Stress monitoring method of SPMMRT track carriage beam based on FBG

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***Abstract*—The suspended permanent magnet maglev rail transit (SPMMRT), as a new type of rail transit has the advantages of green, intelligent and safety. However, when the vehicle is walking in the rail carriage beam, it will produce lateral swing, which will affect the contact mechanical characteristics between the guide wheel and the steel beam, and then affect the safety, stability and comfort of driving. Therefore, it is necessary to monitor the crossing stress of the carriage beam. In this paper, a stress monitoring method based on Fiber Bragg Grating(FBG) for SPMMRT track carriage beam is proposed. It is used to monitor the stress exerted by the guide wheel on the rail carriage beam when the vehicle is running and whether the stress is within the safe range, which will be related to the safety of the vehicle. The demodulation of the central wavelength of FBG adopts edge filtering scheme. The vertical deflection stress of the steel beam is separated by low-pass filtering method in order to calculate the stress of the guide wheel. The actual test results show that the monitoring method can obtain the force of the vehicle guide wheel on the rail carriage beam in real time, and effectively ensure the safety of driving.**

Keywords—SPMMRT, FBG, Stress monitoring, rail carriage beam

I. Introduction

Compared with traditional rail transit such as subway and light rail, suspended rail transit is a new type of rail transit system.The system has a unique way of running, that is, the vehicle is suspended under the track beam with rubber tires. It uses steel beam as the vehicle track and bears the load of the train, and each steel beam is suspended on two steel columns. The unique design of the vehicle and track beam has advantages such as strong climbing ability, small turning radius, low running noise, low construction cost, and less land area [1]. However, the rubber tire in the driving process of long-term contact with the steel beam friction will inevitably increase the loss of electric energy, in addition, the rubber wheel needs to be replaced frequently is not economical, and the maintenance cost is high. Therefore, research on SPMMRT has become a hot topic, compared with the suspended monorail transit system. Steel beams and vehicles use permanent magnets, with high suspension efficiency, non-contact running mode.It has the advantages of zero power suspension, low operating cost, environmental protection, comfortable and quiet. It is widely applicable to the development of public transportation and urban landscape construction in scenic spots, along rivers, around lakes, characteristic towns, traffic connections, and small and medium-sized hilly cities with beautiful environment and undulating terrain [2-4].

The SPMMRT is composed of six parts: rare earth permanent magnet suspension module, linear permanent magnet synchronous motor drive module, intelligent positioning and running control module, ground power supply module, wireless data transmission and operation control module, track support and foundation [5-6]. The running control module is mainly controlled by the guide wheel of suspension frame, which controls the smooth running of the train by restraining the guide wheel within the rail carriage beam. The guide wheel is always close to the rail carriage beam through the spring mechanism, and a certain preset stress on the rail carriage beam is required to ensure the control of the vehicle when the train is running [7].The track beam is a thin-walled box beam with an opening at the bottom. The mechanism of the loading of the vehicle maglev plate is quite different from that of the traditional steel wheel rail. It can be seen that compared with the conventional railway system, the dynamic interaction characteristics between the suspended maglev vehicle and the rail carriage beam, the mechanical characteristics of the vehicle and the rail carriage beam, and the driving safety assessment are greatly different. In the process of vehicle operation, environment interference (especially wind) and passenger movement lead to significant lateral swing and lateral vibration, which also leads to changes in the stress between the guide wheel and the steel beam [8]. In order to ensure the safe operation of trains, it is necessary to monitor the stress of the guide wheel to the rail carriage beam, so as to monitor the stress within the designed safety range and ensure the running safety [9]. However, there has no stress monitoring method for the new type of SPMMRT rail carriage beam at present.

Considering SPPMRT's strong magnetic field environment, electromagnetic interference, the FBG with the advantages of electromagnetic interference immunity, no lightning protection, passive, especially suitable for the SPMMRT stress monitoring method[10-11]. The stress monitoring position is arranged on the outer wall of the the rail carriage beam and installed respectively at the position where the upper and lower guide wheels travel. FBG demodulation scheme adopts edge filtering demodulation scheme. The stress of the steel beam is composed of the combination of the stress of the guide wheel and the deflection strain of the steel beam. The low pass filter is used to separate the deflection stress of the vehicle load on the track carriage beam, and then the stress of the guide wheel to the steel beam is calculated. The stress value at the installation point of each sensor is calculated by calibration transformation, and the out-of-limit alarm is carried out according to the design stress threshold. The stress monitoring ensures the health of the rail carriage beam, so as to ensure the safety of the vehicle, and is also the key equipment to ensure the normal operation of the line.The vehicle consists of two straight-through trunks,

The rest of the paper is organized as follows: The section II introduces the inspection of the line of SPMMRT and the mechanical analysis of the vehicle and the rail carriage beam; The section III gives FBG principle, demodulation scheme and stress calculation algorithm. The section IV is experimental test and result analysis; The section V is the conclusion.

