Novel monitoring method of overhead transmission line galloping and torsion based on fiber Bragg grating sensor

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***Abstract*—This paper presents a new method based on FBG sensor to measure the galloping and torsion of overhead transmission lines. The result shows that it can accurately monitor the line galloping amplitude and torsion angle.**

Keywords—Optical fiber sensors, Overhead transmission line , Galloping and torsion measurement, Fiber Bragg grating

I. Introduction

Transmission line galloping is a low-frequency and large-amplitude self-excited vibration of the wire induced by the winds and transmission line icing. The galloping of the transmission line is often accompanied by a strong torsion which can cause various accidents such as flashover between lines, tripping, wire breakage, even towers fall down.

Some related studies on galloping on transmission line have been proposed. Zhang et al. [1] used accelerometer and Cao et al. [2] used camera technology to monitor transmission line galloping, but these methods are easily influenced by the high-voltage environment while the energy supply remains an issue. Moreover, the torsion of the t transmission line has not been discussed.

This paper measures the galloping and torsion variation of transmission line based on Fiber Bragg Grating (FBG) accelerometer which has increasing become important to transmission line monitoring for its great advantages, such as strong anti-electromagnetic interference, higher electrical insulating property, electrically passive and high sensitivity. There are numerous high-voltage overhead transmission lines installed with optical fiber composite overhead ground wire (OPGWs) in China. Our newly developed optical motion and twist sensor can achieve monitoring of specific locations. Optical signals are transmitted through OPGWs to obtain on-site information in real-time at monitoring stations several tens of kilometers away. This resolves issues such as power supply, electromagnetic interference, and lifespan as mentioned above. The paper discussed the galloping amplitude and torsional angle of the transmission line when galloping happens.

II. Principle and Theoretical Models

A. Mathematical basis for galloping and torsion monitoring

The sensor affixed to the transmission line is utilized to quantify its acceleration, which is then subjected to double integration to compute the corresponding galloping amplitude value. Given the discretized nature of the acquired acceleration data, an approximation technique must be employed during the integration process.

$$\begin{cases} v(t) = \int a(t)dt = \sum_{i=1}^{N} [\frac{a_i + a_{i+1}}{2}]\Delta t \\ s(t) = \int v(t)dt = \sum_{i=1}^{N} [\frac{v_i + v_{i+1}}{2}]\Delta t \end{cases} \quad (1)$$

Where a(t), v(t) and s(t) are the continuous acceleration, velocity and displacement data in the time domain, a_i and v_i are the acceleration and velocity values at time i respectively.

Similarly, the angular displacement can be calculated based on the measured angular acceleration value.

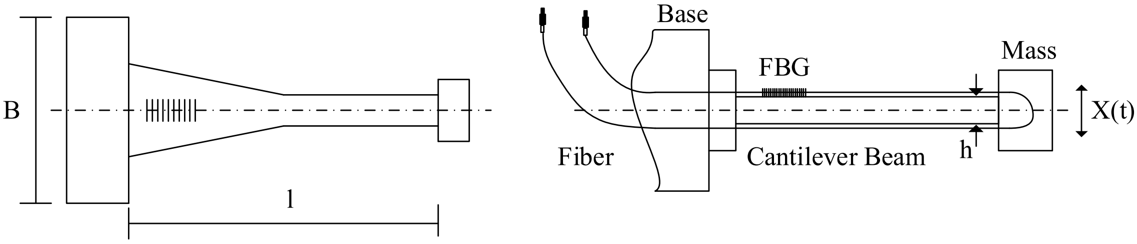

Figure1 The principle circle of fiber Bragg grating acceleration sensor

$$\begin{cases} \omega(t) = \int \beta(t)dt = \sum_{i=1}^{N} [\frac{\beta_i + \beta_{i+1}}{2}]\Delta t \\ \theta(t) = \int \omega(t)dt = \sum_{i=1}^{N} [\frac{\omega_i + \omega_{i+1}}{2}]\Delta t \end{cases} \quad (2)$$

where $\beta(t)$, $\omega(t)$ and $\theta(t)$ are the continuous angular acceleration, angular velocity and angular displacement data in the time domain, β_i and ω_i are the angular acceleration and angular velocity values at time i respectively.

Using sensors placed on the conductor, the acceleration and angular acceleration values of the conductor's motion are measured. By integrating these values twice, the displacement and twist angle of the conductor's motion can be obtained. Compared to some non-contact measurement methods that can only measure the relative displacement between the sensor and the acquisition point, this method not only ignores the limitations of rigid foundations, but also ultimately measures the absolute displacement and twist angle of the conductor's motion. This approach provides a more accurate measurement of the conductor's motion and twist, as it takes into account the full range of motion and twist, rather than just the relative displacement between the sensor and acquisition point.

B. *Measurement principle of a cantilever beam*

A fiber Bragg grating (FBG) sensor system was constructed by affixing an FBG along the central axis of a cantilever beam, which was subsequently attached to a support carrier at its thick end, and fixed with a mass at its thin end. As illustrated in Figure 1, the FBG sensor system can be modeled as a second-order single-degree-of-freedom forced vibration system. The system comprises of a vibrating mass, an equivalent spring stiffness (representing the cantilever beam's stiffness), and air damping.

The sensing model of the fiber Bragg grating acceleration sensor is:

$$\frac{\Delta\lambda_B}{\lambda_B} = -(1-p_e)\frac{6lm}{EBh^2}\frac{d^2x(t)}{dt^2} \quad (3)$$

Where E, h, l and B are the elastic modulus, thickness, length and width of the cantilever beam, x(t) is the absolute displacement of the base vibration, p_e is the valid elastic-optic constant $p_e = 0.22$.

