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## Temperature-Dependent Elongation Sensitivity of a Silica Single-Mode-Multimode-Single-Mode Optical Fiber Sensor at 1310 nm

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### ABSTRACT

The elongation sensor based on the singlemode-multimode-singlemode (SMS) optical fiber structure is an interesting candidate for strain measurement applications, as its optical response is quite sensitive to light propagation changes in the multimode section. Even so, temperature's influence should not be overlooked, as it affects the sensor's response and is a parameter that warrants serious consideration during calibration. Based on this, the study examined the extent to which temperature affects the elongation sensitivity of a silica-based SMS optical fiber sensor, using a 5.4 cm multimode segment tested at a wavelength of 1310 nm. Testing covered three temperature variations (38, 48, and 58 °C), with elongation applied gradually from 0 to 100  $\mu\text{m}$  in 10  $\mu\text{m}$  increments, and each point was repeated 3 times to evaluate short-term repeatability. Changes in optical loss (dB) were used as the main indicator of the sensor's response. The results showed a fairly consistent pattern, optical loss tended to increase with elongation across all three tested temperatures. The linear regression results showed a sensitivity of 0.002388 dB/ $\mu\text{m}$  at 38 °C, increasing to 0.002723 dB/ $\mu\text{m}$  at 48 °C and reaching 0.003062 dB/ $\mu\text{m}$  at 58 °C. The respective  $R^2$  values were 0.9378, 0.9273, and 0.9346. These values confirming a near-linear relationship between optical loss and elongation within this testing range. When the temperature was raised from 38 to 58 °C, the sensitivity increased approximately 28%. The relatively small standard deviation further supports the sensor's fairly good repeatability. Overall, these results indicate that temperature needs to be incorporated into the calibration process of SMS elongation sensors. However, these findings remain preliminary and apply specifically to the tested configuration, namely a 5.4 cm MMF segment at 1310 nm, within a temperature range of 38–58 °C and elongation of 0–100  $\mu\text{m}$ .

#### Contribution to Sustainable Development Goals (SDGs):

**SDG 9:** Industry, Innovation, and Infrastructure

**SDG 11:** Sustainable Cities and Communities

**SDG 12:** Responsible Consumption and Production

## 1. INTRODUCTION

### 1.1. Research Background

One thing that should not be taken lightly in monitoring the condition of a component or its structure is the ability to detect

elongation and small-scale deformation. Just imagine, even the smallest mechanical change could serve as an "early signal" of loading, displacement, or even developing damage within a system. This is precisely why sensor technology that is truly stable and sensitive in capturing such elongation changes is needed. The built monitoring system can become more robust, and its results can be trusted [1].



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However, in practice, elongation measurements do not always occur under ideal or constant environmental conditions. In practical applications, temperature changes rarely occur in isolation. They may accompany mechanical deformation, particularly in industrial equipment, outdoor installations, and components exposed to continuous heating. Under these conditions, the sensor response may shift, causing the measured values to differ from those predicted by the initial calibration. Therefore, the effect of temperature must be understood before the calibration is applied under different operating conditions and before the measurement results are interpreted [2].

Speaking of technology choices, optical fiber sensors are one of the fairly promising candidates for elongation measurement. The reason is their solid yet compact size, and no less important, their immunity to electromagnetic interference. One configuration that is relatively simple yet effective is the singlemode-multimode-singlemode (SMS) structure, namely an arrangement in which a multimode fiber segment is spliced between two singlemode fiber segments. This kind of structure has great potential as an optical-loss-based sensor, given that its optical response will change as soon as a mechanical perturbation occurs in the sensor's area [3], [4].

Based on these considerations, this study was designed to evaluate the extent to which temperature affects elongation sensitivity in the SMS optical fiber sensor. The main focus of this study is to observe how optical loss varies with elongation across different temperature conditions, and to determine whether the sensor's sensitivity remains stable or changes as temperature rises.

## 1.2. Literature Review

The singlemode-multimode-singlemode (SMS) structure has actually been developed for quite some time as a fiber-optic-based sensing platform. This is due to its advantage of offering a simple configuration while still maintaining an all-fiber construction. In simple terms, the SMS structure can be pictured as a single multimode fiber (MMF) segment "inserted" between two singlemode fibers (SMFs) [5], [6]. When light is launched from the input SMF, it enters the MMF section and excites several guided modes simultaneously. Because each of these modes propagates with a different propagation constant, modal interference arises before the light is eventually recoupled into the output SMF [7].

