Principle of the steel cable tension measurement based on spatial magnetic field distributions

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Abstract

It is of great significance to measure the axial tension of a steel cable for its safe operation. The magnetic hysteresis loop of the cable can change with its axial tension, so the cable tension can be measured through acquiring magnetic parameters from its hysteresis loop. This is so-called measuring method based on magnetomechanical effect. We should note that a changing magnetic field must be excited to acquire magnetic parameters relevant with the tension in this method. Currently, the excitation magnetic field changing with time is usually adopted, which makes the measurement complex and time-consuming. So this paper puts forward a principle of the steel cable tension measurement based on spatial magnetic field distributions. The magnetic field changing in a special area along the axial direction is used to replace time-dependent magnetic field in the conventional testing method. Therefore, this measurement is relatively simple and fast.

Keywords: Steel cable tension, Magnetomechanical effect, Spatial magnetic field distribution

1. Introduction

Steel cables have been widely used in long-span prestressed structures like large span bridges, tourism cableways and so on, due to their outstanding advantages such as high strength, light weight. As one of the key bearing components, the steel cable plays an important role in maintaining the safe operation of the overall structure. However, because of the long-term high strength load, stress relaxation and stress losses may happen on the steel cable [1], the steel cable tension changes afterwards, which leads to the redistribution of stress in the overall structure, and may cause overload fracture in the weakness point, resulting in major accidents. For example, Kongqi River Bridge Located in Korla of Xinxiang Uyghur autonomous region of China collapsed On April 12, 2011; the Wuyi mountain villa bridge located in Wuyishan city of Fujian Province of China also collapsed On July 14, 2011, one person was killed and 22 injured in this accident. Especially, the 18 cables supporting the Martin Olav Sabo Bridge broke suddenly on February 20, 2012 after being conducted a major on-site review just six months ago [2]. These accidents are all due to the abrupt failure of the steel cable. So it is of great significance to research and develop the convenient and effective method for steel cable tension measurement to prevent overload fracture from occurring and ensure the safe operation of long-span prestressed structures.
2. The state of the art related to steel cable tension measurement

At present, there have been several methods for steel cable tension measurement. The existing methods can be divided into direct methods and indirect methods depending on the difference of the measurement principles [3]. Pressure gauges or pressure sensors are used to measure the steel cable tension in direct methods; this method is usually used to control the axial tension of a steel cable during its pretension process, not for in-service steel cables [4]. Some physical or mechanical parameters of steel cables can change with its axial tension. Then, the steel cable tension can be deduced by picking up these parameters, this is so called indirect methods, mainly including vibration methods, acousto-elastic methods and electromagnetic methods.

Vibration methods are currently the most widely used steel cable tension measurement methods for in-service steel cables. However, because of the inherent problem, the measurement results of this method are not accurate when the steel cable is short or shock absorbers are fixed on the steel cable [4]. In the acousto-elastic method, the change of sound velocity with the tension is picked up to measure the axial tension of the steel cable. However, the excitation and reception of the guided wave is difficult to realize in this method [5]. Electromagnetic methods are based on the change of the electromagnetic properties of the ferromagnetic material with the applied stress namely magnetomechanical effect first discovered by Vilari in 1865. B Kvasnica and P Fabo [6] firstly put forward the electromagnetic methods for measuring mechanical stress in low-carbon steel wires. As a non-contact measurement method, the measurement results of this method are not affected by the cable sag and boundary conditions [7]. Thus, this method has been widely concerned and becomes one of the focuses in this field. We should note that it is important to find out the appropriate magnetization working point which is directly relevant to the sensitivity and linearity of the measured feature parameter in this method. At present, a time-dependent magnetic field is always adopted to find out the appropriate magnetization working point. The structure sketch of common sensors in existing electromagnetic methods adopting time-dependent excitation magnetic field is shown in figure 1.

![Figure 1 The structure sketch of sensors in existing electromagnetic methods](image)

As shown in figure 1, an alternating current is applied to the outer primary coil to excite a time-dependent magnetic field in the steel cable, then, the inner secondary coil picks up the magnetic induction intensity changing with time to get the magnetic parameters relevant with the tension. When measuring the axial tension of the
in-service steel cable, a special sensor winding rig is needed to install the primary coil and the secondary coil [8], which makes the measurement complex and time-consuming. What’s more, the temperature variation of steel cables induced by the heating problem of the primary coil when applied with electricity for a long time has a bad effect on the measurement results [8]. Based on this, a principle of the steel cable tension measurement based on spatial magnetic field distributions is put forward in this paper. A spatial-varying magnetic field is used to replace the time-dependent magnetic field used in the existing electromagnetic methods. Permanent magnets are to be used to provide the spatial-varying magnetic field to eliminate the problems of complex installation and coil heating.

3. The Principle and verification experiment

3.1 Principle

The mechanical characteristics of steel cables are analyzed before describing the principle. The length of steel cables in practical application can reach dozens or even hundreds of meters. Thus, the stress distribution among a short length such as 2 meters along the axial direction of the cable can be assumed approximately identical according to the force analysis. Then, the measurement result of any measurement point distributed in the short length of the cable under the same conditions should be identical. Basing on this, a steel cable tension measurement method based on spatial magnetic field distributions is put forward. The principle of the steel cable tension measurement method based on spatial magnetic field distributions is shown in figure 2. Permanent magnets are adopted to provide a magnetic field changing from zero to the value being able to magnetize the cable to approximate saturation to the short length of the cable. Then, the characteristic quantities under different magnetic intensities namely different magnetization working points can be acquired by the magnetic field measurement device. Finally, the feature parameter, which has a good sensitivity and linearity at the appropriate magnetization working point, maybe obtained to measure the steel cable tension.

