Performance Analysis of by-pass Excitation Cable Force Sensor

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Abstract. The sleeve cable force sensor based on magnetoelastic effect has developed rapidly in recent years, and has been widely used in the field of bridge cable force measurement in China. Existing sleeve cable force sensor needs to be installed at the beginning of construction, so it is difficult to reinstall them later, and its long-term performance is also difficult to evaluate and measure online. To solve this problem, the tension measurement of the designed by-pass excitation cable force sensor is carried out, and the influence of signal line length and ambient temperature on the measurement results is analyzed. The results show that the designed by-pass excitation cable force sensor has high linearity, which is expected to solve the problem of the existing sleeve cable force sensor.

Keywords: cable force measurement, bypass excitation, magnetoelastic effect, cable force sensor

1. Introduction

With the continuous progress of bridge technology in China, cable technology is increasingly widely used in long-span bridges. Cable is the most important part of the whole structure as load-bearing components of various large-scale buildings and structures, and its stress condition plays an extremely important role in the overall structural safety [1, 2]. Because of long-term alternating stress, corrosion and wind-induced vibration environment, it is easy to cause local fatigue and damage of cables, which not only shortens the service life of cables, but also directly affects the internal force distribution and structural line type, endangering the safety of the whole structure. Real-time measurement of cable force is the main means to judge whether the bridge structure is safe or not. At present, many measurement methods have been developed, such as vibrating string type, optical fiber strain type, pressure gauge type, magnetic flux type, etc. [3-7]. Among them, the cable force sensor based on magnetic flux method is widely used in practical engineering because of its excellent sensing performance and long-term stability [8-10].

The existing magnetic flux cable force sensors are designed with sleeve type, which has simple structure, uniform magnetic field, good linearity and accurate measurement results. However, due to the sleeve design, it is necessary to be installed at the initial stage of bridge construction. Once completed, it is difficult to carry out subsequent disassembly and assembly. After long-term operation, the measurement accuracy of the sensor cannot be determined, and it is difficult to disassemble and calibrate. Therefore, a kind of high-precision cable force sensor is urgently needed, which is easy to
This kind of sensor can be used for completed bridges and to calibrate existing cable force sensors in situ. In this paper, a kind of by-pass excitation cable force sensor which is convenient for later disassembly and assembly is introduced. The tension calibration and measurement experiments are carried out, and some factors affecting the measurement accuracy are analyzed experimentally.

2. By-pass Excitation Cable Force Sensor

In this paper, experimental verification and performance analysis of the designed by-pass excitation cable force sensor are carried out. The by-pass excitation cable force sensor is mainly composed of bypass core, cover plate, excitation coil and measuring coil, and its structure design is shown in Figure 1. The bypass core and cover plate are processed with pure electrical iron to ensure good magnetic conductivity, and the system magnetic circuit is composed of the tested cable, the bypass core and cover plate. When the sensor is connected, it is necessary to ensure that the magnetic field generated by the four excitation coils is in the same direction when passing through the cable. The sensor is arranged on both sides of the cable in a symmetrical structure. Figure 2 shows the installation effect of the sensor.

3. Sensor performance test

In order to test the performance of the designed sensor, it needs to be connected to the main machine of magnetic flux cable force measurement, namely the magnetoelastic instrument (OVM PowerStress EM Sensor Measurement Unit). In the experiment, the tension of the cable is exerted by a tension
machine, and then measured by a magnetoelastic instrument. The experimental system is shown in Figure 3.

![Figure 3. Cable force measurement experimental system](image)

3.1 Tension measurement experiment

In the experiment, the induced integral voltage was measured five times under each tension, and the average value was taken. The measured data and calculated average value are shown in Table 1. The average value was linearly fitted and the results are shown in Figure 4. It can be seen from the chart that the fitting linearity of the tension and the induced integral voltage is 0.99854, which is close to the level of the existing sleeve magnetic flux sensor. Since the parameters of sleeve cable force sensor are used in the experiment, these parameters have not been optimized for the by-pass cable force sensor. After a large number of experiments and parameters optimization, the measurement sensitivity and accuracy of the by-pass cable force sensor may be further improved.

