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Reliability of fiber optic sensor for weight measurement system

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Abstract

Weight data monitoring is needed on transportation for assessment conditions. This study thoroughly investigates the reliability of fiber optic sensor in weight measurement systems, specifically focusing on hysteresis, repeatability, and eccentricity. By providing practical experimental observations, this research aims to find out the reliability characteristic of fiber optic sensor. It enhances the understanding of the capabilities and limitations of fiber optic sensor. The impact of hysteresis on sensor performance in dynamic loading and unloading scenarios. Repeatability tests have been done by conducting careful back testing with 7 kg and 10 kg, each involving 10 repeated data. Then, eccentricity is applied to loading at five points. They are the center, front, left side, back, and, right side. The research results show that linear data is suitable for use in fiber optic sensor. It's each value of ascending data and descending data are 0.9906 and 0.989. The values of repeatability are 0.007 and 0.03. It shows that the resulting data is trustworthy and reliable. The eccentricity test shows that the maximum value is 0.25. It is crucial to consider for future measurement uncertainty calculations. From the research data, it can be said that the fiber optic sensors can be implemented for weight measurement.

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Keywords

Fiber optic, Sensor, Weight measurement system

Introduction

In recent years, fiber optic sensors technology has played a crucial role in various fields [1],[2],[3],[4]. For example, in the field of health [5],[6], humidity [3],[7], transportation [8],[9],[10],[11], and natural disasters such as landslides [12],[13],[14]. One crucial aspect in the field of transportation is weight data monitoring. However, in its implementation, existing weight measurement systems are still suboptimal. The prevalence of overloaded vehicles persists within the realm of truck transportation services. This phenomenon can be attributed to a substantial number of users who exceed the recommended capacity of their vehicles. Furthermore, the occurrence of illegal levies imposed by unscrupulous policymakers and economic actors is widespread. These levies are often enforced to expedite the passage of non-compliant vehicles, thereby evading regulatory constraints [15]. To address this challenge, the research endeavors to develop a load measurement monitoring system utilizing fiber optic sensors.

The monitoring system utilizing fiber optic sensors offers distinct advantages, they exhibit high sensitivity, can operate effectively over long distances, and can be seamlessly integrated into a networked measurement system across multiple points [1].

Research on weight measurement systems has been previously conducted by various scholars. Yoeseph et al. [16] asserted that fiber optic sensors can detect the presence or absence of a moving load with an accuracy level of 100%. Kacik et al. [17] explained that load detection using fiber optic sensors can be employed for both static and dynamic load measurements. Obrien et al. [18] applied the vehicle-bridge interaction to derive vehicle acceleration based on fiber optic sensors. The outcome of their study indicates that this concept can be utilized for calculating vehicle loads.

Mefina et al. [19] elucidated that fiber optic sensors can function effectively in speed measurements without the need for additional speed sensors. The research findings demonstrate that fiber optic sensors are proven to be reliable, and their results closely approximate real speeds. Pimentel et al. [20] applied fiber optic sensor technology to identify train speed, geometry, and static axle information.

In the realm of evolving research, it is evident that one crucial facet of employing fiber optic sensors is their reliability. Sensor reliability denotes the degree to which we can depend on the data generated by the sensor. The significance of sensor reliability in measurements can be elucidated through various aspects, with measurement precision being paramount.

A dependable sensor can furnish more precise and consistent measurement outcomes. This precision holds critical importance in numerous applications, including industrial settings, laboratories, and everyday consumer devices. Sensor reliability plays a pivotal role in minimizing measurement errors and ensuring the trustworthiness of the produced data. The primary objective of this research is to ascertain the reliability characteristics of fiber optic sensors, specifically focusing on hysteresis, repeatability, and eccentricity.