Upon closer examination, the sensing mechanism in the SMS structure relies on multimode interference (MMI). Any change in the physical or optical condition of the MMF section will, in turn, alter the effective refractive index, optical path length, modal distribution, and coupling efficiency. It is through this process that changes in external parameters can be "captured," whether through variations in intensity, spectral response, or optical loss [8]. Owing to these characteristics, it is not surprising that the SMS structure has been widely utilized to measure various physical parameters, ranging from temperature, strain, and displacement to curvature and refractive index [6].

The characteristic of the SMS structure as a temperature-sensitive device is not a new finding, as previous studies have reported similar results. Interestingly, temperature change turns out to affect the fiber not through a single pathway alone, but through two mechanisms at once. On one hand, temperature modifies the fiber's refractive index through the thermo-optic effect. On the other hand, temperature also alters the fiber's

physical dimensions due to thermal expansion. The combination of these two mechanisms disturbs the phase relationship among the modes propagating in the multimode section. This causes the modal interference pattern to shift, thereby affecting the measured optical response [9], [10]. From this, it is fairly clear that temperature plays a role in determining the SMS sensor's characteristics.

The SMS structure also has a broader scope of application, namely, for detecting strain and various other forms of deformation. When the SMS section is mechanically disturbed, the propagation of modes within the MMF segment is also affected. The impact of this change can appear in various forms. Ranging from spectral shifts, changes in optical intensity, to variations in the measured optical loss [6], [11]. The SMS structure is quite flexible for detecting various mechanical changes.

However, the use of SMS structures as elongation sensors still faces calibration challenges under varying temperatures. Previous studies have generally discussed the SMS response to temperature or strain as separate parameters, or have developed simultaneous measurement schemes for both [12]. For optical-loss-based elongation sensing, however, a more specific evaluation is still needed to determine how elongation sensitivity changes under different temperature conditions. This issue is important because temperature-dependent sensitivity can lead to inaccurate interpretation of elongation if the sensor is calibrated at only a single temperature.

This study addresses this gap by evaluating the elongation sensitivity of a silica SMS structure with a 5.4 cm MMF section at 1310 nm. Unlike previous studies that examine elongation response under a single thermal condition, this study compares the optical loss response to elongation at 38, 48, and 58 °C. Therefore, the main contribution of this study is to provide a temperature-dependent calibration analysis for an optical-loss-based SMS elongation sensor.

## 1.3. Research Objective

This study aims to evaluate the effect of temperature on the elongation sensitivity of a silica singlemode-multimode-singlemode (SMS) optical fiber sensor with a 5.4 cm MMF section at a wavelength of 1310 nm. The sensor was tested under three temperature conditions, namely 38, 48, and 58 °C, with elongation ranging from 0 to 100  $\mu\text{m}$  at intervals of 10  $\mu\text{m}$ . The sensor response was analyzed based on the variation in optical loss, expressed in dB.

Specifically, this study aims to: (1) analyze the relationship between optical loss and elongation under each temperature condition; (2) determine the elongation sensitivity of the sensor based on the slope of the linear regression; (3) compare the sensitivity changes at 38, 48, and 58 °C; and (4) evaluate the repeatability of the sensor response based on repeated measurements at each elongation point.

## 2. MATERIALS AND METHODS

### 2.1. Research Design

This study employed an experimental method to evaluate the effect of temperature on the elongation sensitivity of a singlemode-multimode-singlemode (SMS) optical fiber sensor. The independent variables were temperature and elongation,

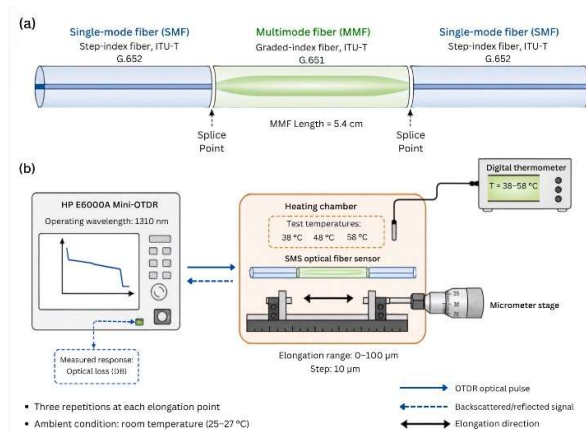
while the observed response variable was optical loss, expressed in dB. The experiment was conducted at three temperatures: 38, 48, and 58 °C. At each temperature, the sensor was subjected to elongation ranging from 0 to 100 µm in 10 µm increments. Each measurement point was repeated three times to evaluate the repeatability of the sensor response.

