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Reliability Investigation of Fiber Bragg Grating Sensors Used in Icing Monitoring of Overhead Power Lines

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Abstract: A novel tension sensor based on fiber optic Bragg grating(FBG) is proposed. The sensor is designed to monitor ice accumulation on overhead power lines. Reliability of the sensor is investigated by Electromagnetic interference(EMI) tests and icing environmental tests. The experiments results show that the sensor is immune to electromagnetic interference and it is capable of working in harsh environment.

1. INTRODUCTION

There are many disasters such as line disconnection, tower failure and flash over caused by atmospheric icing and ice shedding [1].

A useful way to prevent the disasters is monitoring the total load of overhead power-line by tension sensor[2]. However the traditional sensor has many problems such as vulnerable to magnetic interference.

Because fiber optic Bragg grating(FBG) is immune to electromagnetic interference[3] with a long lifetime and capability of working in harsh environment[5], it is proved to be a good candidate to monitor power equipment.

In this paper, a FBG Tension Sensor(FTS) is designed with presenting its properties: be immune to electromagnetic interference and works in a harsh environment such as low temperatures, high air humidity and ice.

2. RESULTS AND DISCUSSION

Fig.1 depicts the working condition of FTS and ETS. We can find the FTS works normally, however the ETS receives some disturbance. Fig.2(a) depicts the FTS is not influenced under the lightning impulse. However, three times of ETS experimental results are shown in Fig.2(b),(c),(d), we can find the ETS is largely influenced by the disturbance, especially in the third time, it's reading changes greatly and not restores to the normal. Fig.3 depicts the measured result of the loading and unloading process. The sensor works normally in the conditions of low temperature, high air humidity and icing.

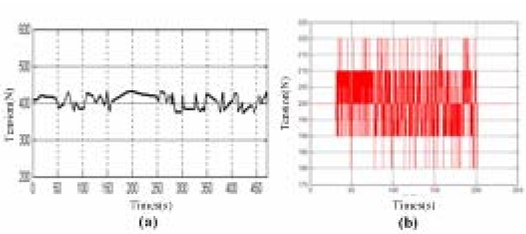

Figure 1: Tension measured by FTS and ETS under power frequency magnetic field disturbance

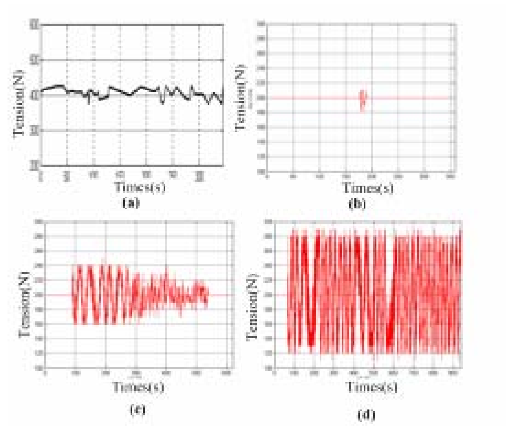

Figure 2: Tension measured by FTS and ETS under lighting impulse disturbance

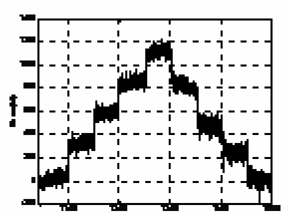

Figure 3: Tension measured by FTS under the icing condition

3. CONCLUSION

A tension sensor based on Fiber Bragg Grating(FBG) is proposed. In order to verify the reliability of FBG Tension Sensor and Electronic Tension Sensor working in a harsh electromagnetic environment, a series of EMI experiments were carried out in our laboratory. The EMI experiments show that the FBG Tension Sensor is immune to Electromagnetic interference, while the other one is sensitive to that. The icing experiment shows the FBG Tension Sensor works normally in low temperature, high air humidity and icing condition.

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***Abstract*—A novel tension sensor based on fiber optic Bragg grating(FBG) is proposed. The sensor is designed to monitor ice accumulation on overhead power lines. Reliability of the sensor is investigated by Electromagnetic interference(EMI) tests and icing environmental tests. The experiments results show that the sensor is immune to electromagnetic interference and it is capable of working in harsh environment.**

Keywords-FBG tension sensor; Electronic tension sensor; Icing monitoring; overhead power lines

I. INTRODUCTION

There are many disasters such as line disconnection, tower failure and flash over caused by atmospheric icing and ice shedding[1]. To prevent these disasters, monitoring the power-line is an important way for early warning. Many scholars have done a lot of researches on monitoring, such as installing cameras on the overhead power lines which can transfer the images of lines from remote areas to the power stations. But the images may be blurred in a heavy snow or dust, which will difficultly to tell the icing condition clearly.