This study was conducted by exploiting light loss attributed to macro bending. The fiber optic was positioned transversely and wound around a coil constructed from silicone rubber. The coil's dimensions, including length, outer diameter, and inner diameter, were set at 100 mm, 20 mm, and 18 mm, respectively. Additionally, the core-to-core distance between the fiber optic coils was maintained at 10 mm. The system employed 10 coils of fiber optic, and weight testing was conducted on the plane of the fiber optic winding coil. The schematic representation of this setup is illustrated in Figure 1.

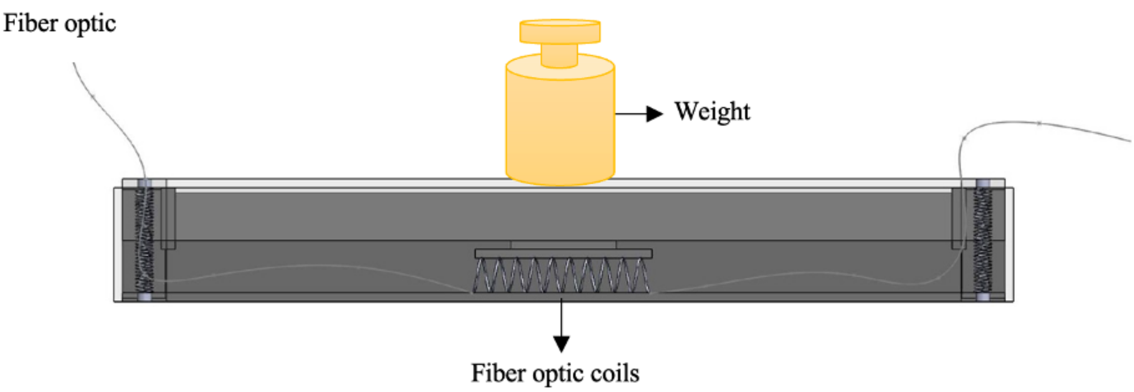

Figure 1. Front view of weigh plane fiber optic sensor

Methods

In this study, we explore the interaction of light with a wavelength of 1330 nm generated by a light source. The light is directed through an optical fiber that is intricately linked with a weighted plane. This integrated system is designed to respond to external forces, inducing deformation in the fiber coil located within the weight plane. As a consequence of this deformation, the light intensity received by the light sensor manifested as an Indium Galium Arsenide (InGaAs) photodiode is diminished. Notably, this reduction in light intensity exhibits a linear relationship over a specified measurement range. The light intensity detected by the light sensor undergoes conversion into voltage data through the process of data acquisition. The presentation of this data is visible on a laptop.

The ensuing slide will delve into a comprehensive explanation of the observed linear curve, elucidating the correlation between external forces, fiber coil deformation, and the resultant reduction in light intensity. Weigh measurement has been done by static load test from 0 kg to 15 kg. The depicted framework is illustrated in Figure 2.

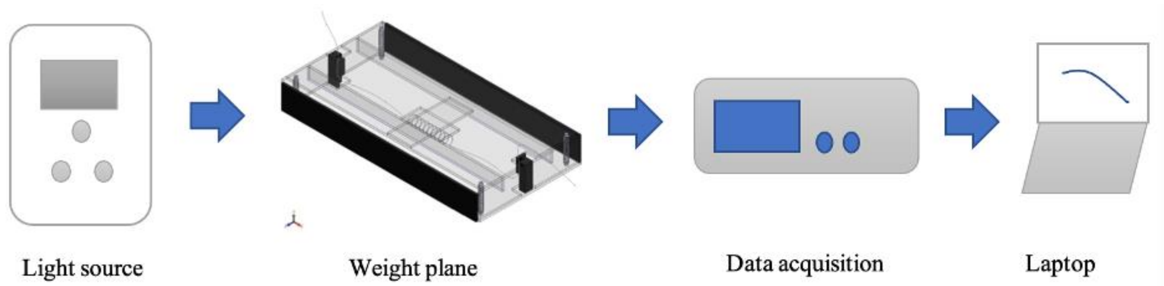

Figure 2. Design of reliability fiber optic sensor

This research involves the investigation of three parameters. The first parameter is hysteresis, followed by repeatability and eccentricity. Hysteresis describes the material's response to the load test. Hysteresis testing employs a measurement method ranging from 0 kg to 15 kg. Data acquisition begins at 0 kg, with a continuous increase in load by 0.5 kg increments up to the maximum load. Subsequently, measurements are taken from 15 kg with a decreasing load until reaching 0 kg again.

