancements.

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