An Intensity Demodulated FBG Axle Counter System

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Abstract: A simple, low cost and high demodulation speed axle counter system is realized by using fiber Bragg grating (FBG) sensor and edge filter. FBG sensor axle counting system uses FBG to detect the change of rail strain in the process of wheel rail coupling to realize the train axle counting. In order to meet the need of high speed and low cost demodulation method of fiber Bragg grating, a fast demodulation of wavelength is realized by using optical circulator, 3dB optical coupler and optical filter. The experimental results show that this demodulation method has obtained linearity higher than 0.99 in the strain detection test. In the field experiment of FBG sensor axle counter system, the signal-to-noise ratio is more than 24dB, which meets the application requirements of train axle counter and direction determination.

1. Introduction

The axle counter system is the basic equipment used in the railway and urban rail transit signal system to check the occupation of the track section. At present, the electromagnetic axle counter system is widely used in the rail transit system. Its basic principle is to count the number of train axles by cutting the magnetic lines of sensors on the rail with wheels. Therefore, it is easy to suffer from electromagnetic interference, such as thunder and lightning, and even the passing of shovels. Optical fiber sensing technology is an effective solution to this problem. Optical fiber sensing is a kind of optical signal modulation, which integrates signal transmission and sensing. Therefore, in essence, it has a good anti electromagnetic interference ability, especially the fiber Bragg grating (FBG) sensor has the advantages of easy networking, high precision, coupled with the increasingly mature packaging technology, which makes it widely used in engineering monitoring[1]. FBG sensing technology has become a hot spot in the field of rail transit safety monitoring, and it has also made rich research results in the application of FBG sensing technology in axle counter equipment. Wuhan University of science and technology has developed an axle counter based on the installation of FBG strain sensor at the bottom of the rail. Three axle counter devices are used to form one axle counter, which can realize the function of counting and judging the direction of train axle[2]. Shijiazhuang Railway University uses FBG sensors at the rail bottom and rail waist to monitor the bending stress and shear stress of wheel rail coupling respectively[3]. The results show that both methods are feasible. The research of FBG sensor technology in the early stage of the axle counter system has made useful progress in the feasibility, but it needs further research in the engineering application, especially the high cost of high-speed FBG wavelength demodulation module limits its application and promotion. In view of this, a simple and low-cost demodulation method of FBG based on the linear optical filter is established to realize the high-speed and low-cost processing of FBG sensing signal in the axle counter system.

2. The Principle of FBG Axle Counter Detection

In this paper, the sensing element of the axle counter system is FBG. FBG is an optical passive device, which can filter the optical wave signal in the optical fiber. When the broadband incident light enters the FBG, only the light of a specific wavelength can be reflected back, and the rest of the light is transmitted out, as shown in Figure 1. When the external parameters (strain, temperature, etc.) act on the FBG, the central wavelength of the reflection spectrum will shift. By detecting the central wavelength shift of the FBG, the external parameters can be measured.

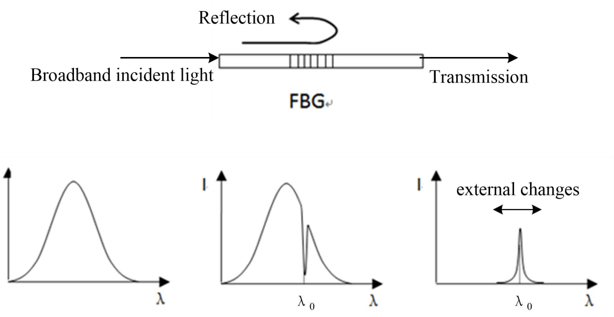

Figure 1: Reflection characteristics of FBG.

The axle counter system in this paper uses FBG to detect the change of rail strain in the process of wheel rail coupling to realize the train axle counting. As shown in Figure 2, the FBG sensing device is installed on the rail between two sleepers. When a train passes through the rail, the rail will deform under the action of the wheel. Using the strain sensing characteristics of the FBG sensing device, the force of the wheel on the rail can be detected. The signal of a wheel passing through FBG sensing device has obvious extreme value. By transforming the signal into a sequential pulse signal and counting the number of pulse signals, the axle counting can be realized.

