Research on Additive Manufacturing Strain Sensor Based on Parametric Design

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ABSTRACT

With the rapid development of fiber grating sensing technology, fiber grating sensors have high sensitivity and anti-electromagnetic The advantages of interference, small size, quasi-distributed sensor network construction, corrosion resistance, etc., are very suitable for health monitoring of building structures. Measurement. Additive manufacturing technology, commonly known as 3D printing technology, is an advanced manufacturing technology that has developed rapidly in the past 30 years. The advantage lies in the fast and free fabrication of three-dimensional structures. In this study, additive manufacturing technology and parametric design were introduced for the development and design of fiber grating strain sensors, which made the sensor design more flexible and easy to customize, and avoided the generation of bubble defects in the cemented section of the previous sensor. The theoretical basis and case analysis are provided for the optimal design, sensitivity adjustment and new packaging methods of fiber grating strain sensors.

Keywords: additive manufacturing; sensor; fiber grating

1. INTRODUCTION

With the continuous development of modern society and economy, the structural forms of civil engineering show a trend of diversification and complexity. At the same time, super high-rise structures and large-span structures have been vigorously developed [1]. These buildings are often unique in shape, with irregular flat and façade arrangements. At the same time, the requirements for the use of these building structures are getting higher and higher [2]. It is difficult to predict and evaluate the problems in the construction and use phases of these building structures. Loading, material aging or harsh environmental factors lead to the accumulation of damage to structural components, the reduction of structural resistance, and eventually component damage or even collapse [3]. Once the damage occurs, it will cause huge loss of life and property [4]. Engineering mechanics is the theoretical basis for the vigorous development of construction engineering, and stress and strain are its most important physical quantities [5]. It runs through all stages of engineering design, construction, inspection and monitoring, and reinforcement. The calculation and monitoring of the stress and strain of each engineering component is a Guarantee of structural safety in service [6]. Zhang Xiaopeng [10] carried out the structural strain monitoring of the offshore platform using the fiber grating strain sensor, determined the relationship between the component strain and the ice load of the offshore platform, and realized the magnitude of the ice load by monitoring the change of the structural component strain. The icing hazards of platform structures provide a valuable reference. Wang Qi [7] designed the overall and local layout scheme of distributed fiber grating sensing based on distributed fiber grating sensing network, and studied the full-scale monitoring method of steel structure based on distributed fiber optic sensing technology. the layout method was tested for calibration, repeatability, etc.and the steel structure full-scale fiber grating strain sensor based on distributed optical fiber sensing technology was obtained. Compared with traditional electrical sensors, it has high sensitivity, corrosion resistance and high precision. quasi-distributed arrangement, anti-electromagnetic interference, small size and other advantages [9], it is very suitable for the health monitoring of building structures, stress and strain, and it is concluded that the distributed optical fiber sensing technology is suitable for the full life of large steel structures. Conclusions of health monitoring [8].

Additive manufacturing technology subverts the traditional fiber grating sensor packaging method, which introduces custom geometry and functional control attributes, avoiding tedious steps in the pre-

manufacturing process. In order to improve the efficiency of sensor development, the introduction of additive manufacturing technology has brought the design and packaging of fiber grating sensors into a new era - "parametric design", which shortens the product development cycle on the basis of creating complex shape sensing elements; Reduce the cost of assembly, that is, create more value with less time, material and human input; create conditions for large-scale mass production.

2. GRATING SENSING MECHANISM

The advent of fiber grating sensing technology has enabled traditional materials to be endowed with more functions, and more new smart materials have been derived. Fiber grating sensing technology has been widely used due to its incomparable advantages over other sensing technologies. Monitoring in many fields, such as smart aerospace materials, smart bars in engineering, etc. It can realize the multi-parameter real-time monitoring of the component to be tested by establishing a distributed sensor network. In this chapter, the basic structure of the fiber Bragg grating sensing system and the mechanism of the fiber Bragg grating strain sensing model are described in detail, which provides a theoretical basis for the development of a new type of additively manufactured fiber Bragg grating strain sensor.
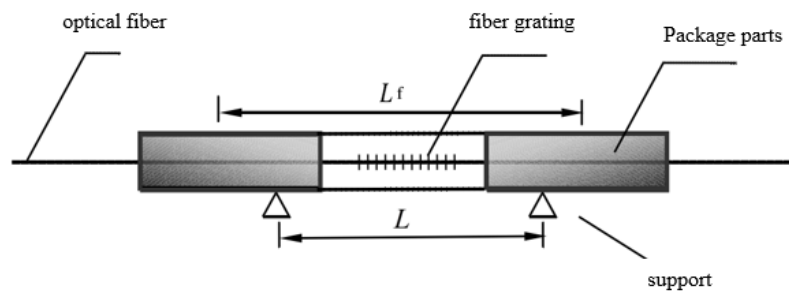

Figure 1: The schematic diagram of the structure of the additively manufactured fiber grating strain sensor

The additively manufactured fiber grating strain sensor designed in this paper is based on the proposed use of additive manufacturing technology to package the fiber grating sensor, and the use of additive manufacturing technology to package the fiber grating strain sensor. The purpose is to modify the sensor parameters according to actual engineering needs. The parametric design of fiber grating strain sensor is realized.