A useful way to prevent the disasters is monitoring the total load of overhead power-line by tension sensor [2]. The tension sensors are usually incorporated between insulator string and cross arm of electric tower. The ice load can be easily gained by substrate the wind load from the measured load. Many products have been invented like the Electronic Tension Sensor(ETS) which has been widely used in china for icing monitoring. However, it has some shortcomings: Firstly, since there is no on-site power, solar are frequently used to power the sensor. The solar-powered cell is supposed to be invalid in continuously cloudy and rainy days though. Secondly, the senor is easily disturbed by the strong electromagnetic field when installed beside the power lines since it is sensitive to the Electromagnetic interference(EMI). Thirdly, the performance of ETS will become worse in high air humidity condition.

Because fiber optic Bragg grating(FBG) is immune to electromagnetic interference[3, 4] with a long lifetime and capability of working in harsh environment[5].It is proved to be a good candidate to monitor power equipment.

II. PRINCIPLE OF FBG

FBG are well known and any change in fiber properties, such as strain or temperature will change the Bragg wavelength. In a FBG sensor, a relative shift of the Bragg wavelength, $\Delta\lambda_B / \lambda_B$, depends on a change in applied strain ($\Delta\varepsilon$) and a change in temperature (ΔT), approximately given by[6]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (\alpha_f + \xi)\Delta T + (1 - p_e)\Delta\varepsilon \qquad (1)$$

Where p_e is the strain optic coefficient, ξ is the thermo-optic coefficient, α_f is the thermal expansion coefficient of the optical fiber.

Thus Fiber Bragg Grating can be used as a direct sensing element for measuring strain and temperature. In order of sense strain only, what we have to do is to compensate the influence of temperature which is introduced in the next portion.

III. DESIGN OF FBG TENSION SENSOR

In order to connect the sensor with the link fittings, the top and bottom of the FBG Tension Sensor(FTS) are specially designed as presented in Fig.1[7]. FBG is glued in the both sides of web plate, which can eliminate the influence of temperature by subtracting the value of two FBGs. The structure of the tension sensor is based on shear beam for the purpose of increasing the precision and reducing the influence of the eccentric load. The shape of the sensor web plate is shown in Fig.2.

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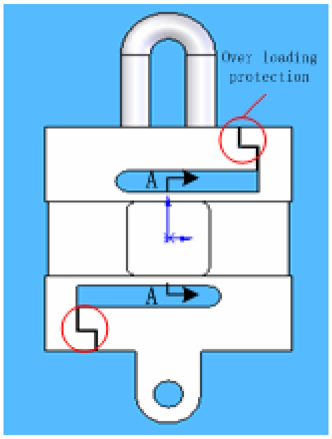

Figure 1: Schematic of FTS

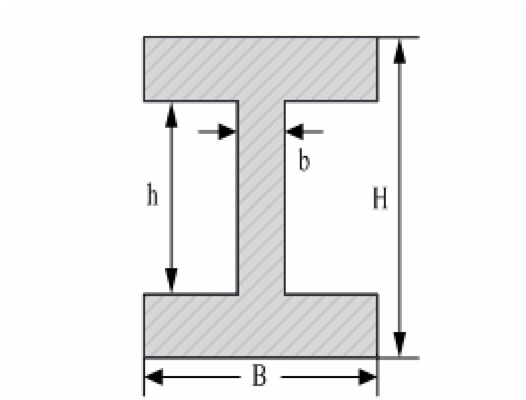

Figure 2: A-A Sectional view of the sensor

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Experiment of EMI

Several electromagnetic interference tests, including power frequency electric field disturbance, power frequency magnetic field disturbance, lightning impulse disturbance and gap breakdown disturbance, are carried out in our laboratory to investigate the anti-electromagnetic interference property of the FTS and ETS.

1) Power frequency electric field disturbance test

In order to study the influence of electric field to the sensor, we assume that the senor is installed in voltage grade for 220kv class power lines. We can calculate the electric field through the equivalent electric charge method which is proposed on the international power grid meeting by the 36.01 workgroup [8].

$$\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} = \begin{bmatrix} \lambda_{11} & \lambda_{12} & \lambda_{13} \\ \lambda_{21} & \lambda_{22} & \lambda_{23} \\ \lambda_{31} & \lambda_{32} & \lambda_{33} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} \tag{2}$$

Where [U] is the matrix of power lines potential to ground, [λ] is the matrix of potential coefficient, [Q] is the matrix of equivalent electric charge.

