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A NOVEL SENSOR FOR MONITORING SETTLEMENT

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Abstract – In this study we describe a new concept for a sensor using fully distributed sensing along optical fibres designed especially for monitoring lateral movements in embankments and settlement areas, and deformations of excavation walls and tunnels. The sensor design includes four components: mass block housing, middle cylinder, connector housing, optical fibers and mass-block. The block housing is to hold the mass block and guide its sliding. Two blocks are designed to stretch sensing optical fiber when the block housing has inclination. The sensing optical fiber are required for performing sensing task in a ela range. One end of the whole pipe sensor is fixed to a pole, which was deeply embeded in soil of embankment dam. The permofmance of designed pipe sensor was carried out by a loading model of the dam settlement. DiTeSt-STA202 is then adopted to read and determine the sensitivity of the pipe sensor, which is the most impotant parameter for a sensor. The sensor provides a useful and precise method to detect and mornitor inside change of the embankment dam, as well as to detect and mornitor the settlement of other structures.

Keywords: fiber optic sensing, settlement, monitoring

1. INTRODUCTION

Settlement monitoring surveys are performed to determine the degree of horizontal and vertical displacement of above structures over a defined period [1]. Severe pavement damages and structural failures can be a direct result of settlement and therefore it is critical that displacement are detected and measured in a very early time [2]. The optical fiber sensing technology is getting popular where the optical fiber is used as an excellent sensor component. The optical fiber can combine two functions of sensing and communication. With the advancement towards higher-resolution, the distributed optical fiber sensing technology has radically improved the ability to achieve accurate results and locates the position of events any 0.5 meter along the embankment [3-5]. It thus offers an interesting alternative for customers or those owners of embankment dams. Furthermore, since Brillouin scattering properties only depending on the fiber material, this sensing technique is absolutely stable in time. The distributed fiber technology for temperature and strain sensing is currently applied in leakage of pipeline, in power plants or power transfer stations and concrete dams [6,6]. Those methods can not be simply introduced into a long earth embankment dam monitoring since the earth embankment dam is loose where the optical fiber can not work as it did in a concrete dams. There are some commerical product about settlement measurement. One of representative products is used to measure vertical settlement at up to 8 selected horizons within a borehole and is an automatic magnetic extensometer, rather than the conventional manually lowered sensor and cable assembly. The accuracy of the system is ± 0.5mm.

A new concept for a sensor using fully distributed sensing along optical fibres is proposed and its performance is described.

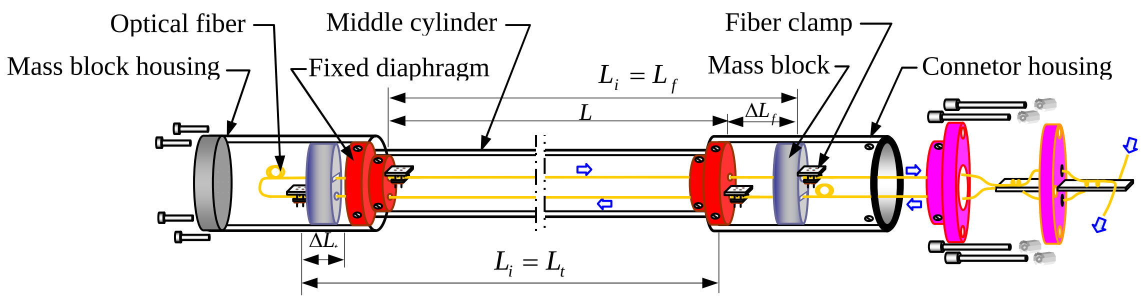

Fig. 1. Structure of smart pipe sensor.

(a) Mass-block (b) Connector housing (c) Assembly pipe sensor

Fig. 2. Prototype of smart tube sensor.