Table.1 Mechanical properties of optical fiber and additive manufacturing coatings

Material properties	unit	sign	parameter size
Fiber Elastic Modulus	MPa	Eg	7.2×10^4
Modulus of Elasticity of AM Layers	MPa	Ep	4000
Fiber cross-sectional area	mm2	Af	0.0123
AM layer cross-sectional area	mm2	Ap	25

Table 1 shows the mechanical properties of the optical fiber and the additively manufactured protective layer used for the additively manufactured fiber grating strain sensor designed in the examples of this paper.

3. RESEARCH ON ADDITIVE MANUFACTURING STRAIN SENSOR

In this paper, a parametric design of a surface-mounted additively manufactured fiber grating strain sensor is designed. The sensor sensitivity can be changed by modifying the parameter family of the surface-mounted fiber grating strain sensor, and the fiber grating can also be effectively protected from external interference. A surface-mount additively manufactured fiber Bragg grating strain sensor is encapsulated with ABS additive manufacturing consumables. The design diagram of the surface-mounted additively manufactured fiber grating strain sensor is shown in the figure. The sensor is equipped with fasteners, which can be pasted on the surface of the structure to be measured, and the fiber grating is encapsulated into the additive manufacturing protective layer by the additive manufacturing method. there are reserved holes in the grid region in the additive manufacturing protective layer, which avoids the formation of uneven strain in the grid region, and eliminates the influence of the uneven axial strain field in this region on the fiber grating. In addition, the bottom of the sensor fastener can be designed into various shapes such as curved surfaces, which can be used for stress-strain monitoring on the surface of curved structures.
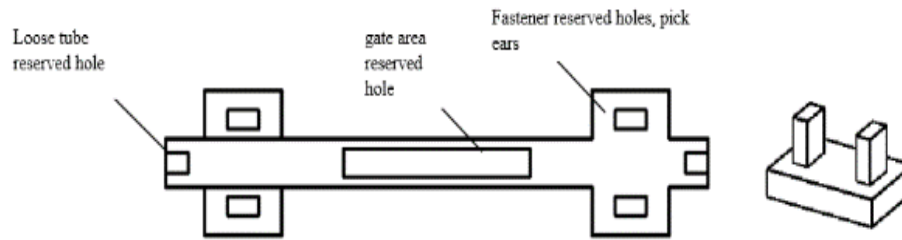
Figure 2: Fiber Bragg Grating strain sensor and fastener design for surface - bonded additive manufacturing

Table.2 Sensing characteristics of surface - bonded FBG sensor

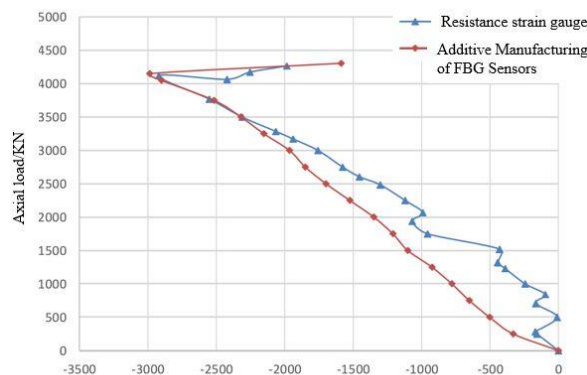| sensor	Original wavelength (mm)	Test calibration wavelength formula λ=kx+b	Sensor Sensitivity Coefficient 1/k （με/ pm)
surfacemount	1546.7	λ =0.0002x+1546.7	5.00με/ pm

Figure3: FBG sensor manufactured by additive was compared with resistance strain gauge data

It can be seen from Figure 3 that in terms of linearity, the resistance strain gage data fluctuates abnormally at the initial stage of test loading, while the additively manufactured FBG strain sensor performs well without large fluctuations. Table 2 is the sensing characteristics of the sensor. In terms of sensitivity, the additively manufactured FBG sensor is more sensitive than the resistance strain gauge in the initial loading stage, and the two tend to be the same when the concrete is about to reach the ultimate compressive strain. In summary, the additively manufactured FBG strain sensor is superior to the resistance strain gauge in both linearity and sensitivity. This paper mainly proposes a packaging method of fiber Bragg grating sensor with parameterizable design, which makes the sensor design more flexible and easy to customize, and avoids the generation of bubble defects in the cemented section of the previous sensor. Two types of additively manufactured fiber grating strain sensors are parametrically designed, their strain transfer

