TEST OF SINGLE REFLECTIVE GRATING BASED FIBER OPTIC SENSOR DESIGN FOR MEASUREMENT OF TILT ANGLE

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1. Introduction

The tilt angle is one of the important parameters for monitoring the stability of structures in landslide areas, bridges or dams under load. Although there are various types of tiltmeters, a fiber optic tiltmeter is the prospective candidate for civil structures which are usually very large and demand easy cabling of the many sensors at numerous critical points. The immunity to electromagnetic interference (EMI) makes it especially suitable for the sensor to be used in electronic environments. Furthermore, long distance transmission without data loss is possible for monitoring inaccessible environments such as soil slope movement [1]. However, there are only a few optic sensors for the monitoring of the tilt angle compared to that for other parameter measurement.

This paper describes a fiber optic tiltmeter composed of a single reflective grating, which causes variations in the reflected signal, and two optical fibers as a light transceiver for tracking the tilting direction. This sensing mechanism leads to greater simplicity and easier cabling than the conventional moiré-fringe based tiltmeter [2].

In order to minimize the effect of eccentricity for stable reflectivity as the sensing probe is tilted by the influence of gravity, a symmetric design of the top and bottom spring was employed. The tilting of the solid pendulum induced by gravity causes the variation in the reflected light thanks to the grating attached to the solid pendulum. Therefore, the tilt angle can be calculated by tracking the variation of received optical signal. The natural frequency of the m-k system was measured for the quantification of static acceleration. The tilt angle can be inferred through comparison between the variation of static acceleration and that of gravity.

Therefore, this paper describes the prototype design of the fiber optic tiltmeter which is developed to obtain a stable reflected signal when the tilt angle dependent sine function load is applied. Variations of the reflected signals from tilt angle of 0° to -90° was continuously measured and recorded. From this experiment, it was demonstrated that a higher degree precision process or advanced sensing principle should be considered for acquisition of stable reflected sinusoidal signal.

2. Principle

2.1 Basic Principle

The most basic principle of the tiltmeter is the influence of gravity. The basic structure of inclinometers can be classified into three categories: solid, liquid, and gas pendulum. When the sensor is tilted, a solid pendulum based tiltmeter functions in a generally simple and straightforward manner. However, the structure of this kind of inclinometer is relatively complex and large. A liquid pendulum based tiltmeter consists primarily of electrolytic- and capacitance-based technologies. On the other hand, these sensors are limited in terms of response time, however, most applications are effectively static, so this is not a significant problem. The other fluid-filled types (gas pendulum) are relatively bulky, and cannot achieve high resolution. A gas pendulum based tiltmeter measure the angular change by measuring the movement of the bubble. Therefore, tiltmeter design depends on how it can measure the movement or strain variation of the pendulum induced by gravity.

2.2 Sensing Mechanism

In a restricted condition which depends on grating width and spacing width on grating panel parameters, the reflected signal has a sinusoidal signal form [3]. This measurement principle can be integrated with a single degree of freedom system, as shown in Fig. 1.

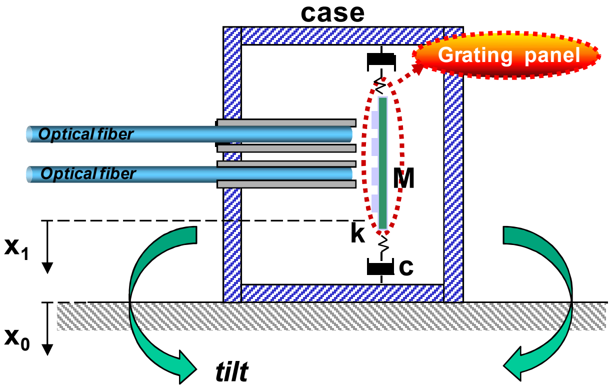


Fig. 1. Schematic diagram of fiber optic sensor for measurement of tilt angle.

Two optical fibers are employed for transceivers. The single reflective grating panel is used for variation of reflected light. The optical fibers were apart from each other with a distance of *d* over 4, where *d* is grating period, to produce a phase difference of 90°. When the tilt angle was changed, the grating panel was moved by the gravitational force. The reflected optical signals can be expressed Eq. (1).

$$S_1(\theta) = A_1 \sin(\theta) + M_1 \quad (1)$$

$$S_2(\theta) = A_2 \sin(\theta + \frac{\pi}{2}) + M_2 = A_2 \cos(\theta) + M_2$$

Where $A_n = \dfrac{\max_n - \min_n}{2} \quad (n = 1,2)$

$$M_n = \frac{\max_n + \min_n}{2} \quad (n = 1,2)$$

By tracking the reflected signal from the optical fibers, the relative displacement ($X_0 - X_1$) and tilt angle can be inferred [4].

The grating was attached to a solid pendulum as shown in Fig. 2. A grating period of 280 μm was used.