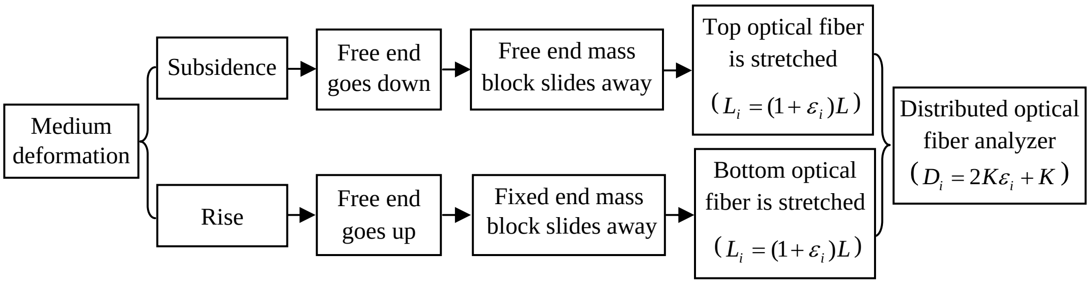

Fig.3 Operation process of smart deformation displacement tube Sensor block diagram

2. PRINCIPAL OF THE SENSOR

2.1. The structure of the pipe sensor

The structure of the novel settlement monitoring sensor is shown in Fig.1. A prototype, shown in Fig.2, is available for reference and is adapted to spur dikes along Yellow River in China to detect its damages.

The sensor consists of four components: mass block housing, middle cylinder, connector housing, optical fibers and mass-block. The novel features of this smart pipe sensor include a hollow cylinder-shaped cantilever structure with double-ended sealing, the sensor itself being a right circular cylinder of height or length 2000mm and external diameter 38 mm. The internal diameter of the sensor is 30 mm; its inner surface is sufficiently smooth to enable two mass-blocks to move inside the cylinder with slight friction.

This sensor provides a novel precise measurement method to monitor field settlement and inclination, together with ground slide.

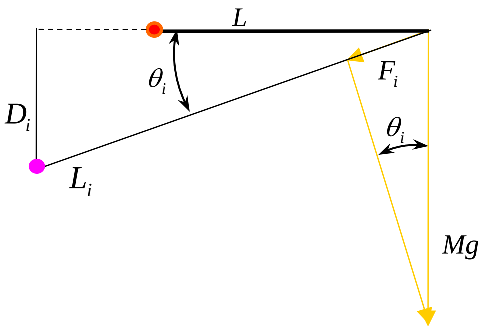

Fig.3 Mechanics analysis of Deformation/elongation of top optical fiber when stretching.

2.2. The working principal of the pipe sensor

The original length of optical fiber (sensing part) is L. The angle between the horizontal level and optical fiber is θ. When there is no any land subsidence or rise, the angle θ is zero. When the pipe with optical fiber slopes, a new angle θ_i arises. The subscript letter i represents location number of the optical fiber. The optical fiber is stretched by the partial force of mass block gravity, F_i can be described as

$$F_i = Mg \cdot \sin\theta_i \tag{1}$$

Consequently, left mass block slips away outside, the new length of the optical fiber is L_i. The strain of the optical fiber is ε_i. They have the following relation

$$\varepsilon_i = (L_i - L)/L \tag{2}$$

$$L_i = (1+\varepsilon_i) \cdot L \tag{3}$$

Thanks to the relation between the length L_i and the force F_i,

$$L_i = k \cdot F_i \tag{4}$$

Here, k is constant coefficient for certain fiber. Substituting equation (1) into equation (4), we get

$$L_i = k \cdot Mg.\sin\theta_i \tag{5}$$

So,

$$\sin\theta_i = \frac{L_i}{k \cdot Mg} \tag{6}$$

Plus, the displacement of the subsidence D_i is

$$D_i = L_i \cdot \sin\theta_i \tag{7}$$

Substituting equation (6) into equation (7), we get

$$D_i = L_i \cdot \frac{(1+\varepsilon_i)\cdot L}{k \cdot Mg}$$
$$= (1+\varepsilon_i)\cdot L \cdot \frac{(1+\varepsilon_i)\cdot L}{k\cdot Mg} \quad (8)$$
$$= \frac{L^2}{k\cdot Mg}(1+\varepsilon_i)^2$$
$$= \frac{L^2}{k\cdot Mg}(1+2\varepsilon_i+\varepsilon_i^2)$$

The strain ε_i can be given from distributed optical fiber demodulating instrument (such as DiTeSt), and then the displacement can be calculated using equation (8).