The test temperature was controlled using a heating chamber, and monitored with a digital thermometer. Elongation was applied gradually using a micrometer stage. The optical loss response of the sensor was measured using an HP E6000A Mini-OTDR at a wavelength of 1310 nm.

## 2.2. SMS Optical Fiber Sensor Structure

The sensor used in this study was a silica singlemode–multimode–singlemode (SMS) optical fiber structure, fabricated by splicing a multimode fiber (MMF) section between two single-mode fiber (SMF) sections. The SMF was a step-index fiber compliant with ITU-T Recommendation G.652, while the MMF was a graded-index fiber compliant with ITU-T Recommendation G.651. The length of the MMF section in the SMS structure was 5.4 cm.

The SMS structure operates on changes in the light-propagation conditions within the MMF section. Light from the input SMF enters the MMF section, exciting several guided modes. These modes interfere during propagation within the MMF section before being recoupled into the output SMF. When elongation is applied to the sensor, the modal propagation and coupling conditions may change, resulting in a measurable variation in optical loss recorded by the OTDR.



**Fig. 1.** (a) Structure of the singlemode–multimode–singlemode (SMS) optical fiber sensor and (b) schematic diagram of the experimental setup for elongation measurement under different temperature conditions.

## 2.3. Experimental Setup and Procedure

The experimental setup consisted of five main components: an HP E6000A Mini-OTDR, used as the optical loss measurement system; an SMS sensor structure, used as the sensing element; a micrometer stage, used as the elongation adjustment device; a heating chamber, used as the temperature control system; and a digital thermometer, used as the temperature monitoring device. All measurements were conducted at a wavelength of 1310 nm.

The SMS sensor was placed inside the heating chamber and tested at 38, 48, and 58 °C. At each temperature, elongation was increased from 0 to 100 µm in 10 µm increments using a

micrometer stage, and the corresponding optical loss was recorded in dB using the OTDR. Each temperature–elongation combination was measured three times. The mean optical loss at each elongation point was used in the analysis, while the standard deviation of repeated measurements was used to assess sensor response stability and measurement repeatability.

**Table 1.** Experimental parameters of the SMS optical fiber sensor

| Parameter                      | Value                                          |
|--------------------------------|------------------------------------------------|
| Sensor structure               | Singlemode–multimode–singlemode                |
| Singlemode fiber type          | Step-index fiber, ITU-T Recommendation G.652   |
| Multimode fiber type           | Graded-index fiber, ITU-T Recommendation G.651 |
| Multimode section length       | 5.4 cm                                         |
| Fabrication method             | Splicing                                       |
| Optical measurement instrument | HP E6000A Mini-OTDR                            |
| Operating wavelength           | 1310 nm                                        |
| Temperature control            | Heating chamber                                |
| Temperature measurement        | Digital thermometer                            |
| Elongation adjustment          | Micrometer stage                               |
| Temperature variation          | 38, 48, and 58 °C                              |
| Elongation range               | 0–100 µm                                       |
| Elongation interval            | 10 µm                                          |
| Number of repetitions          | Three measurements at each point               |
| Measured response              | Optical loss                                   |

## 2.4. Data Analysis

The three repeated optical loss measurements were used to calculate the mean and standard deviation at each elongation point. The mean represented the primary sensor response, while the standard deviation assessed measurement repeatability.

The mean optical loss was calculated using:

$$\bar{L} = \frac{1}{n} \sum_{i=1}^n L_i \quad (1)$$

where  $\bar{L}$  is the mean optical loss,  $L_i$  is the optical loss measured during the  $i$ -th repetition, and  $n$  is the number of repeated measurements. In this study,  $n=3$ .

The standard deviation was calculated using:

$$SD = \sqrt{\frac{\sum_{i=1}^n (L_i - \bar{L})^2}{n - 1}} \quad (2)$$

where SD is the sample standard deviation,  $L_i$  is the optical loss measured during the  $i$ -th repetition,  $\bar{L}$  is the mean optical loss, and  $n$  is the number of repeated measurements.