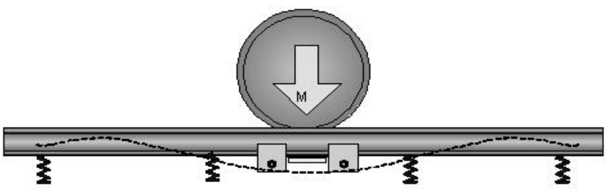

Figure 2: Force diagram of wheel rail coupling dynamics.

3. Demodulation Method

The axle counter system judges the train running direction based on the sequence of strain process of different measuring points. In order to count the axle and judge the direction accurately, the distance between measuring points shall not be greater than the minimum distance between axles. Therefore, it is necessary to adopt the method of high-speed demodulation to improve the sampling rate of FBG wavelength, so that the axle counter system can adapt to the high-speed train. In this paper, the demodulation method based on linear edge filter is used, the system structure is shown in Figure 3. It consists of an optical circulator, a 3dB optical coupler, an optical filter and two photoelectric conversion circuits. The light from the broadband light source enters the FBG through the optical circulator, and the reflected light wave enters a 3dB coupler through the optical circulator, and the reflected light is divided into two equal intensity channels, one is filtered by a filter related to the wavelength, and the other is used as the reference beam. The two signals are received by the detector, amplified and divided by the analog filter to get the output value related to the center wavelength of the FBG.

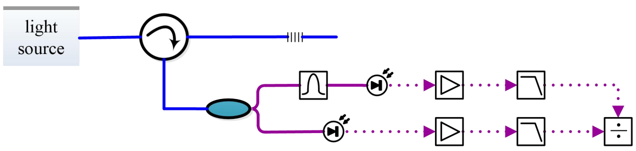

Figure 3: Composition of demodulation system based on edge filter.

The principle of the demodulation system is shown in Figure 4.Orange curve represents the optical power density $R(\lambda-\lambda_0)$ curve of FBG's reflection spectrum. λ_0 is the central wavelength of FBG, The reflected light intensity of FBG is:

$$I_1 = \int_{-\infty}^{\infty} R(\lambda - \lambda_0)\, d\lambda \tag{1}$$

The blue curve represents the transfer function curve of the optical filter, which is expressed by the normalized transmission spectrum function $H(\lambda)$. Then the output light intensity of the FBG after passing through the optical filter is:

$$I_2 = \int_{-\infty}^{\infty} H(\lambda) R(\lambda - \lambda_0)\, d\lambda \tag{2}$$

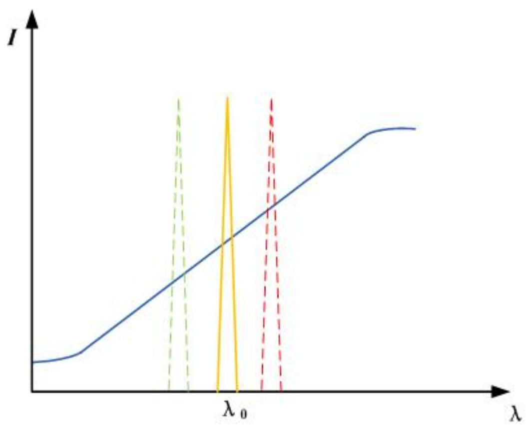

Figure 4: The principle of demodulation system based on edge filter.

Because the 3dB bandwidth of the commonly used FBG is only about 0.3nm, it is very narrow compared with the spectral width of the linear region of the linear edge filter. Therefore, in the FBG spectral range, the transfer coefficient of the filter can be regarded as a uniform change, and the value is $H(\lambda_0)$, then I_2 can be approximately a linear function:

$$I_2 = H(\lambda_0)\int_{-\infty}^{\infty} R(\lambda - \lambda_0)\,d\lambda \tag{3}$$