II. MECHANICAL ANALYSIS OF VEHICLE AND RAIL CARRIAGE BEAM

A. SPMMRT

The test line is about 800 meters long, with a station and a static adjustment warehouse at both ends, and a switch at the station entrance. The test line adopts double-line suspension beam Y-shaped column, and the space distance between the two suspension support columns is about 25m. The vehicle consists of two straight-through trunks, and the vehicle control and suspension are realized by four suspension frames, which are composed of eight guide wheels and four permanent magnet maglev plates. The total length of the vehicle is about 20m, the maximum running speed of the vehicle is 80km/h, and the steel rail carriage beam is equipped with reinforcing bars at intervals of a distance. As shown in Figure 1, it is a schematic diagram of vehicle suspension guide wheel and track carriage beam.

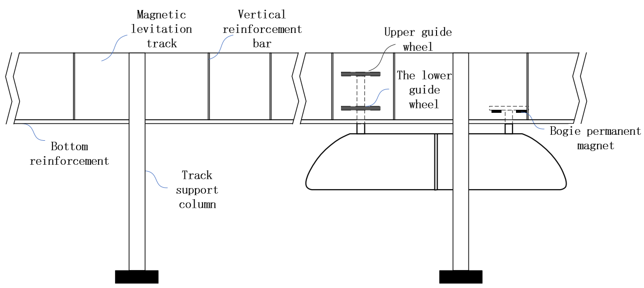

Figure 1 Diagram of SPMMRT

B. Mechanical analysis of vehicle and rail carriage beam

In order to monitor the stress of the rail carriage beam, a section of the rail carriage beam between two Y-shaped columns is selected for analysis. As shown in Figure 2, it is the section diagram of the vehicle when it passes through the rail carriage beam. It can be seen from the figure that in the *O-xy* plane, the rail carriage beam is mainly subjected to the stress *Fs* in the horizontal direction of the guide wheel along the *x*-axis. The stress of the upper guide wheel is *Fsu*, the stress of the lower guide wheel is *Fsd*, one side guide wheel of the vehicle is composed of eight guide wheels.

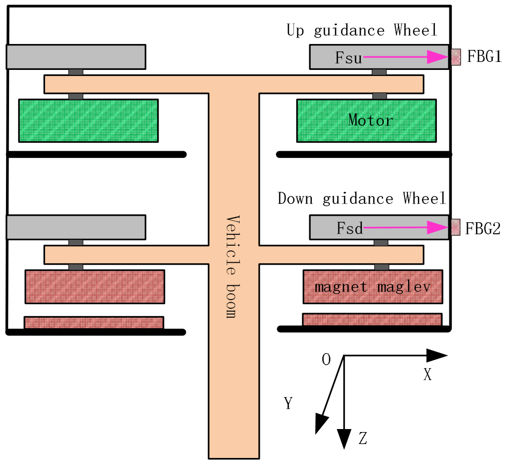

Figure 2 Section view of the rail carriage beam

Figure 3 shows the front view of the track carriage beam when the vehicle moves along the track. FBG1 is installed at the track position of the upper guide wheel, while FBG2 is installed at the track position of the lower guide wheel. The track carriagebeam can be simplified into a simple supported beam model. When vehicle load q is loaded on the track beam, the track beam will produce flexural deformation in the *O-yz* plane. FGB1 is above the neutral layer and FBG2 is below the neutral layer. Therefore, there will be compressive stress F_1 along the Y-axis at FBG1, and tensile stress F_2 along the *Y*-axis at FBG2.