The relationship between optical loss and elongation was analyzed using linear regression:

$$L = mE + b \quad (3)$$

where  $L$  is the optical loss in dB,  $E$  is the elongation in  $\mu\text{m}$ ,  $m$  is the elongation sensitivity in dB/ $\mu\text{m}$ , and  $b$  is the intercept in dB. The sensor sensitivity was obtained from the slope of the linear regression, while the coefficient of determination ( $R^2$ ) was used to evaluate the linearity of the sensor response.

### 3. RESULT AND DISCUSSION

#### 3.1. Optical Loss Response to Elongation

Fig. 2 presents the optical loss response of the SMS optical fiber sensor under different temperature conditions. The Mean optical loss increased with elongation from 0 to 100  $\mu\text{m}$  at all tested temperatures. At 38 °C, it rose from 3.6737 dB at 0  $\mu\text{m}$  to 3.8690 dB at 100  $\mu\text{m}$ . Corresponding increases were observed at 48 °C, from 3.6793 to 3.8993 dB, and at 58 °C, from 3.6907 to 3.9393 dB. The total changes were 0.1953, 0.2200, and 0.2487 dB at 38, 48, and 58 °C, respectively, indicating that the SMS sensor response depended on both elongation and ambient temperature.

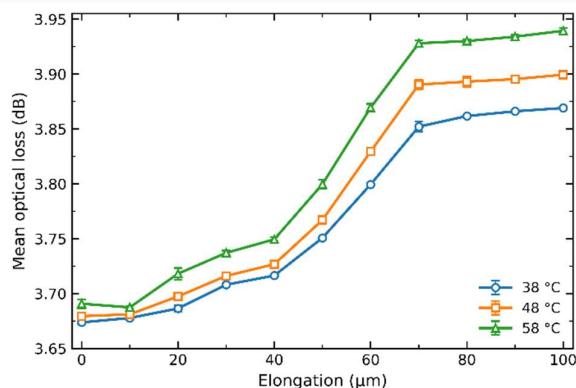


Fig. 2. Mean optical loss response of the SMS optical fiber sensor as a function of elongation at 38, 48, and 58 °C. Error bars represent the standard deviation of three repeated measurements ( $n = 3$ ).

The observed increase in optical loss can be explained in relation to the light propagation behavior within the SMS structure. When elongation is applied to the sensing region, the physical state of the multimode fiber (MMF) section may be perturbed. Such perturbation can alter the modal propagation condition, optical path length, and recoupling efficiency from the MMF section into the output singlemode fiber (SMF). Consequently, the optical power recoupled into the guided mode may vary, resulting in a measurable change in optical loss. This interpretation is consistent with the multimode-interference-based response typically reported for SMS fiber structures, although the internal modal distribution was not directly measured in this study [13].

As shown in Fig. 2, the error bars indicate that the differences among the three repeated measurements are quite small at each point. This serves as fairly convincing evidence that the constructed experimental setup exhibits good short-term repeatability. It should be noted, however, that the resulting trend does not always progress smoothly or monotonically from beginning to end. As seen at 58 °C, the average optical loss

decreased slightly from 3.6907 dB at 0  $\mu\text{m}$  to 3.6873 dB at 10  $\mu\text{m}$ , then rose again as elongation increased. Even so, such a minor decrease is not particularly significant relative to the overall change in optical loss, so the increasing trend, which represents the main pattern, can still be regarded as a valid conclusion.

The small fluctuation may arise from multimode interference within the SMS structure because elongation can affect the supported modes differently. Changes in intermodal phase differences and recoupling conditions alter the optical power coupled into the output SMF, producing a small “bump” in the optical loss curve. Other possible contributors include slight mechanical fiber shifts, minor temperature variations, micrometer-positioning uncertainty, and limited instrument resolution. However, the internal modal field was not isolated, and the individual uncertainty sources were not quantified separately. Therefore, the experiment could not determine the exact origin of the observed variation.

At Above 70  $\mu\text{m}$ , the increase in optical loss became less pronounced. From 70 to 100  $\mu\text{m}$ , the total changes were 0.0170 dB at 38 °C, 0.0090 dB at 48 °C, and 0.0113 dB at 58 °C. This trend suggests a plateau-like response, although the available data are insufficient to establish full saturation. Further elongation in this range may produce only limited changes in intermodal phase relationships and light coupling from the MMF section into the output SMF, resulting in progressively smaller changes in optical loss.