| Tension (KN) | Measured integral voltage (V) | Average integral voltage (V) |
|-------------|-------------------------------|------------------------------|
|             | First | Second | Third | Fourth | Fifth |                 |
| 4           | 66.1  | 66.1   | 66    | 66.1   | 66.2  | 66.1             |
| 32          | 70.6  | 70.6   | 70.5  | 70.5   | 70.6  | 70.56            |
| 61          | 75.6  | 75.5   | 75.2  | 75.4   | 75.4  | 75.42            |
| 90.5        | 80.1  | 79.8   | 80.1  | 79.9   | 80    | 79.98            |
| 121.1       | 85    | 84.8   | 84.3  | 84.5   | 84.5  | 84.62            |
| 150.3       | 88.6  | 88.3   | 88.9  | 88.4   | 88.5  | 88.54            |
| 179.8       | 93    | 93     | 93.1  | 92.5   | 92.4  | 92.8             |
3.2 Influence analysis of signal line length

In field measurement, multiple sensors often share a set of measuring instruments. There will be a long signal line between the measuring instrument and the sensor, which will adversely affect the signal transmission and the measurement results. In order to understand the influence of the length of signal line on the experimental results, the tension in signal lines of different lengths was measured at the standard tension of 120 KN. The measurement data and error analysis are shown in Table 2.

Table 2. Measurement results of tension in signal lines of different lengths

| Length of signal line (m) | Standard tension (KN) | Measured average tension (KN) | Difference value | Same level error | Comprehensive error |
|--------------------------|-----------------------|------------------------------|------------------|------------------|--------------------|
| 52                       | 120.81                | 116.67                       | -4.14            | -3.43%           | -2.30%             |
| 105                      | 120.67                | 113.50                       | -7.17            | -5.94%           | -3.98%             |
| 157                      | 120.54                | 115.07                       | -5.47            | -4.54%           | -3.04%             |
| 210                      | 124.30                | 115.40                       | -8.90            | -7.16%           | -4.94%             |

It can be seen from the experimental results that the length of the signal line does affect the measurement results. Therefore, different line lengths should be calibrated or compensated in practical application.

3.3 Influence analysis of temperature

The permeability of the material is a physical quantity that varies with temperature, and the temperature change will have a significant impact on the measurement results. In actual product development, sensor calibration experiments at different temperatures are needed. In the actual measurement, it can be used as a temperature compensation database to correct the cable force data at the actual temperature.

The bypass excitation sensor designed in this paper also needs large-scale temperature calibration experiments for product development. This paper mainly introduces the principle experiments and results of design performance, so only the permeability analysis at different temperatures is carried out.
In the experiment, the cable and the by-pass cable force sensor installed on it were placed in the oven. The oven temperature can be read directly. At the same time, a temperature sensor was placed on the cable force sensor to measure the temperature of the cable force sensor accessories.

Table 3. Measurement data of bypass excitation sensor at different temperatures

| Oven display temperature (°C) | Magnetoelastic temperature (°C) | Measured integral voltage (V) | Average integral voltage (V) | Permeability |
|-------------------------------|---------------------------------|------------------------------|-------------------------------|-------------|
| 12                            | 12                              | 89.40                        | 89.50                         | 89.47       | 1.437920    |
| 25                            | 23                              | 88.30                        | 88.30                         | 88.30       | 1.399981    |
| 31                            | 30                              | 87.40                        | 87.40                         | 87.40       | 1.370714    |
| 42                            | 42                              | 85.80                        | 85.80                         | 85.70       | 1.317600    |
| 50                            | 50                              | 84.10                        | 84.20                         | 84.17       | 1.265570    |

Figure 5. The relationship between permeability and temperature

Table 3 shows the experimental results of the bypass cable force sensor at different temperatures. Figure 5 shows the relationship between permeability and temperature. It can be seen from the above measurement results that the permeability decreases with the increase of temperature, which is in line with the theoretical expectation.

4. Conclusions

In this paper, a kind of by-pass excitation cable force sensor is introduced, and the measurement performance of the sensor is tested. The results show that the by-pass excitation cable force sensor has high linearity, which ensures high measurement accuracy, the ambient temperature and the length of signal line have an impact on the measurement results, which must be considered in practical applications. The by-pass excitation cable force sensor is convenient to install in the measurement site, which can solve the problem that sleeve cable force sensor cannot be installed subsequently, and it is expected to perform effective on-site calibration of the existing sleeve cable force sensor.

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