Obviously, the change of the central wavelength of FBG will cause the change of reflected light intensity, which is determined by the characteristics of edge filter. When the optical loss of signal transmission is considered, the optical loss coefficient k is introduced, then the formulas (1) and (3) are as follows:

$$\begin{cases} I_1 = k\int_{-\infty}^{\infty} R(\lambda - \lambda_0)\,d\lambda \\ I_2 = kH(\lambda_0)\int_{-\infty}^{\infty} R(\lambda - \lambda_0)\,d\lambda \end{cases} \tag{4}$$

Then, I_2 divided by I_1, the result is as follows:

$$A = I_2/I_1 = H(\lambda_0) \tag{5}$$

By eliminating the influence of the common mode factor in the transmission path of the two-way photoelectric conversion unit, the change of the central wavelength λ_0 of the sensing FBG is only related to the characteristic of the linear optical filter $H(\lambda)$. The center wavelength shift of FBG can be obtained by using the results of the ratio of the two optical signal intensities to realize the sensing detection. The demodulation method is simple in structure, and it can demodulate the wavelength of FBG only through two photoelectric conversion units, so it is easy to achieve high-speed demodulation by using high-speed analogue-to-digital (AD) converter.

4. Making and Testing of Demodulation Module

According to the principle of demodulation system based on edge filter, the test system is made, as shown in Figure 5 and Figure 6. In this test system, amplified spontaneous emission (ASE) wide-band light source is selected, its spectrum range is the whole C band, and the total output optical power is about 17dBm. The light emitted from ASE light source enters into three FBGs respectively through couplers, and then the FBG reflected light is processed by three demodulation units respectively through couplers.

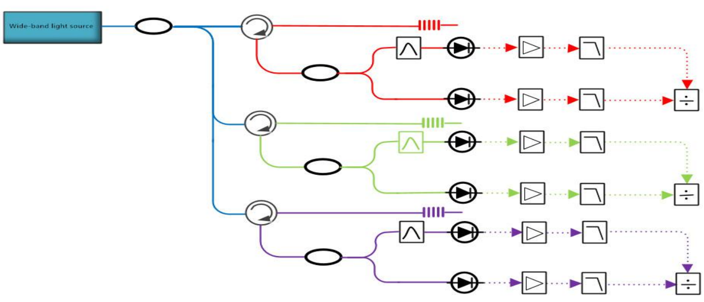

Figure 5: Logic topology of demodulation module.

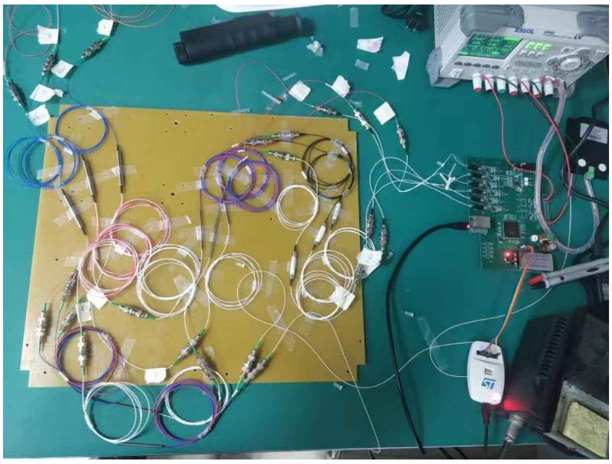

Figure 6: Physical connection diagram of demodulation module.

The spectrum of ASE light source in demodulation unit is shown in Figure 7, the spectral characteristics of the optical filter is shown in Figure 8, and the spectrum of the FBG is shown in Figure 9.

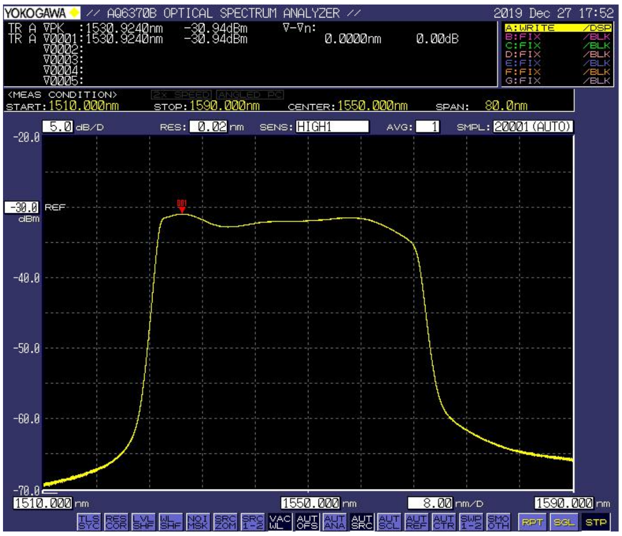

Figure 7: Spectrum of ASE light source.

