Application of fiber optic sensors for vibration and ignition monitoring of a belt conveyor system

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The project was supported by the 2017 national key research and development plan, "Key technology and equipment research and development of the Internet of things in mine safety production" project No: 2017YFC0804400.

Abstract

The belt conveyor serves as the main coal transport equipment in a coal mine and its safe operation is the lifeline of safety in coal mine production. However, traditionally, monitoring for ignition and for roller faults along the belt conveyor is problematic and so this paper puts forward an approach using radial grating vibration sensing technology for both belt conveyor roller vibration monitoring. This can then be used to predict the fault state in the roller and its position, using distributed optical fiber temperature measurement technology which can be used for 'hot spot monitoring'. This enables better fire prevention along the belt conveyor, which plays a positive and effective role in better mine safety.

Key words: belt conveyor, optical fiber sensing, vibration monitoring, fire monitoring.

1、preface

As the key transportation equipment in a coal mine, the belt conveyor is an important tool to allow more effective coal mine production. Traditionally manual inspection of belt machinery is used, although this is often somewhat inefficient, as phenomena which present a safety hazard can easily be missed. The roller system is an important part of the belt conveyor system and a large number of widely distributed rollers are used to support the conveyor belt and its considerable weight. The rollers account for 35% of the total cost of a belt conveyor and generate over 70% of the resistance and ensuring both its integrity and flexibility is important for the normal and safe operation of a belt conveyor. The continuous operation of idlers aggravates the failure rate and the traditional manual inspection method used is inefficient, with problems frequently missed due to incorrect inspection, resulting in poor effectiveness of the conveying process. The troubleshooting method used after an accident shows significant potential problems for maintaining effective coal mine production and therefore to improve the situation and create a more safe environment, a better on-line monitoring system for the running state of the rollers is needed.

Optical fiber sensing is especially suitable for use in flammable and explosive situations, such as in coal mines because of its non-electrical and intrinsically safe nature, with additional advantages such as resistance to electromagnetic interference, operation over a long distance and thus large range, coupled to ease of networking for example. The multi-point, continuous and online monitoring of belt conveyor roller needed

AOPC 2019: Optical Fiber Sensors and Communication, edited by Jie Zhang, Songnian Fu, Jun Yang, Proc. of SPIE Vol. 11340, 113401Z · © 2019 SPIE
CCC code: 0277-786X/19/$21 · doi: 10.1117/12.2548165

is then possible, based on using fiber optic acceleration sensor technology, which can be used to find potential faults in the roller operation and also accurately locate the fault position. Further, distributed fiber optic temperature measurement technology can be used for large-scale hot spot monitoring of the belt conveyor transportation line and this is important for better fire prevention.

2、Key technical principles

2.1 Principle of Fiber Bragg Grating acceleration monitoring approach used

The Fiber Bragg Grating acceleration sensor designed for this application is shown in Figure 1. The Fiber Bragg Grating is fixed directly on the structure and here K1 is the elastic coefficient of the fiber, K2 is the elastic coefficient of the structure, C is medium damping coefficient and M is the mass of the block used.

The situation can be described theoretically as follows:

$$|\overline{H}| = \frac{1}{\omega_0^2 \sqrt{\left(1-q^2\right)^2 + 4\xi^2 q^2}} \quad (1)$$

where $\overline{H}(\omega)$ is the complex frequency response of the system，δIs the relative damping coefficient，ω_0 is the natural frequency of the system and $\xi = \frac{\delta}{\omega_0}$. The damping ratio，$q = \frac{\omega}{\omega_0}$。$|\overline{H}|$. The relationship between ξ and q is shown in Figure 2，where at a value of ξ=0.7 approximately，the value of q over a large range of $|\overline{H}| \approx 1/\omega_0^2$ can be seen and the frequency response range of the sensor is wide.