Choose the typical 220kv class power line's parameters: wire radius is 10 mm, the height apart from the ground is 23 m, phase spacing is 7.5 m[9]. The installation point of transducer is 2 meters height away from wire. Suppose the transducer is installed in the middle phase and it induces the biggest field 9.37kV/m through the equivalent charge method. While the sensor is installed in the other two phase the sensor influences field 8.94 kV/m.

In this experiment, a power frequency transformer is used to apply AC voltage, and to simulate the corona environment in the same time. HV terminal is connected to a wire whose diameter is 2mm. Sensor and wire are decorated parallel, the distance between them is 20cm, and the wire is 1m apart from the ground. A 400N insulator is hanged at the bottom of the sensor. Through the same equivalent electric charge method to calculate the electric-field intensity, when adding voltage to 14.85 kV, the biggest electric field place of the sensor will be 9.72 kV/m. It can simulate the actual conditions. The results of power frequency electric field interference of FTS and ETS are shown in Fig.3.

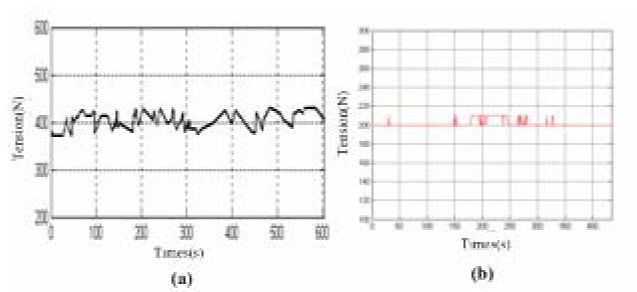

Figure 3: Tension measured by FTS and ETS under power frequency electric disturbance

Fig.3 depicts that both the FTS and ETS can work normally in power frequency electric field and corona disturbance.

2) Power frequency magnetic field disturbance test

When power lines is under operation, the current in the conductor can reach to hundreds ampere and form a strong magnetic field. We carry on the power frequency magnetic field interference test to check the sensor's working performance. The magnetic field of power lines induce to the sensor pensile point which can be calculated by infinite long wires formula, since each of them is apart far away. The current of 220kV power-line is 600A, the sensor is apart from transmission line 2 meters, so the maximum of the magnetic intensity is:

$$H = \frac{I}{2\pi r} = \frac{600}{2\pi \times 2} = 47.74(A/m) \tag{3}$$

Large current wires were used in laboratory to simulate the power lines: the current of wires is 21.2A, and it is 0.1 meters apart from sensor 0.1 meters. Because the conductor is not infinite long, the maximum magnetic field of the place where the sensor installed can be calculated by using Eq.(3), where θ_1 and θ_2 are related with the location of wires. In this experiment θ_1 =25 °and θ_2 = 125 °.

$$H = \frac{I}{4\pi r}(\cos\theta_1 - \cos\theta_2) = 24.98(A/m) \quad . \quad .$$

When two wires are used, the magnetic intensity reaches to 49.95A/m, to which extent that the magnetic intensity can be used to simulate the field environment.

In our experiment the sensor is installed parallel to wires, and the distance between them is 0.1m. At the bottom of the sensor there are 400N weighted insulators. Fig.4 shows the working conditions of FTS and ETS. We can find the FTS has been working normally, although the ETS has received some disturbance.

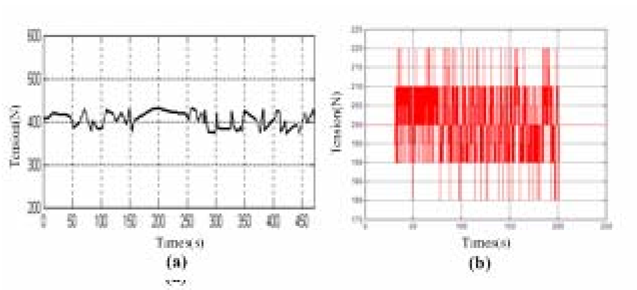

Figure 4: Tension measured by FTS and ETS under power frequency magnetic field disturbance

3) lightingim pluse disturbance test

Sensors used in overhead power lines usually suffer lighting impulse which inducts an overvoltage to the lines. Sensors will face with major problem with the high frequency of lighting impulse. As result, examining sensors' performance becomes more important under this test.