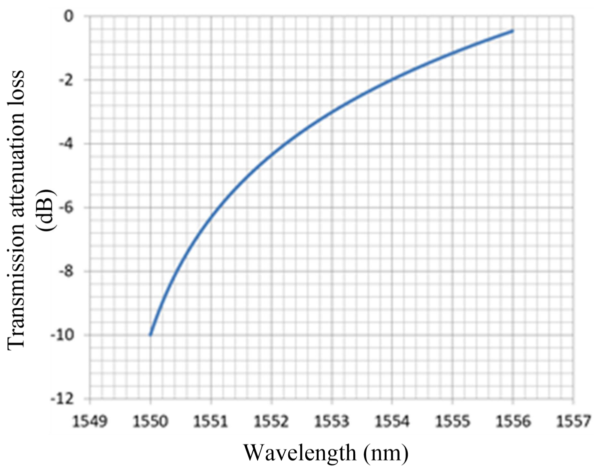

Figure 8: The spectral characteristics of the optical filter.

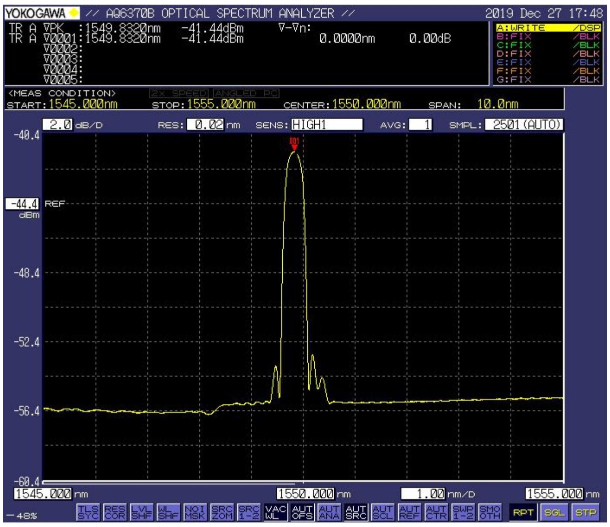

Figure 9: The spectrum of the FBG.

Three FBGs are respectively solidified on the fretting platform, as shown in Figure 10. The center wavelength of FBG is adjusted by using the fretting platform, and test data is collected by the communication interface on the demodulation unit. The test results are shown in Table 1 and the data curves are shown in Figure 11. It is obvious that the linear fit between the central wavelength offset and ratio of each FBG sensor is higher than 0.99. The experimental results are in line with the theoretical analysis.

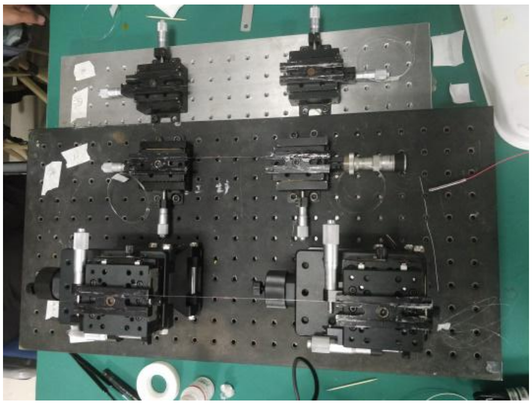

Figure 10: The fretting platform for FBG.

Table 1: Test result of demodulation optical path ratio.