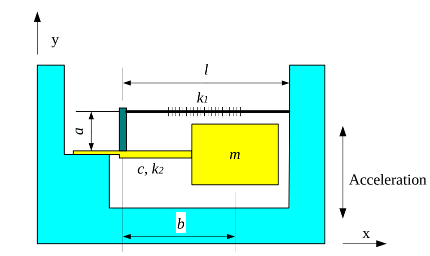

Figure 1. Structural mechanical model of the Fiber Bragg Grating acceleration sensor used in this work

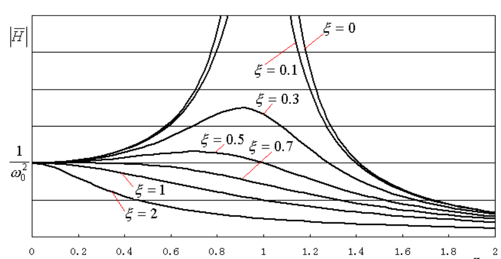

Figure 2. The relationship between the value of q and $|\overline{H}| \approx 1/\omega_0^2$

2.2 Principle of distributed fiber temperature measurement approach

Distributed optical fiber temperature measurement technology based on the principle of Raman Scattering is employed, using a semiconductor laser source which produces a narrow pulse which enters the optical fiber through an optical Wavelength Division Multiplexing (WDM) device. This pulse of laser light will allow Raman scattering to be produced in the fiber and detected by a photoelectric detection module, as shown schematically in Figure 3. A high-speed processing chip DSP is used, coupled to data acquisition and preliminary signal demodulation.

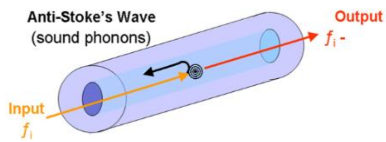

Figure 3. Schematic of the Raman scattering process

$$\frac{1}{T} = \frac{1}{T_0} - \frac{k}{hcv_0}[ln\,R\,(T) - ln(\,T_0)] \quad (2)$$

Equation 2 shows the relationship between the measured temperature, T of the hot spot and the surrounding temperature T_o, where k is Boltzmann's constant, h is Planck's constant, c is the velocity of light in a vacuum and v_0 is the optical frequency. The spatial positioning of the temperature excursion point (at temperature T) is obtained by using optical time domain reflectometry (OTDR). When the laser pulse is transmitted along the optical fiber, due to the microscopic inhomogeneity of the fiber, backscattering will be generated. Here the time required for the light pulse incident on the fiber scattered back to return to the end face of the fiber is t, so the distance L between the scattering point in the fiber and the end face of the fiber is given by

$$L = \frac{V \cdot t}{2} \quad (3)$$

$$V = \frac{c}{n} \quad (4)$$

where V is the speed of light in optical fiber and n is the refractive index of the fiber. Therefore, the location of any abnormally high temperature, indicative of faults or breakpoints along the fiber can be determined using the optical time-domain reflectometry approach

3. Application to monitoring of a belt conveyor system

3.1 Overview of the system design

The optical fiber monitoring of the belt conveyor has two major roles – one is to obtain vibration information on the performance of the bearings, through using the Fiber Bragg Grating-based acceleration sensor mounted on the belt conveyor roller, where the output signal is fed-back to the optical fiber signal demodulator. The demodulator can be used to obtain the vibration spectrum of the roller through using a Fast Fourier Transfer (FFT) spectral analysis to determine whether there is a fault. In addition, by laying multi-mode temperature sensing cable along the belt machine to sense the distribution of hot spots along the belt machinery, any abnormal temperature changes can be obtained in real time and accurate positioning data also can be monitored.

3.2 Key engineering problems in implementing the system

Careful installation of sensor is a key issue for the system, as errors can affect the final result obtained. Based on good engineering practice, the Fiber Bragg Grating acceleration sensor has been designed to be installed on the support to the roller bearing, perpendicular to the contact surface, and fixed by using a strong magnetic field to increase the degree of coupling to the sensor. The temperature sensing cable is laid along the roller channel and wound around the roller support to increase the monitoring sensitivity and improve the spatial resolution in the result obtained. Figure 4 shows a schematic of the set up where the temperature sensing fiber optic cable is shown in red and the Fiber Bragg Grating acceleration sensor position shown in blue.