In our experiment we use the standard lighting impulse generator to generate a lighting impulse. One side of a spherical gap is connected to the generator and the other side is connected to the ground. The distance of the spherical gap is larger than breakdown voltage's. Then we put the FTS and ETS around the spherical gap and get the results in Fig.5.

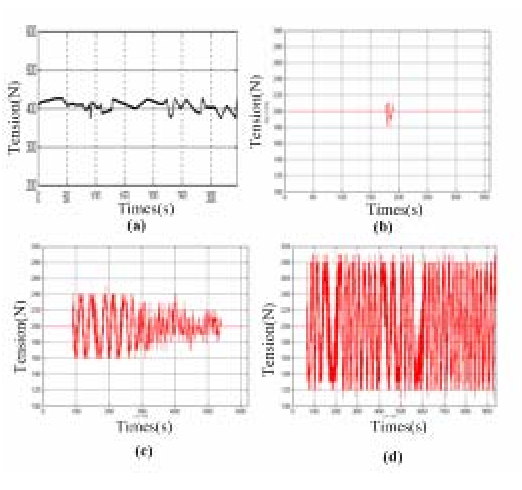

Figure 5: Tension measured by FTS and ETS under lighting impulse disturbance

Fig.5(a) depicts that the FTS is not influenced under the lightning impulse. However, three times of ETS experimental results are shown in Fig.5(b),(c),(d), and we can find that the ETS is largely influenced by the disturbance, especially in the third time, it's reading changes greatly and isn't restores to the normal.

4) Gap breakdown disturbance

Sometimes counter-attacks and breakdown could happen between the phases nearby the power lines. These attacks will generate strong electromagnetic interference. A gap puncture interference experiment is designed for testing the performance of FTS and ETS. The gap breakdown disturbance test arrangement is similar to the lighting impulse test, except the sphere gap was reduced to 3cm. The breakdown voltage is calculated to be 120kV. When the gap breakdown happens the wire will generate a high frequency of truncation wave. The FTS is not affected in the gap breakdown disturbance test, and the test result is shown in Fig.6. However the ETS was damaged during the test, and it has to be restarted for next usage.

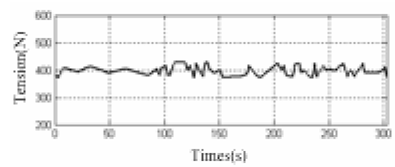

Figure 6: Tension measured by FTS under gap breakdown disturbance

B. Icing Experiment

Sensor works in low temperatures, high air humidity and snow condition should be confirmed too. The FTS is put into a climatic chamber to realize above condition. Firstly we drop the temperature to -6℃, and maintain for a while. A poise weight of 250N was loaded every 30 mins, and the poises were unloaded in the same way after 2 hours, the water was sprayed to the sensor at the same time. Fig.7 shows the loading and unloading process. The sensor works normally and measure correctly in the conditions of low temperature, high air humidity and icing.

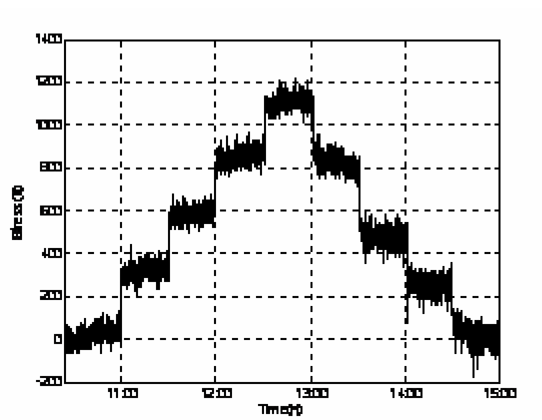

Figure 7: Tension measured by FBGs under the icing condition

V. CONCLUSION

A tension sensor based on Fiber Bragg Grating(FBG) is proposed. In order to verify the reliability of FBG Tension Sensor and Electronic Tension Sensor working in a harsh electromagnetic environment, a series of EMI experiments were carried out in our laboratory. The EMI experiments show that the FBG Tension Sensor is immune to Electromagnetic interference, while the other one is sensitive to that. The icing experiment shows the FBG Tension Sensor works normally in low temperature, high air humidity and icing condition.

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