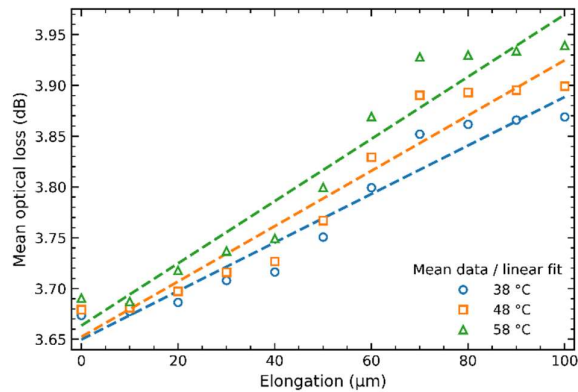
The plateau-like response limits linear regression's ability to capture the full 0–100  $\mu\text{m}$  range. Although the linear model provides satisfactory calibration, sensitivity decreases at larger elongations. Therefore, the regression-derived sensitivity should be interpreted as an average over the tested range rather than a constant value at every measurement point. Whether the plateau is an inherent sensor characteristic or an artifact of the experimental configuration remains uncertain. Further testing with smaller elongation intervals, loading–unloading cycles, and multiple independent sensors is needed to characterize the response in greater detail and assess its consistency.

#### 3.2. Linear Regression and Elongation Sensitivity

Linear regression was used to determine the elongation sensitivity of the SMS optical fiber sensor at each temperature. Sensitivity was defined as the slope of mean optical loss versus elongation and expressed in dB/ $\mu\text{m}$ . The regression results are presented in Fig. 3 and summarized in Table 2. At 38 °C, the sensitivity was 0.002388 dB/ $\mu\text{m}$ , with an intercept of 3.649742 dB and an  $R^2$  of 0.9378. Sensitivity increased to 0.002723 dB/ $\mu\text{m}$  at 48 °C (intercept = 3.652439 dB,  $R^2 = 0.9273$ ) and reached 0.003062 dB/ $\mu\text{m}$  at 58 °C (intercept = 3.663515 dB,  $R^2 = 0.9346$ ).

The  $R^2$  values consistently fall within the range of 0.9273 to 0.9378. This provides reasonable grounds to conclude that the linear model can describe the overall relationship between optical loss and elongation. Even so, it should be emphasized that the sensor's response is not perfectly linear. Its sensitivity is also not always constant at every measurement point. Small fluctuations are observed at lower elongations, with a tendency toward a plateau at higher elongations. The linear regression in this study should not be interpreted as an absolute representation; rather, it is more appropriately viewed as a practical, average calibration. It should be kept in mind that the validity of this approach only

holds within the temperature and elongation boundaries tested in this study, and therefore should not simply be generalized beyond that range.



**Fig. 3.** Linear regression analysis of mean optical loss as a function of elongation for the SMS optical fiber sensor under different temperature conditions.

**Table 2.** Regression-derived calibration parameters of the SMS optical fiber elongation sensor.

| Temperature (°C) | Sensitivity, $m$ (dB/ $\mu$ m) | Intercept, $b$ (dB) | $R^2$  |
|------------------|--------------------------------|---------------------|--------|
| 38               | 0.002388                       | 3.649742            | 0.9378 |
| 48               | 0.002723                       | 3.652439            | 0.9273 |
| 58               | 0.003062                       | 3.663515            | 0.9346 |

Note:  $L = mE + b$ , where  $L$  is mean optical loss in dB and  $E$  is elongation in  $\mu$ m.

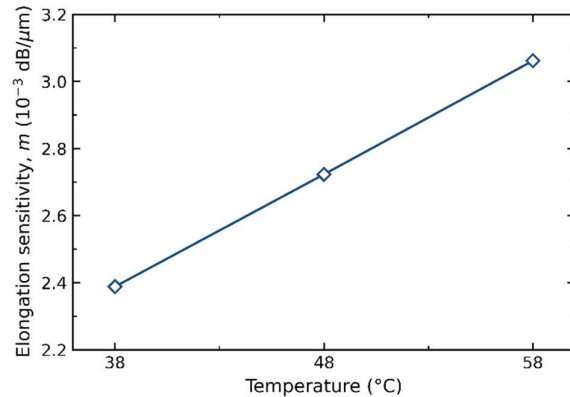
The  $R^2$  values, ranging from 0.9273 to 0.9378, suggest a reasonably linear relationship between optical loss and elongation. Nevertheless, the response is more accurately described as approximately linear rather than perfectly linear, an interpretation supported by the local non-monotonic behavior observed at low elongation and the plateau-like tendency at higher elongation values. Thus, the regression model is suitable as an initial calibration approach, although its validity should be limited to the tested conditions of 0–100  $\mu$ m elongation and 38–58 °C temperature.