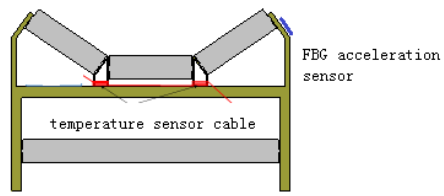

Figure 4. Schematic of the installation of the two sensor systems

4. Results of Tests carried out and data analysis

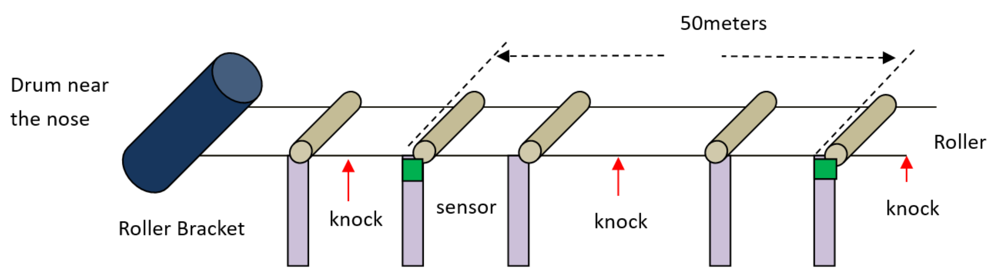

Figure 5. Schematic of the sensor installation for a simulated failure test of the idler, due to vibration

In the set up shown in Figure 5, the distance between the two sensors is known to be 50 meters, where the sensor close to the 'nose' is about 100 meters from the 'nose' to ensure that it is not affected by the vibration. To simulate the effects, they are 'tapped' in the middle and at both ends of the sensor, where the distances from the sensor are 3 meters, 10 meters, 20 meters and 30 meters respectively. The tapping frequency is 1Hz, and the tapping acceleration is no less than 1g. The optical wavelengths of the sensor used are ~1528nm and 1563nm.

Figure 6 shows the output of the 1563 nm sensor and the 1528nm sensor in the roller, during normal operation, with the axes labelled as shown. In the figure, the range shown is representative in the frequency domain signal as a characteristic frequency where at the wavelength near 1528 nm sensor 15 Hz or 60 Hz signal is selected as a reference, whereas near 1563 nm sensor, a 400 Hz signal is selected as the characteristic frequency signal.