C. *Galloping and torsion monitoring system*

Figure 2 shows the diagram of a galloping and torsion monitoring system based on fiber Bragg gratings (FBGs), as proposed in this paper. The monitoring system comprises two main components, namely the sensing system and the vibration generating system. The sensing system is responsible for detecting the galloping and torsion motion of the system using FBGs, while the vibration generating system produces the necessary vibrations to stimulate the system and generate the motion being measured. This two-part design allows for accurate and reliable monitoring of galloping and torsion.

The sensing system primarily acquires the optical signal of the motion attitude of the transmission line through a sensor. The obtained optical signal is subsequently transmitted back to the demodulator for demodulation and calculation through the optical fiber or OPGW. On the other hand, the vibration generating system applies a disturbance characterized by a specific frequency and amplitude to the transmission line as a reference value.

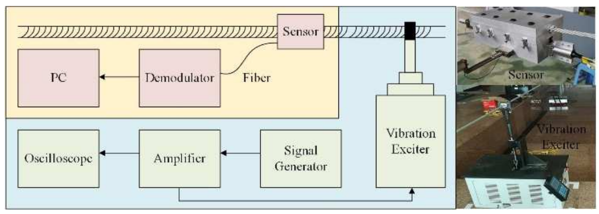

Figure2 Schematic of the galloping and torsion monitoring system

III. EXPERIMENTAL RESULTS

We performed a sequence of experiments at the specialized optical fiber cable laboratory of the China Electric Power Research Institute (CEPRI), which facilitates the simulation of transmission line galloping and torsion. The Optical Ground Wire (OPGW) was subjected to the force of a stretching machine, simulating galloping and twisting in a natural environment, while being controlled by a vibration generating system. The maximum amplitude of galloping was found to be 25cm.The galloping amplitude measurement experiment employed three different measurement methods, namely ruler as reference amplitude, electronic acceleration sensor, and fiber sensor.

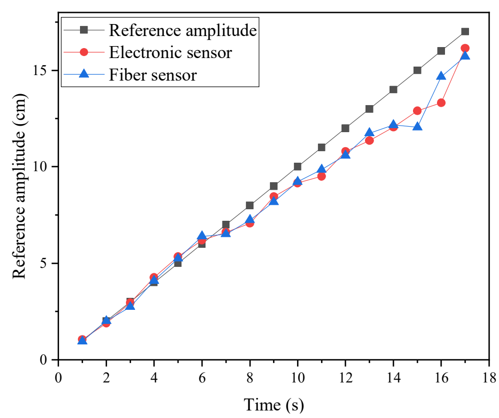

Figure3 The results of the three measurement methods when the amplitude is gradually increased

The experimental results are presented in Figure 3 where the amplitude uniformly increases from 0 and in Figure 4 where the frequency uniformly increases from 0. The transmission line is in a stable vibration state when the measurement is conducted step by step with a fixed amplitude, and the results obtained from the optical fiber sensor are consistent with those obtained from the other two measurement methods. However, when the measurement is conducted step by step with a fixed frequency, the transmission line exhibits strong self-excited torsion and violent galloping at a specific frequency, which is the most destructive situation under natural conditions. Nevertheless, the optical fiber sensor is capable of measuring the amplitude of the galloping, even under such violent conditions.

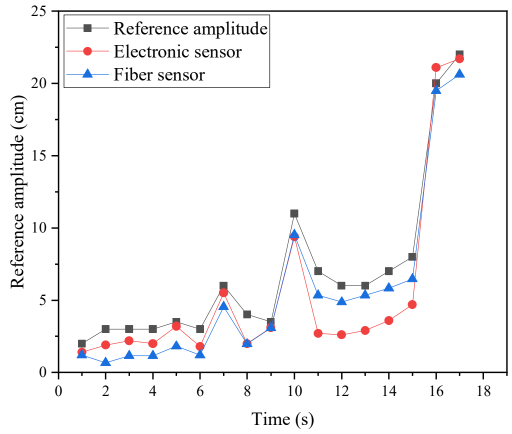

Figure4 The results of the three measurement methods when the frequency is gradually increased

The torsion angle measurement experiment was conducted using both electronic and optical fiber sensors, and their results were compared. Figure 4 illustrates the outcomes of the measurement method where the frequency uniformly increases from 0. When the measurement was conducted step by step with a fixed frequency, the wire exhibited strong self-excited torsion, and the maximum torsion angle exceeded 12 degrees, resulting in the generation of a large torque in an unsafe state. Nevertheless, the optical fiber sensor was still able to accurately measure the degree of torsion at this point in time.

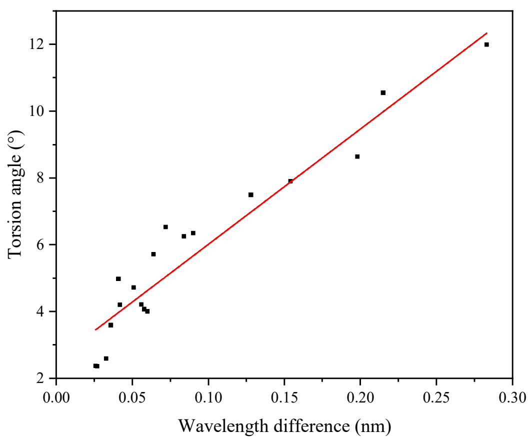

Figure4 Relationship between wavelength difference and twist angle

IV. Conclusion

A novel Fiber Bragg Grating (FBG)-based sensor for measuring galloping and torsion of transmission lines has been proposed and implemented. Feasibility has been verified through experiments. The experimental results indicate that the monitoring scheme can accurately and in real-time obtain the amplitude of galloping and the angle of twisting when they occur. The novel monitoring scheme enables remote monitoring and its passive nature holds potential value for certain special occasions.

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