### 3.3. Effect of Temperature on Sensor Sensitivity

As shown in **Figure 4**, it can be clearly seen how temperature plays a role in affecting the elongation sensitivity of the tested SMS optical fiber sensor. Based on the regression slopes, sensitivity increased from 0.002388 dB/ $\mu$ m at 38 °C to 0.002723 dB/ $\mu$ m at 48 °C, then continued to rise to 0.003062 dB/ $\mu$ m at 58 °C. When calculated using the slope values, the increase in sensitivity from 38 to 58 °C reached approximately 28.2%. This figure sufficiently confirms that the elongation sensitivity of this SMS sensor is indeed temperature-dependent, at least within the temperature range tested in this study.

The rise in sensitivity conveys an important message: the optical loss response to elongation is not always the same under different thermal conditions. In other words, an identical amount of elongation can produce different changes in optical loss, depending on the sensor's operating temperature at the time.

Findings such as this certainly carry significant implications for sensing applications, since if calibration is performed at only a single temperature, the resulting elongation interpretation may become less accurate once the operating temperature changes.



**Fig. 4.** Temperature-dependent elongation sensitivity of the SMS optical fiber sensor obtained from the slope of linear regression. The connecting line is used as a visual guide.

From a physical standpoint, the influence of temperature on the SMS response arises from two main effects: the thermo-optic effect and thermal expansion. As temperature changes, the thermo-optic effect alters the refractive index in both the core and the cladding of the fibre. Such changes automatically modify the effective refractive index and propagation constant of the guided modes in the MMF section. Because each mode propagates at a different rate, even a relatively small temperature change can alter the accumulated phase difference along the 5.4 cm MMF section.

Thermal expansion also alters the physical length and diameter of the MMF. These geometric changes affect the optical path length, mode distribution, and overall multimode interference conditions. The combination of these two effects ultimately determines how much optical power successfully "recouples" into the output SMF. Given that the OTDR essentially measures only the total optical loss, any temperature-induced shift in interference condition or coupling efficiency will directly affect both the measured optical loss value and the slope of the loss-versus-elongation curve [14], [15].

The fact that our measured sensitivity increased from 38 to 58 °C suggests that the fiber's optical condition appears to become more "sensitive" to stretching at higher temperatures. Even so, this study has not independently measured the actual changes in refractive index, fiber expansion, or the behavior of each individual mode separately. Therefore, although the thermo-optic effect and thermal expansion represent the most logical explanations and are supported by the fundamental principles of SMS, both effects should still be regarded as physically plausible interpretations, rather than mechanisms that have been directly verified within the present testing configuration.

### 3.4. Repeatability of Sensor Response

The repeatability of the SMS sensor response was evaluated based on three repeated measurements at each elongation point. The standard deviation was used to assess the variation in optical loss under the same temperature and elongation conditions. The repeatability metrics are summarized in **Table 3**.

**Table 3.** Repeatability metrics of the SMS optical fiber sensor response.

| Temperature (°C) | Average SD (dB) | Maximum SD (dB) | Average CV (%) |
|------------------|-----------------|-----------------|----------------|
| 38               | 0.00134         | 0.00458         | 0.0357         |
| 48               | 0.00266         | 0.00462         | 0.0695         |
| 58               | 0.00280         | 0.00529         | 0.0735         |

*Note: SD represents the standard deviation of three repeated measurements at each elongation point. CV represents the coefficient of variation.*

The average standard deviations at 38, 48, and 58 °C were 0.00134, 0.00266, and 0.00280 dB, respectively, while the maximum standard deviations were 0.00458 dB at 38 °C, 0.00462 dB at 48 °C, and 0.00529 dB at 58 °C. These values are small relative to the total optical-loss changes observed over the 0–100  $\mu\text{m}$  elongation range, which ranged from 0.1953 to 0.2487 dB. This comparison supports the interpretation that the repeated measurements exhibited acceptable short-term repeatability under the experimental conditions applied.