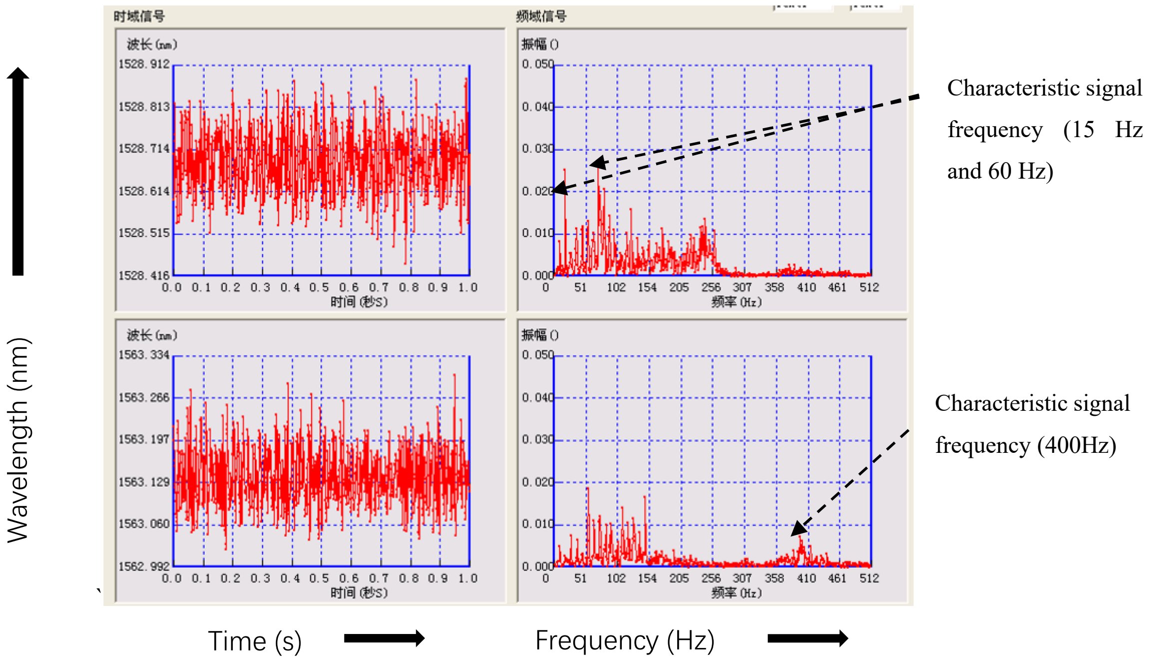

Figure 6. Time-frequency diagram under normal monitoring. Top – wavelength in the 1528 nm region; Bottom – wavelength in the 1563 nm region

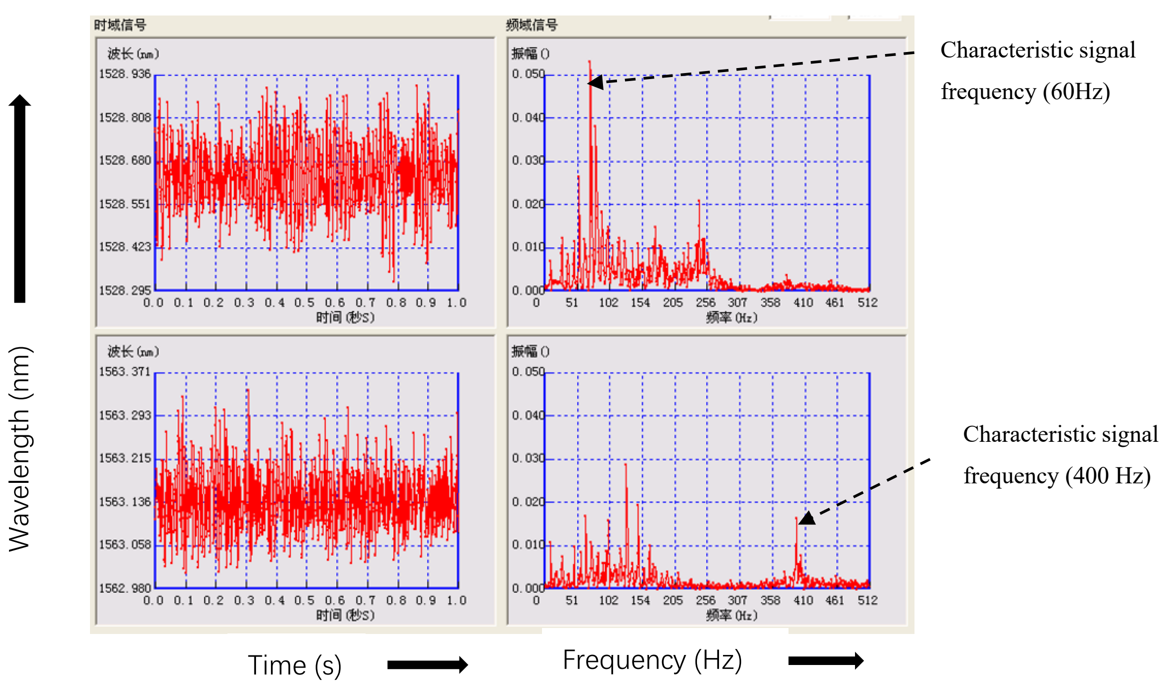

Figure 7. Time-frequency diagram under monitoring with a knock at about 3 meters. Top – wavelength in the 1528 nm region; Bottom – wavelength in the 1563 nm region

Figure 7 shows the time domain signal and frequency domain signal changes of the sensor at two different positions when tapping close to the position of 3m is made, with the 1528nm sensor. It is found that the signal amplitude changes significantly at 60Hz, while that of the 1563nm sensor is at 400Hz.

