Slope monitoring and stability analysis of open pit mine based on fiber Bragg grating sensing technology

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Abstract. With the further development of resources, it is urgent to carry out on-line safety monitoring and early warning for high and steep slopes. Fiber Bragg grating technology used in the slide force monitoring can achieve the slope stability evaluation and the landslide pre-warning. The design and development of the fiber Bragg grating cable force sensor was carried out and achieved the automatic temperature compensation of fiber Bragg grating cable force measurement sensor in this paper, the center wavelength and the stress, temperature has a good linear relationship, the practice showed that the fiber Bragg grating anchor cable force sensor could meet the needs of open pit mine slope stability monitoring.

1. Introduction
Fiber Bragg grating sensing technology is a new generation of sensing technology developed rapidly since the 1970s with the application of optical fiber communication technology. It has the characteristics of "transmit" and "sense" in one [1-3]. The principle of fiber Bragg grating sensing technology is to study the change of optical properties caused by external signals, such as intensity, wavelength, frequency, phase and polarization state, so as to detect and transmit external signals [4]. Slope monitoring and early warning technology is one of the hot spots in the prevention and control of slope disasters in various fields. The main technical equipment including GPS, In-SAR, GB-SAR, 3D laser scanning, fixed inclinometer etc. [5-7].
In this paper, the FBG sensing technology was applied in real-time monitoring of slope sliding force. The relationship between the change of the central wavelength of the fiber Bragg grating and the stress and temperature was theoretically analyzed, and the fiber Bragg grating anchor cable force sensor was developed and installed in the open pit slope for slope sliding force monitoring. Result shows that FBG sensor can make accurate measurement on the slope sliding force, achieve accurate evaluation of the slope stability and make advance warning of the landslide.

2. Development of the FBG anchor cable force sensor
2.1. Sensor structure
The structure of the sensor to include temperature compensation grating 1, effective perception of external pressure grating 2 and pressure-bearing part, protective devices and optical fiber pigtail lead out hole, the section view as shown in figure 1. In the picture, R and r represent the outer and inner radius of the pressure-bearing part of the sensor respectively.
2.2. Principle of sensor detection

The effective section area \( (S_{\text{eff}}) \) of the FBG anchor cable force sensor can be expressed as:

\[
S_{\text{eff}} = \pi R^2 - \pi r^2
\]

Assuming that the value range of the external pressure \( F \) is in the linear action interval of the pressure sensor, then at this time, the strain produced by \( F \) acting on the pressure-bearing part is:

\[
\varepsilon = \frac{F}{E \cdot S_{\text{eff}}}
\]

In the formula \( (2) \), \( E \) represents the modulus of elasticity of the material of the sensor bearing element, GPa.

Under the interaction caused by the change of external temperature \( \Delta T \) and strain due to external pressure \( \varepsilon \), the change of pressure sensitive grating central wavelength \( \Delta \lambda_{B2} \) can be expressed as:

\[
\Delta \lambda_{B2} = K_e \varepsilon + K_T \Delta T
\]

In the formula \( (3) \), the \( K_e \) and \( K_T \) represent the strain of the fiber Bragg grating (the theoretical value is 1.2pm/\mu\varepsilon) and the sensitivity of temperature detection. Similarly, the change of the central wavelength of temperature compensation grating under the outside temperature changes can be expressed as:

\[
\Delta \lambda_{B1} = K_T \Delta T
\]

From formula \( (1)-(4) \), the central wavelength drift of FBG anchor cable force sensor under the action of external pressure can be expressed as:

\[
\Delta \lambda_B = \Delta \lambda_{B2} - \Delta \lambda_{B1} = K_F \cdot F
\]

In the formula \( (5) \), \( K_F \) indicates the pressure sensitivity coefficient of the anchor cable force sensor, which can be expressed as:

\[
K_F = K_e / [E(\pi R^2 - \pi r^2)]
\]

Analysis formula \( (6) \) can conclude that, the dependent variable (external pressure \( F \)) and independent variables (sensor grating central wavelength variation caused by stress \( \Delta \lambda_B \)) of the anchor cable force sensor showed a good linear relationship.

3. Study on the characteristics of FBG anchor cable force sensor

The pressure tester of 2000kN is selected as the pressure calibration instrument of the sensor, and the MOI SM130 demodulator (demodulation wavelength 1510-1590nm, precision 1pm) is selected to perform the pressure performance test for the FBG anchor cable force sensor. Its frame is shown in Figure 2.
3.1. Pressure sensitivity test
When the FBG anchor cable force sensor is in free state, the initial wavelength of the temperature compensation grating and the pressure sensitive grating is 1555.2134nm and 1537.9404nm, respectively. Increase pressure of 100kN each time, until 2000kN, this will be counted as a test cycle. The pressure performance test was repeated 3 times. Figure 3 shows the trend diagram of the pressure sensitive grating central wavelength change with the external pressure in the whole test.

Figure 3. Pressure performance test data of the pressure sensitive grating
The analysis of Figure 3 shows a good linear relationship between the central wavelength of the pressure sensitive grating and the external pressure during the whole test. Using the least square method to fit the figure 3, the corresponding relationship between the external pressure and central wavelength change of the anchor cable FBG force sensor can be expressed as: $\Delta \lambda_B = -0.0107F + 1538$,  $R^2 = 0.9993$; $\Delta \lambda_B = -0.0105F + 1538$,  $R^2 = 0.9975$; $\Delta \lambda_B = -0.0109F + 1538$,  $R^2 = 0.9981$.

4. Engineering application

4.1. Engineering survey
The experimental mine, located in Liaoning, China, is now one of the largest single opencast iron mines in Asia. In May 2014, new sliding force monitoring points at 478m-526m level around the steps were installed, the new sliding force monitoring using FBG anchor cable force sensor, and the initial prestress is about 300KN.

![Site installation of the FBG anchor cable force sensor](image)

Figure 4. Site installation of the FBG anchor cable force sensor

4.2. The process of monitoring and early warning
The new sliding force monitoring point put into use in January 10, 2015, until October 1, 2016, the slope landslide occurred at the stope footwall. The sliding force curve of NO.478-3 monitoring point below shows the whole process of landslide occurrence.
5. Conclusion

(1) The paper designed a FBG anchor cable force sensor for monitoring the slope sliding force of open-pit mine. It has high sensitivity, the stress change and central wavelength variation curve has good linearity and repeatability, and the correlation coefficient is higher than 0.997.

(2) There is a good linear correlation between the central wavelength of the sensor grating and the temperature. The temperature compensation coefficient of the pressure sensitive grating relative to the temperature compensated grating is 0.417.

(3) Monitoring the slope sliding force of open-pit mine can be converted to the measurement of axial force of the anchor cable for reinforcing the slope. By analyzing the measured value of the sliding force, we can realize the early warning for the slope landslide.

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6. References

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