Repeatability measures how much measurement or experimental result can be reproduced precisely. Repeatability testing is conducted with two different nominal measurements, each involving 10 repeated data acquisitions using the same load of 7 and 10 kg, respectively.

In accordance with the EURAMET CG 18, the calibration test involves the utilization of at least one test load, referred to as load test (L_T). The selection of this L_T is crucial, as it should maintain a reasonable relationship with the instrument's maximum capacity and resolution. This facilitates a comprehensive evaluation of the instrument's performance. For instruments featuring a constant scale interval, a load within the range of approximately $0.5max < L_T < max$ is commonly employed [21]. In the context of this study, the maximum L_T applied was 15 kg. Consequently, for the repeatability test, nominal L_T values of 7 kg and 10 kg were chosen for assessment purposes.

The final test focuses on eccentricity, where loading is applied at five points: the center, front, left side, back, and right side. This test aims to assess the equipment when the load is not centered on the sensor. The distance of the load from the center is 120 mm. This depicted in Figure 3.

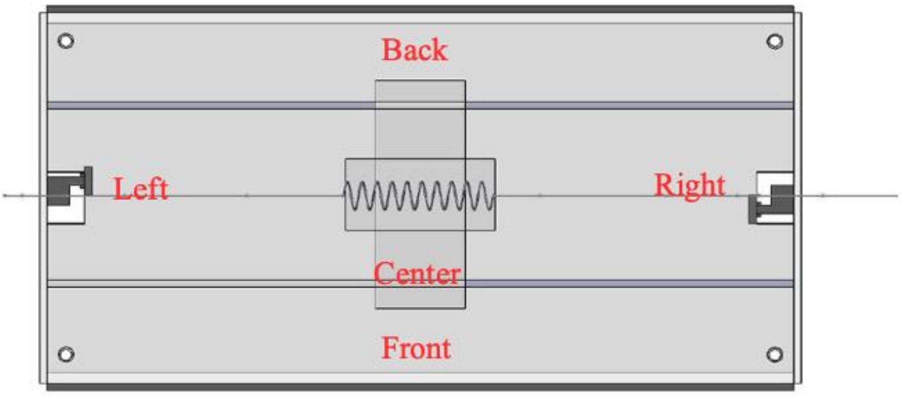

Figure 3. Weighing position on eccentricity test

Result and discussion

In this study, the fiber optic sensor employed leverages macro bending induced by loading. Macro bending leads to the attenuation of light within the optical fiber. The corresponding light loss is then transduced into voltage through data acquisition. This voltage value serves as a crucial parameter for load monitoring systems that employ fiber optic sensors. The outcomes of the hysteresis test, conducted as part of the reliability investigation of the fiber optic sensor, are illustrated in Figure 4.

In the realm of fiber optic sensor, linear data proves to be particularly. This suitability arises from the fact that even a marginal alteration in the parameter along the x-axis manifests as a discernible shift in the corresponding parameter along the y-axis. As illustrated in Figure 2, it is evident that the data exhibiting the highest level of linearity is observed within the weight range of 8 kg to 12.5 kg. The linearity values for ascending data are represented by $R^2 = 0.9906$, while for descending data, the corresponding value is $R^2 = 0.989$. In the course of this research, the findings indicate a direct correlation between the loading value and the magnitude of light loss, wherein an increase in the loading value corresponds to a decrease in the voltage parameter. The aforementioned statement aligns with Marzuki et al. [22] and Yunianto et al. [23] which posits that an increase in the magnitude of the change in coil diameter resulting from macro bending corresponds to a proportional increase in light loss.