![Figure 2 The principle diagram of the steel cable tension measurement method based on spatial magnetic field distributions](image)

3.2 Verification experiment

To verify the validity of the steel cable tension measurement method based on spatial
magnetic field distributions, An experiment is conducted on a double-thread screw which is used to simulate and replace the steel cable in practical application. The layout diagram of the experiment is shown in figure 3. YJZ-500A axial-force meter is used to apply an axial load to the double-thread screw and monitor the change of the axial load. Two U-magnetizers are adopted to excite an appropriate spatial-varying magnetic field on the screw. Then, the normal magnetic induction intensity $B_y\alpha$ on the cylindrical surface of the screw is picked up by the SAF81-1908-10-T axial probe of the Bell8030 Gauss Meter.

![Figure 3 The layout diagram of the experiment measuring axial thrust of the screw based on magnetic field space distribution](image)

There are 28 measurement points distributing symmetrically about the U-magnetizers on the 2-meter screw. The distance between two points on each side is 55mm. The distribution of measurement points on the 2-meter screw is shown in figure 4. Thus, the normal magnetic induction intensities at different magnetization working points can be acquired. The experiment steps are as follows: Firstly, a spatial varying magnetic field provided by the two U-magnetizers is applied to the screw the initial axial force of which is zero; the normal magnetic induction intensities at the 28 measurement points $B_{y1\alpha} - B_{y28\alpha}$ are measured afterwards. Secondly, the axial force of the screw is increased at the step length of 30kN to 30kN, 60kN, 90kN and 120kN. The normal magnetic induction intensities at the 28 measurement points $B_{y1\alpha} - B_{y28\alpha}$ are measured at the end of every load step. Finally, the measurement data at every step are analyzed to find the appropriate feature parameter reflecting the change of the axial force of the screw.

![Figure 4 The distribution of measurement points on the 2-meter screw](image)

4. Experiment results and discussion

According to the symmetry of the layout of the experiment, the normal magnetic...
induction intensities of the 1~14 measurement points in the left hand of the U-magnetizers are analyzed here. The relationship between the normal magnetic induction intensity and the distance from measurement point 1 is shown in the figure 5(a) in the case of different axial force; the relationship between the normal magnetic induction intensity and the axial force is shown in the figure 5(b) at the different measurement points. As is shown in figure 10, the normal magnetic induction at 1~6 measurement points increases linearly with the increase of the axial force from 0kN~120kN; while the normal magnetic induction at 7~14 measurement points decreases linearly with the increase of the axial force from 0kN~120kN. The normal magnetic induction at the measurement point 14 changes most sensitively with the axial force. However, the linearity of the relationship between the normal magnetic induction intensity and the axial force at different measurement points cannot be acquired intuitively. Thus, the normal magnetic induction intensity at measurement points 12~14 which change sensitively with the axial force are selected to analyze the linearity of the relationship between them and the axial force.

Figure 5 (a) The relationship between the normal magnetic induction intensity and the distance from measurement point 1; (b) the relationship between the normal magnetic induction intensity and the axial force

The first-order linear fitting is used to fit the relationships between the normal magnetic induction intensity at measurement points 12~14 and the axial force. The relationship between the normal magnetic induction intensity at measurement points 12~14 and the axial force is respectively shown in figure 6(a), 6(b) and 6(c).
The relationship between the normal magnetic induction intensity at measurement points 12, 13, 14 and the axial force is shown in Figure 6. The variation of the normal magnetic induction intensity and the R-square of the fit at measurement points 12~14 are listed in Table 1.

<table>
<thead>
<tr>
<th>Measurement point</th>
<th>Variation/(Gs)</th>
<th>R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>54.6415</td>
<td>0.9894</td>
</tr>
<tr>
<td>13</td>
<td>79.299</td>
<td>0.9971</td>
</tr>
<tr>
<td>14</td>
<td>117.1815</td>
<td>0.9928</td>
</tr>
</tbody>
</table>

As is shown in Table 1, the variation of the normal magnetic induction intensity at the measurement point 14 is the largest, which means the normal magnetic induction at the measurement point 14 changes most sensitively with the axial force. While, the R-square of the fit at the measurement points 13 is the largest, which means the normal magnetic induction at the measurement point 13 changes most linearly with the axial force. However, the R-square of the fit at the measurement points 14 also reaches 0.9928, thus, the normal magnetic induction at the measurement point 14 can be chose as an appropriate feature parameter for measuring the axial force of the screw. The experiment results show that the method of the steel cable tension measurement based on spatial magnetic field distributions is feasible.

5. Conclusion

The existing methods for measuring the axial tension of steel cables are reviewed and analyzed in this paper. A new method of the steel cable tension measurement based on spatial magnetic field distributions is put forward aiming at overcoming the deficiencies of the existing methods. The principle of the new method is described in detail. An experiment is conducted on a double-thread screw which used to simulate and replace the steel cable in practical application to verify the validity of the new method. The operation of this measurement method is relatively simple and fast and can overcome the deficiencies of the existing electromagnetic method. The experiment results also show that the new method for the steel cable tension measurement is feasible.

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References


3. Soojin Cho; Jinsuk Yim, M.ASCE; Sung Woo Shin; Hyung-Jo Jung; Chung-Bang Yun, M.ASCE; and Ming L. Wang. Comparative Field Study of Cable Tension Measurement for a Cable-Stayed Bridge. J. Bridge Eng. 2013.18:748-757