These results indicate that the repeated measurements produced relatively small variations in optical loss. Therefore, the sensor can be considered to exhibit acceptable repeatability under the experimental conditions applied. However, the repeatability discussed in this study is limited to short-term repeated measurements at each elongation point. Long-term stability, hysteresis, and sensor response after repeated loading cycles were not evaluated in this work and should be addressed in future studies.

### 3.5. Practical Implications and Limitations

The results of this study offer a practical calibration perspective for SMS optical fiber structures used as optical-loss-based elongation sensors. In applied sensing, the sensor response should be evaluated not only as a function of elongation but also with respect to operating temperature. The present results show that the regression-derived elongation sensitivity varied with temperature, indicating that calibration should account for temperature when the sensor is used under varying thermal conditions.

This finding carries important implications for distortion monitoring purposes. Whether for engineering systems, industrial components, or infrastructure elements, whose conditions frequently undergo simultaneous changes in mechanical elongation and temperature. In practice, an instrument of this kind should ideally be calibrated at the actual operating temperature. For field conditions involving multiple temperature variations, calibration should be performed separately for each temperature condition. When calibration is performed at a single temperature, the optical-loss response will vary with the actual field temperature, which can obscure the interpretation of the true elongation results. For this reason, calibrating the measurement method should be carried out based on the range of temperature variations likely to be encountered. At the very least, temperature monitoring should be performed simultaneously whenever this SMS-based elongation sensor is applied in practice.

Several limitations should be acknowledged. First, the experiment was conducted at only three temperature conditions, namely 38, 48, and 58 °C; therefore, the sensitivity–temperature relationship cannot yet be generalized to a wider temperature range. Second, the elongation range was limited to 0–100  $\mu\text{m}$ , and

the optical loss response exhibited a plateau-like tendency at higher elongation values. Third, the study employed a single SMS sensor configuration with a 5.4 cm MMF section and an operating wavelength of 1310 nm; therefore, the results may not directly apply to other MMF lengths, fiber types, or operating wavelengths. Fourth, hysteresis, long-term stability, repeated loading cycles, and a complete uncertainty budget were not evaluated in this work.

Considering these limitations, the present study should be regarded as an initial temperature-dependent calibration analysis of an optical-loss-based SMS elongation sensor. The main contribution lies not in claiming universal sensor performance, but in demonstrating that elongation sensitivity varies with temperature and that calibration should account for this effect within the tested operating range.

## 4. CONCLUSION

This study investigated how temperature impacts the elongation sensitivity of a silica SMS optical fiber sensor (using a 5.4 cm MMF section at 1310 nm). The results showed that as the fiber was stretched up to 100  $\mu\text{m}$ , the average optical loss tended to increase across all tested temperatures, namely 38, 48, and 58 °C. Through linear regression analysis, sensitivity values of 0.002388, 0.002723, and 0.003062 dB/ $\mu\text{m}$  were obtained, respectively, with  $R^2$  values ranging from 0.9273 to 0.9378. These figures are sufficiently convincing to suggest that a linear calibration model is a feasible approach, although it must be acknowledged that minor local fluctuations were still observed, along with a tendency toward a plateau effect at larger elongations.

The most notable finding is the increase in elongation sensitivity of approximately 28% when the temperature was raised from 38 to 58 °C. This provides fairly strong evidence that the sensor is highly dependent on the ambient temperature. Not stopping there, the relatively small standard deviation observed across repeated tests further supports the conclusion that this sensor exhibits fairly reliable short-term repeatability. Given that this temperature dependence is fairly pronounced, the practical implementation of the SMS sensor cannot be carried out without simultaneous temperature monitoring, or, at the very least, it needs to be supported by a calibration model that accounts for temperature compensation.

Finally, it is important to note that these findings are preliminary and apply specifically only to the tested configuration, namely a 5.4 cm MMF, a wavelength of 1310 nm, a temperature range of 38–58 °C, and an elongation range of 0–100  $\mu\text{m}$ . Therefore, these results should not simply be generalized to fiber configurations with different lengths or wavelengths without first undergoing further validation. Looking ahead, further research certainly remains widely open, for instance by expanding the tested temperature range, trying different SMS geometries, applying loading–unloading cycles, evaluating long-term stability, and carrying out more comprehensive uncertainty analyses.

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