Wavelength measured by spectrometer	Output result of demodulation optical path ratio		
	FBG1	FBG2	FBG3
1551	0.226274	0.226417	0.226417
1552	0.365132	0.366633	0.367019
1553	0.50399	0.506849	0.507621
1554	0.627709	0.63891	0.631922

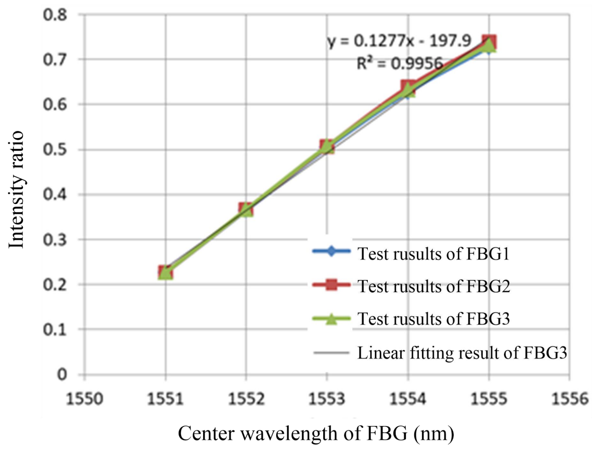

Figure 11: Test results and linear fitting result.

5. Application

A set of FBG axle counter monitoring device is designed, and installed on a section of railway, as shown in Figure 12. The Sensor signals is detected and processed by using the demodulation method. A FBG axle counter contains two FBG sensing units which is used to detect the rail strain. The two FBG sensing units are arranged along the railway at a distance of 300mm.

Figure 12: Field test diagram of axle counter.

In this application experiment, a train coach is used. There are two bogies in the coach, each bogie has two wheel sets. Push the coach back and forth to test the axle counting and direction determination function of the axle counting scheme. Figure 13 shows the test data curves of two FBG sensor units during one round-trip movement of the coach. It can be seen that each wheel set has formed obvious pulse signals when passing through FBG, the peak value of noise signal without vehicle is only 6pm, the peak value of axle counter pulse signal with vehicle passing is greater than 100pm, and the signal-to-noise ratio is more than 24dB, which is very conducive to wheel identification. In addition, when the wheels pass through two FBGs at different positions in the same sensor device, the two pulse signals have obvious clock skew, which can be used to determine the driving direction.

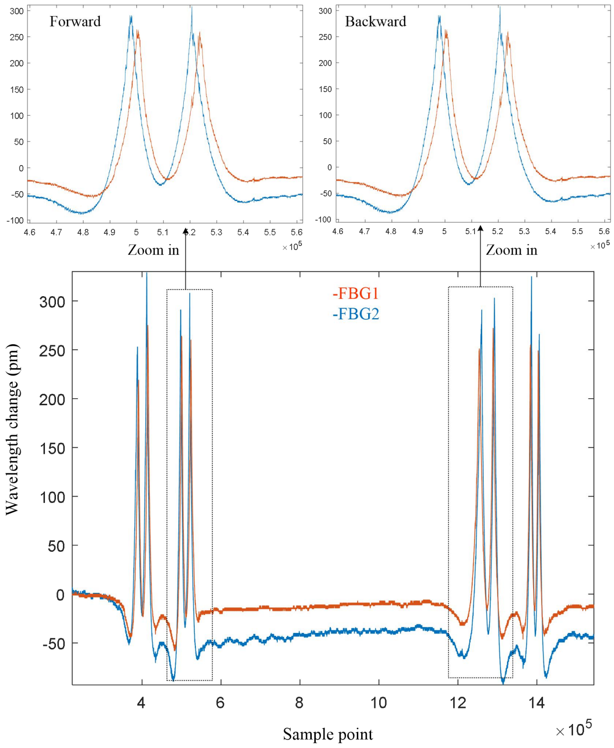

Figure 13: Field test diagram of axle counter.

6. Conclusions

Aiming at the requirement of engineering application of train axle counter system based on FBG sensor, a demodulation scheme based on edge filter is proposed. In this paper, the principle of demodulation based on edge filter is analyzed in detail, and the test system of demodulation is made. The experimental results show that the change of FBG center wavelength and the demodulation output have good linearity. The demodulation module is used for field test of axle counter, and the signal-to-noise ratio of the measured axle counter pulse signal is more than 24dB, which meets the application requirements of train axle counter and direction determination. This method is simple in structure and low in cost, and has a good prospect of large-scale popularization and application.

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