Figure 8 shows the output near 1563 nm when the knock sensor location is 3 m and two different locations of the sensor show the change of the frequency domain and time domain signals. The 102 Hz signal shows obvious changes and at 400 Hz, there was no obvious change, and at 1528 nm, near 15 Hz or 60 Hz, the frequency characteristics of the sensor has an obvious change, but with an amplitude change smaller than is seen in Figure 7.

The tests show that the spectrum obtained by the sensors close to different positions is different. The location of the fault point can be determined according to the change of the characteristic frequency signal as a result.

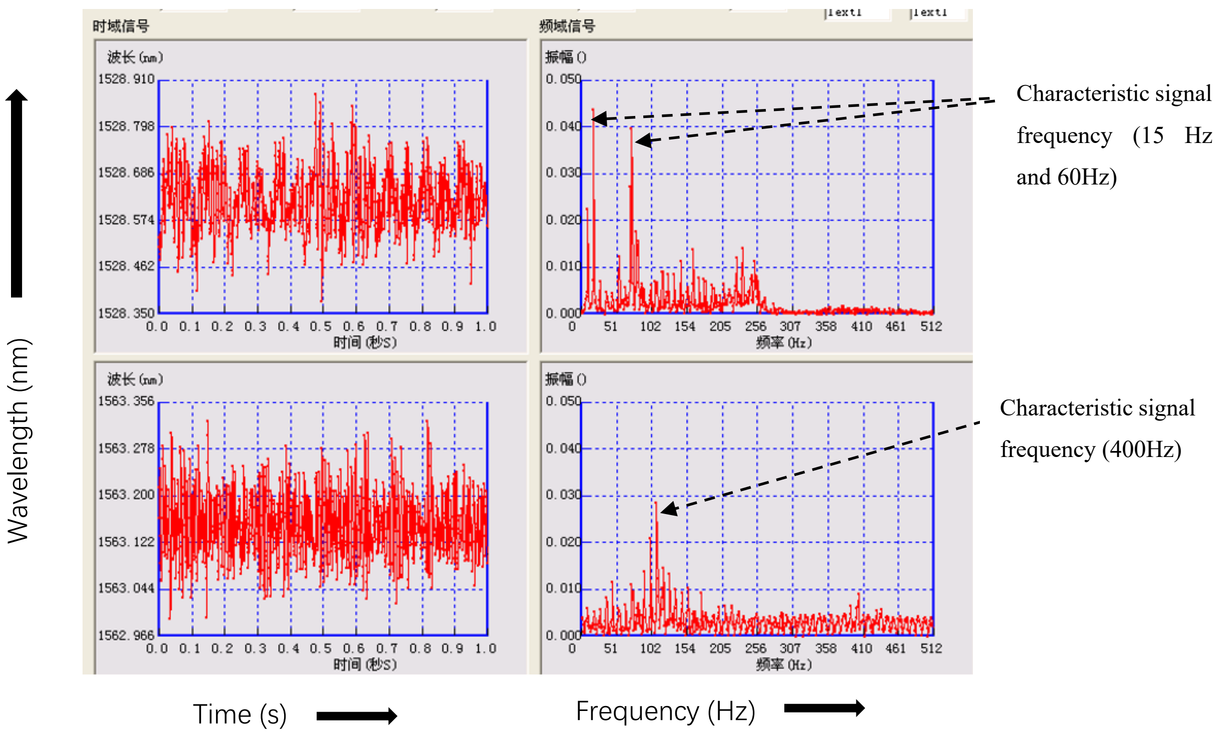

Figure 8. Time-frequency diagram under monitoring with a knock at about 3 metres.. Top – wavelength in the 1528 nm region; Bottom – wavelength in the 1563 nm region

5. Conclusion

The discussion above has shown that fiber optic sensor technology can be used effectively to monitor the vibration of belt conveyor idlers and provide data to indicate potential problems. Further, distributed optical fiber temperature measurement technology can allow effective temperature monitoring, along the belt conveyor for fire prevention and play a positive role in showing the location of the temperature excursion, as well as helping achieve better sensor installation and effective monitoring results.

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