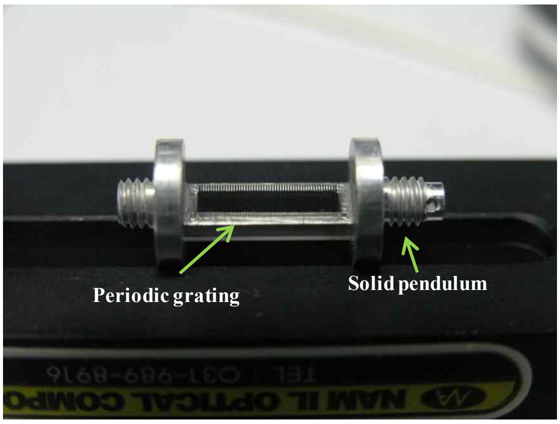


Fig. 2. Solid pendulum after bonding with a reflective grating.

First of all, the reflected optical intensity was measured by the one optical fiber as the movement of the grating bonded solid pendulum as shown in Fig. 3. The received optical signal is plotted in Fig. 4. The horizontal axis plots the moving displacement of the solid pendulum and the vertical axis plots the received optical intensity. The R-square value of 0.997 was obtained through sine curve fitting analysis.

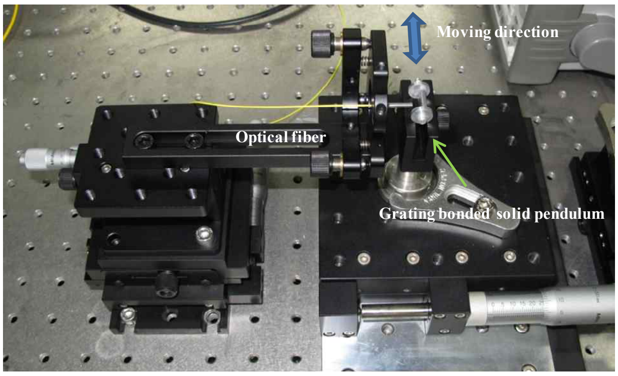


Fig. 3. Verification of original reflection signal induced by the movement of the grating after bonding.

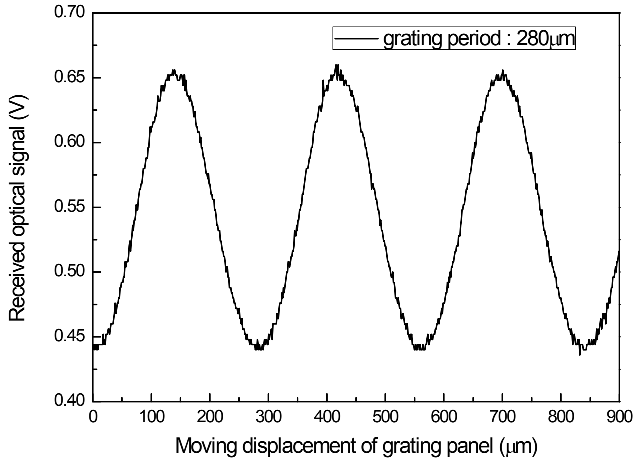


Fig. 4. Received optical signal by the movement of the solid pendulum.

3. Experiment

3.1 Experimental Setup

The prototype was fabricated and then fixed to the rotation jig as shown in Fig. 5. Initially, zero acceleration was verified by the bubble tiltmeter. Then the prototype was tilted. When the jig was rotated, a gravitational force of sine function can be applied to the prototype. It caused the solid pendulum to move. Two optical fibers were used to track the movement direction. Through these fibers, lights were emitted and received from the grating panel. The variation of the reflected signal indicates the moving displacement of the solid pendulum. An optical circulator and photo detector were used for the detection of the reflected light. Variations of the reflected signals from tilt angle of zero degree to -90 degree were continuously acquired by a continuous rotation system, where minus indicates the counterclockwise direction.

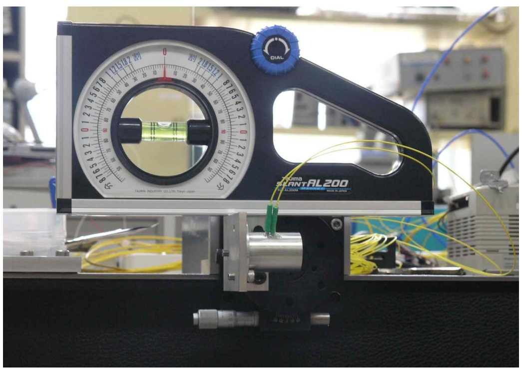


Fig. 5. Schematic diagram of the test fixture.

3.2 Experimental Results

When the tilt angle was varied, the reflected optical signals on the grating were received by optical fibers, as shown in Fig. 6. Although the received optical signal showed a similar sinusoidal signal, the mean value was changed with the movement of the solid pendulum.