When we ignore second-order item ε_i^2 , we get

$$D_i = \frac{2L^2}{kMg}\varepsilon_i + \frac{L^2}{kMg} \quad (9)$$

It is a linear relation between ε_i and D_i .

When the free end of smart pipe rises, right mass block slides away. The similar operation process is to the left mass block. The difference is that top optical fiber not bottom fiber is stretched by right mass block. Although the temperature inside the smart pipe under the ground, some measures designed to make it differently: it includes some loose spare length of fibers inside the pipe just to monitor temperature. Put some spare optical fibers with some length in the connector housing just to compensate the temperature (just to monitor temperature) effect and so to have a pure strain sensing. Then I have a temperature reference this way. Moreover, we can declare that the spare is just to measure temperature.

There is friction between pipe surface and mass block, which may affect the effect. However, the customer does not focus on the process of mass block sliding and the process is not rapid comparatively the instrument's scanning time. Of course, the response time is directly related to the sensitivity of this pipe system. To reduce the friction, some steps can be done, such as ensuring mirrorlike surface and applying lube oil.

3. PERFORMACE OF THE SENSOR

3.1. Characterization – the measurement

In order to verify the calculated results, both bare fiber [8] and pipe sensor are employed during the measurement of the performance. Firstly, bare fiber was stretched by adding series weights. The strain-force data of Fig. 4 can be fitted to a quadric, so that the calibration coefficient can be obtained from this line and this calibration coefficient will be used in the next step for readout system. Strain effect on the Brillouin scattered components is known. Deformation $\varepsilon = \Delta L / L$, and strain coeff equal to 500 MHz/ $\%\varepsilon$ [9], the formula can be written as:

$$y = 608.7472x + 0.2194 \quad (10)$$

Secondly, the assembly pipe sensor was fixed and loaded on free end. Different angle represents series of vertical displacement of the pipe sensor. In the field, future product of pipe sensor will have any inclination angle. So even if the settlement is very tiny, the pipe sensor can capture. The results from DiTeSt-STA202 analyser are shown in Fig.5.

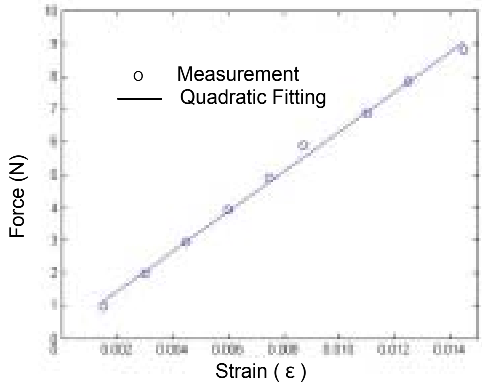

Fig.4 Force versus strain for bare fiber used in pipe sensor.

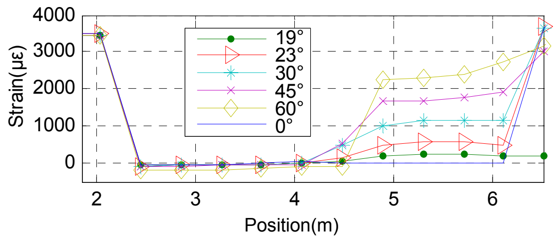

Fig. 5. Performance of smart tube sensor (reading data from DiTeSt)

CONCLUSIONS

This sensor provides a novel precise measurement method to monitor field settlement and inclination, together with ground slide. The permormance is good enough to accomplish the task of a sensor. It is possible that the pipe sensor will be used widely after find a good fixing configuration.

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