mechanism is deduced, and the influencing factors of strain transfer rate are analyzed. energy impact.1) Based on the packaging method of the FBG strain sensor based on additive manufacturing technology proposed in this chapter, the relationship between the total strain of the additively manufactured FBG strain sensor and the FBG strain is given; 2) Through the establishment of the sensor parameter family model, a surface-mounted additively-manufactured fiber Bragg grating strain sensor is designed. The sensor is equipped with additively-manufactured fasteners, and the fasteners can be further designed according to the surface of the structure to be measured to ensure The close fit between the sensor and the component to be tested, and the design of the fastener can make one sensor reused repeatedly, reducing the cost of structural health monitoring. 3) According to the designed additive manufacturing sensor, a calibration test method is designed, and the calibration test of the surface-mounted additively manufactured fiber Bragg grating strain sensor is carried out. The test results show that the linearity of the surface-mounted additively manufactured fiber Bragg strain sensor is linear. The accuracy is 14.16%, the hysteresis is 2.86%, the repeatability error is 8.16%, and the static error is 16.59%. 4) A clamped additive manufacturing layer fiber Bragg grating strain sensor is designed, and a sensor parameter family model is established, which can be parametrically designed according to actual needs. Strain detection, with a capillary steel tube inside to prevent the formation of chirp effect of uneven axial stress field in the grid area. 5) In order to explore the influence of different materials and thicknesses of packaging layers on the sensing characteristics of the sensor, the fiber Bragg grating strain sensors with ABS material packaging thickness of 5 mm, ABS material packaging thickness of 3 mm, and PLA material packaging thickness of 5 mm were parameterized and packaged respectively. , the calibration test of three kinds of clamped additively manufactured fiber Bragg grating strain sensors was carried out. were 4.03%, 6.86% and 2.30%, the repeatability errors were 4.26%, 3.17% and 1.87%, and the static errors were 8.08%, 10.80% and 6.13%, respectively. 6) Comparative analysis of results: From the experimental results, it can be easily seen that the surface-mounted additively manufactured fiber Bragg grating strain sensor is inferior to the clamp-type sensor in various indicators, because the surface-mounted sensor

relies on the fasteners and the pick ears to drive the overall deformation of the sensor. From the point of view of force, it is a cantilever beam model, and there will be displacement under the action of uniform load, resulting in a larger error compared with the clamp-type sensor. In the application test of the axial compression performance of composite material-constrained concrete columns with embedded steel bars, the results were The results show that the linearity and sensitivity of the additively manufactured FBG strain sensor are better than that of the resistance strain gauge, and the reliability is high, which is suitable for strain monitoring in practical engineering structures. From the perspective of additive manufacturing packaging materials, the PLA-encapsulated sensor is more accurate than the ABS sensor, and the The higher sensitivity is due to the higher elastic modulus of PLA, lower strain transfer loss, lower shrinkage rate of PLA material, and lower residual stress inside the sensor during the package curing process, that is, in the larger package size The sensor can meet the accuracy requirements without warping the corners of the package components. From the thickness of the encapsulation layer, theoretically a smaller encapsulation layer thickness should have better sensing characteristics. In the conclusion of the calibration test, the repeatability of the sensor is better, and the difference between linearity and hysteresis is not significant. The reason is that the thickness of the encapsulation layer of the conventional strain sensor is between 2mm and 10mm, and the change of the thickness of the encapsulation layer is too small to have a great impact on the sensing characteristics of the sensor.

4. CONCLUSIONS

In this paper, a lot of work has been done on the application of additive manufacturing technology in the field of fiber Bragg grating sensor packaging and the theoretical research of additive manufacturing strain sensors. The fiber Bragg grating strain sensor is used, and the calibration test of the sensor is carried out. Combined with the test data, the influencing factors of the sensing characteristics of the additively manufactured fiber Bragg grating strain sensor are analyzed, and the strain transfer rate and the average strain transfer rate are theoretically deduced. However, I think that the author's own theoretical knowledge and professional vision are very limited, and the research period is also limited, so this research can be further improved. The author believes that in-depth research on additively manufactured fiber grating sensors can also be carried out in the following aspects: The influence of different additive modulus, packaging radius, packaging distance, and clamping distance on the strain transmissibility of the additively manufactured fiber grating strain sensor should be comprehensively considered. According to the degree of influence on the average strain transmissibility, the influence weight factor is given. Weighted analysis of

average strain transmissibility to optimize additively manufactured fiber Bragg grating strain sensor parameters. During the encapsulation process, high temperature-resistant tape was used to fix the optical fiber in this study. Due to the slender light, the contact area with the tape is limited, which is prone to relative slippage. It is necessary to develop new technologies such as additive manufacturing hotbeds equipped with movable optical fiber holders, etc., to improve the hotbeds of additive manufacturing equipment into micro-fiber platforms. In the strain transfer and parameter analysis, the influence of the additive manufacturing encapsulation layer process on the strain transfer rate is considered. In practical applications, for example, there is still a glue layer on the surface of the fastener of the surface-mounted sensor and the structural member to be measured.it will definitely affect the strain transfer rate of the sensor, and the influence of the adhesive layer of the sensor fastener or clamp should be analyzed, and its The parameters are weighted and the fastener size is optimized.

ACKNOWLEDGEMENTS

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