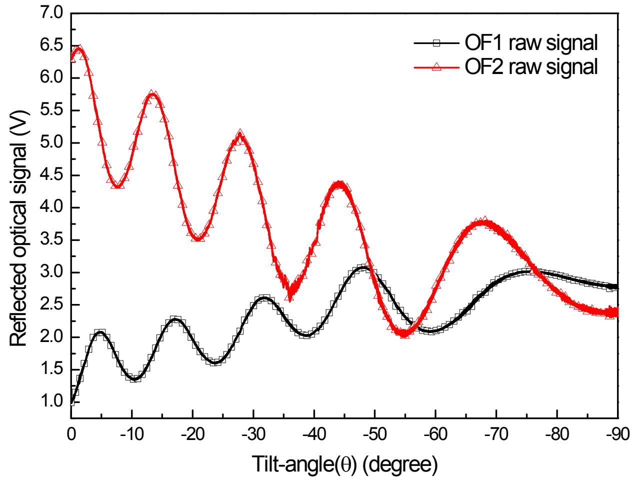
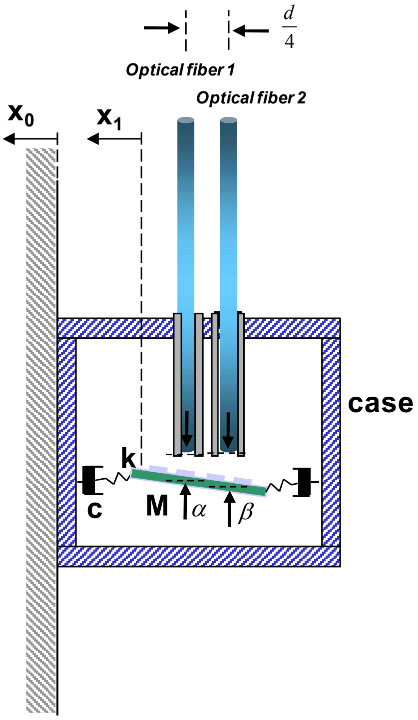
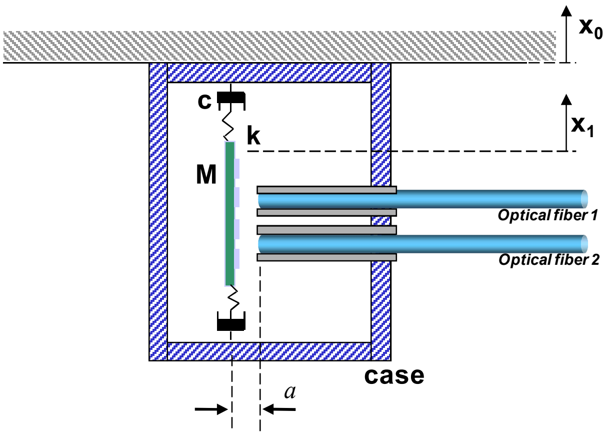


Fig. 6. Reflected raw optical signals by the variation of tilt angle.

The mean value of optical fiber 1 (OF1) decreased with the increase in the tilt angle (θ). On the other hand, the reflected mean value of optical fiber 2 (OF2) increased with the increase in tilt angle. Ideally, the reflected signals should simultaneously show the same behavior of decreasing or increasing in mean value by the variation of the distance a between the end face of the optical fibers and the grating panel. However, the behaviors were not the same. Figure 7 was illustrated to explain the unexpected reflected optical signal. Figure 7 (a), (b) respectively show the inner alignment state at tilt angles 0° and -90°. In Fig. 7 (b), the distance a was approximately kept at 2 *mm* for the initial tilt angle of -90°. However, when the tilt angle θ was closed to 0°, the distance a was changed to α and β at the location of OF1 and OF2, respectively. It indicated that the weight balance and the spring constant-balance were not the same at both end sides of the solid pendulum. Therefore, the result of Fig. 6 was induced by an anisotropic spring coefficient in both sides, and the variation of the distance difference during the operation brought about the unexpected signal.



(a) Inner alignment-state of zero degree tilt angle.



(b) Inner alignment-state of -90 degree tilt angle.

Fig. 7. Schematic diagram for an explanation of the unexpected reflected optical signal.

If the received optical signal is not expressed by a sinusoidal signal, the signal processing mentioned in section 2.2 of this paper cannot be applied to infer the moving displacement.

4. Summary and Further Study

Basically, the signal depends on the reflected light from the grating. Furthermore, optical fibers have a very small acceptance angle to receive the reflected optical light on the grating. Therefore, the end face of the optical fiber should be perfectly perpendicular to the grating during the operation. In other words, minor fabrication errors, microscopic rotations induced by non-axial exciting force and eccentric force were not admitted when the sensing probe was tilted by the influence of the gravity. In accordance with this requirement, a more advanced sensing principle or more high degree of precision process will be considered for a stable reflected signal which only varies with the perpendicular moving grating.

Acknowledgement

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