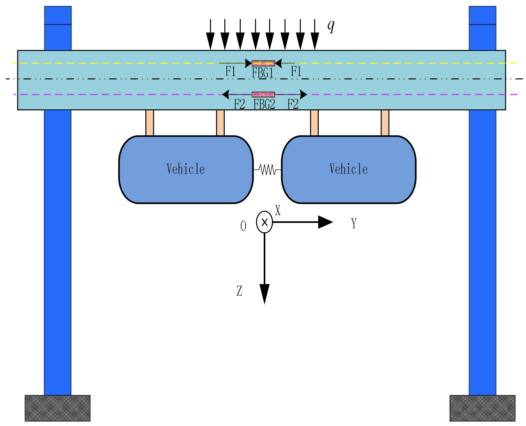

Figure 3 Front view of the rail carriage beam

III. FBG STRESS MONITORING TECHNOLOGY

A. The principle of FBG

FBG is a kind of diffraction grating formed by axial periodic modulation of refractive index of optical fiber core by a certain method, and it is a passive sensor[12-13]. The reflection characteristic of FBG is the broadband light incident into the FBG, only the light of the wavelength satisfying certain conditions can be reflected back, and the rest of the light is transmitted out. In other words, when a beam of broad-spectrum light passes through the FBG, the wavelength satisfying the Bragg condition of the FBG will be reflected, and the rest of the wavelengths will continue to transmit through the FBG. The wavelength λ_{Bragg} of reflected light of FBG is determined by the grating distance Λ , and the relationship between them is determined by the following formula:

$$\lambda_{\text{Bragg}} = 2n_{eff}\Lambda \tag{1}$$

Where n_{eff} is the effective refractive index of the grating.

The principle of FBG applied to the stress monitoring of SPMMRT rail carriage beam is as follows: the stress acting on the steel beam will produce a certain micro-strain, which will be transferred to the FBG to change its grid distance. resulting in the shift of the center wavelength of the FBG reflection, that is, the wavelength change, and the wavelength change is linear relationship with the micro-strain. As a result, the center wavelength of the FBG reflection is shifted, that is, the wavelength change is produced, and the wavelength change is linearly related to the micro-strain.In this way, the variation of the reflective center wavelength of the grating is related to the micro-strain of the steel beam as follows:

$$\Delta\lambda = K_{\varepsilon}\varepsilon \tag{2}$$

Where, $\Delta\lambda$ is the variation of FBG center wavelength, K_{ε} is the strain sensitivity coefficient. As an example, the FBG with the most widely used central wavelength in C band is $1.2pm/\mu\varepsilon$ $(1pm = 1\times10^{-12}m)$.

B. Edge filtering demodulation Scheme

In order to achieve high speed and reliable FBG wavelength demodulation, edge filtering wavelength demodulation scheme is used, which is shown in Figure 4. Amplified Spontaneous Emission (ASE) light source is amplified into FBG through the circulator. The reflected light of FBG is divided into two ways through the coupler. One way is received by the Photo detector (PD) through the optical edge filter, whose attenuation is linearly correlated with the optical wavelength; the other way is directly received by PD as the reference light. The influence of wavelength demodulation can be eliminated by the light intensity ratio of two channels.

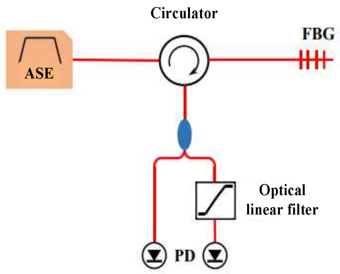

Figure 4 Edge filter demodulation schematic diagram

Edge filtering demodulation scheme is a demodulation scheme based on light intensity. PD converts the received light intensity into weak current information, which can be converted into digital signals that can be processed by micro-controller unit through current voltage circuit, amplifier circuit and analog-to-digital converter circuit. In micro-controller unit, the central wavelength information of FBG can be demodulated by dividing the voltage signals of two PD conversions.

C. Selection of stress monitoring test points

In field test, a section straight track carriage beam was selected for stress test. Two installation positions were selected for FBG track strain monitoring. As shown in Figure 5 below, FBG1 and FBG2 were respectively installed on the surface of the track carriage beam and at the passing position of the upper and lower guide wheels.

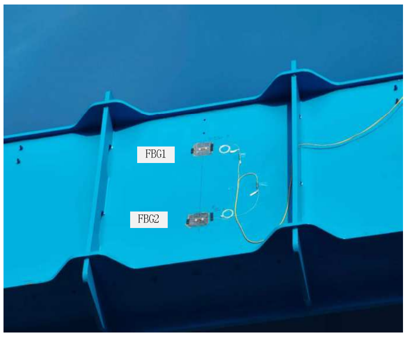

Figure 5 FBG installation drawing

D. Stress monitoring algorithm

After the installation of FBG was completed, the stress monitoring test was carried out on the vehicle. Figure 6 below is the curve diagram of FBG central wavelength variation at 10km/h when the vehicle was going up through the stress monitoring. The blue curve represents the FBG1 central wavelength variation at the upper guide wheel. FBG1 is subject to the compressive stress F1 of the steel beam flexural strain (see Figure 3), so the wavelength variation caused by the flexural strain becomes smaller, while the central wavelength variation of FBG2 at the lower guide wheel is increased due to the tensile stress of the steel beam flexural strain (red curve in the figure).