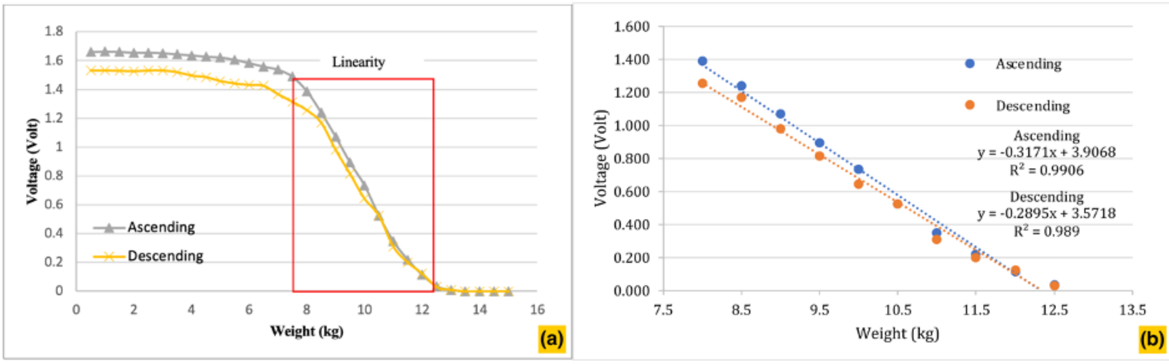

Figure 4. Characteristics of Fiber Optic Sensor: (a) Hysteresis Curve; (b) Linearity

Repeatability result shown in Table 1. This procedure facilitates an assessment of the reliability of the measurement instrument. Through meticulous back testing, it serves to substantiate the consistency of measurement outcomes. The repeatability of the process is exemplified through the calculation of standard deviation values, specifically 0.007 for 7 kg and 0.03 for 10 kg. The standard deviation serves as a metric to assess the precision or resolution of the fiber optic sensor. It ensures that the acquired data is deemed trustworthy and reliable.

Table 1. Repeatability test of fiber optic sensor

No	Data (7 kg)	Data (10 kg)
1	1.29	0.36857143
2	1.29666667	0.314375
3	1.29571429	0.26466667
4	1.30863636	0.29071429
5	1.294375	0.281875
6	1.28263158	0.30916667
7	1.29375	0.25642857
8	1.29875	0.266
9	1.29333333	0.23875
10	1.286875	0.2425
Standard deviation (σ)	0.00701931	0.03941357

Table 2. Eccentricity test of fiber optic sensor

Position	Data 1 (V)	Data 2 (V)	Volt Mean	ΔV to center	Absolute value	Max value of ΔV
Centre	1.13	1.19	1.16			
Front	1.03	1.06	1.05	-0.12	0.12	
Left	0.89	0.94	0.92	-0.25	0.25	0.25
Back	1.04	1.04	1.04	-0.12	0.12	
Right	1.11	1.13	1.12	-0.04	0.04	

Table 2 shows the result of eccentricity test. The findings from the eccentricity test indicate that a minimal variance in voltage values (ΔV) between the front, back, right, and left positions compared to the center correlates with enhanced performance of the fiber optic sensor. The maximum eccentricity value identified is 0.25. This particular value holds significant importance and necessitates careful consideration in forthcoming calculations related to measurement uncertainty.

Conclusion

The research concludes that fiber optic sensors exhibit commendable reliability for applications in weight measurements. This is evidenced the linearity values for ascending data are represented by R^2 = 0.9906, while for descending data, the corresponding value is R^2 = 0.989. This linear data is suitable for utilization in fiber optic sensor. In the context of the repeatability test, each resolution values of a weight 7 kg and 10 kg are 0.007 and 0.03. It ensures that the data obtained is trustworthy and reliable. The maximum eccentricity value identified is 0.25. This value is crucial to consider for future measurement uncertainty calculations.

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