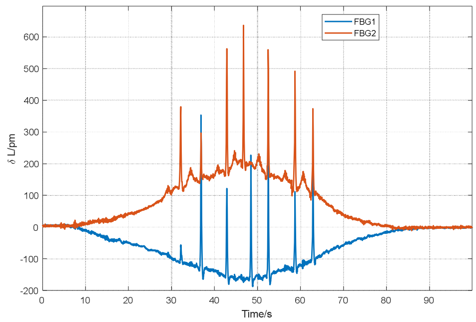

Figure 6 Wavelength variation of FBG1 and FBG2 over the vehicle

The low-pass filter is carried out to separate the wavelength change of flexular-stress, and the original wavelength change is subtracted from the wavelength change of flexular-stress. The remaining wavelength change is the stress of the guide wheel against the carriage beam, namely, the stress of 8 guide wheels, as shown in Figure 7. The above figure is the wavelength change caused by the stress of the lower guide wheel, among which the fourth guide wheel has poor contact with the track carriage beam. The second guide wheel has the greatest stress. The figure below shows the wavelength variation caused by the stress of the upper guide wheel. The fifth guide wheel has poor contact with the rail carriage beam, and the fourth guide wheel has the greatest stress.

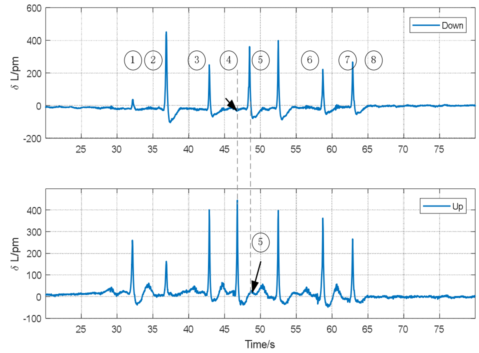

Figure 7. Wavelength variation caused by guide wheel stress

The stress calibration of the calculated wavelength variation can be converted into the corresponding stress value of each guide wheel. The stress of FBG1 and FBG2 was calibrated by applying different force acquisition wavelength variation. The calibration coefficient of FBG1 and FBG2 was 37.4532N/pm, and that of FBG2 was 41.6666N/pm. The up-pass and down-pass tests were carried out. The calculated stress of the track carriage beam is calculated in Table 1, from which the maximum stress can be 20.46kN. Within the range of stress threshold set for the safe running of the track carriage beam, a small amount of guide wheel and the return guide wheel are allowed to be close together in the safe running of the vehicle. However, considering the safety of the running, the guide wheel without good contact needs to be adjusted.

Table 1 Statistical table of stress of track carriage beam in passing test

No.	up-pass		down-pass	
	Fsu(kN)	*Fsd(kN)*	*Fsu(kN)*	*Fsd(kN)*
1	8.99	2.38	7.68	4.08
2	5.47	20.46	4.54	18.92
3	14.91	11.75	12.28	12.00
4	16.37	**0.00**	9.66	**0.00**
5	**0.00**	16.04	**0.00**	14.70
6	14.94	17.96	13.00	17.34
7	14.08	10.46	12.40	10.66
8	10.26	11.67	9.32	11.58
Max.	16.36	20.46	13.00	18.92
Flexural stress	7.50	6.66	7.50	6.66

IV. CONCLUSION

In this paper, a stress monitoring method based on FBG for SPMMRT track carriage beam guide wheel path is proposed. Considering the safety and ride stability, the stress monitoring of the track carriage beam is needed to monitor whether the stress between the guide wheel and carriage beam is within the design threshold. Due to the strong magnetic field and electromagnetic interference, the stress monitoring scheme of FBG sensor and edge filtering demodulation technology with no power on the rail was adopted. A strain gauge based on FBG was installed at the path position of the upper and lower guide wheel as the stress monitoring test point. Under the influence of the weight load of the vehicle body, the stress measurement information of FBG includes not only the stress information of the guide wheel, but also the flexural deformation caused by the vehicle weight, which requires the separation of two kinds of stress. Considering that the long duration of vehicle load on FBG is a low-frequency signal, while the duration of guide wheel action on FBG is relatively short, low-pass filtering is adopted to separate the flexural stress, so as to analyze the stress of guide wheel, and then calculate the stress of guide wheel according to the calibration parameters. The test results of vehicle running stress are in line with expectations.

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