Experimental study on the sensitive parameters of non-destructive test method for the cable based on the leakage magnetic principle

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Abstract. The nondestructive testing (NDT) technique of steel rope based on the leakage magnetic principle has been extensively applied to the cable. In view of the difference of geometric characteristics, structures, loading between steel rope and cable, the applicability of the leakage magnetic NDT and the sensitive parameters on detection accuracy should be studied. So a cable specimen with local defects was designed and fabricated, and then the leakage magnetic testing technique was applied. The experimental electrical signal output of the cable were compared and analyzed. The results show that the accuracy of the test results is strictly related to the geometric characteristics of the test instrument, the depth of internal defects, the height of sensor removal, the sensitivity coefficient of the magnetically sensitive element, the defect spacing, etc., and the qualitative evaluation and individual quantitative index of the cable defects are proposed. The above conclusions can provide data support for the test quantitative index and the application of nondestructive testing technique.

1. Introduction
The cable is as the main component in the large-scale bridge, and it is formed by the high-strength wire or steel strand, the end anchors and external protective measures. It transmit the load on the bridge span to the upper structure and the bridge tower. Under the cooperation action of the environmental climatic conditions and external load, various disease in the cable are inevitably produced, such as the external protective layer cracking, anchor water seepage, cable rust, wire break, etc. [1]. With the growth of service time, the above diseases can cause the performance degradation of the material and component, which will affect the durability, safety and applicability of the bridge structure. Therefore, the rapid and accurate damage identification method can provide a reliable technology and data support for the reasonable assessment on technical status, safety, durability, detection and maintenance programs of the cable.

At present, the non-destructive testing technology (NDT) of the cable mainly include electric vortex effect method, electromagnetic method, magnetic method, ultrasonic method, acoustic detection method, ray method, etc., in which the NDT based on the leakage magnetic has been used to rust and breaking detection of the wire rope. For the leakage magnetic detection technology, researchers’ focus are on the electromagnetic sensor, signal processing, testing instrument, etc., so that the detection technology is tend to digitization, lightweight, automation, functional diversity, etc[2–4].
H.R. Weischedel developed a non-destructive test sensor of the wire rope based on the leakage magnetic principle, it can quantitatively detect the loss of the metal area of the wire rope, and qualitatively analyze the local defects [5]. E. Kalwa applied Hall component to detect leakage flux and main flux of the wire rope, and study on the relationship between the local defect and the detection signal of the wire rope[6,7]. With the optimization of the leak-magnetic sensor system, the detection sensitivity of the leak-magnetic detection technology can be greatly improved, which can accurately detect the small defect and determine the defect location of rope with the large diameter [8,9]. In China, the non-destructive testing technology for the wire rope researched lately. Through studying and importing the advanced NDT of the wire rope, domestic scholars achieved some research results in the excitation device, integrated Hall components, poly-magnetic technology, signal processing, etc. , which successfully applied to LMA and LF detection of the wire rope, and quantitative recognition method of the leaking magnetic signal are obtained [10-12].

The magnetic leakage detection technology has been gradually applied to the damage identification of the cable in large-scale bridge. However, most of the existing research results don’t take into account the difference between the cable and common wire rope, such as the length, diameter, thickness of protection tube, material property, deformation characteristics, structural characteristics, etc. Furthermore, the leakage magnetic field distribution is related to the geometry size, sensor distance, magnetization strength, structure characteristics, etc. Besides, the inversion defect of the leaking magnetic signal causes the inaccurate results. So the leakage magnetic detection technology applied directly to the defect detection of the cable-bridge needs further verification.

Considering the essential characteristics of the cable, a cable specimen with local defects was designed and fabricated, and then the NDT technique based on magnetic leakage was applied to the cable specimen. In which height and thickness of the defect, output sensitivity coefficients, sensor height, defects spacing are considered. By comparing the test results with the characteristics of actual defects, the correctness of the test results and the applicability of the detection technology are verified.

2. The theory of magnetic leakage detection technology
The main defects of wire rope are localized fault and loss of metallic-sectional area. The magnetoresistance increases at above local defects, and then to a certain extent, a detectable leakage magnetic field is formed in the surface of the wire rope. The NDT based on leakage magnetic principle applies the magnetic excitation device to magnet saturation along the wire rope’s axis, and the magnetic sensitive elements can detect the leakage magnetic field at the local defect. The detection signal is processed according to the relationship between the electrical signal and magnetic signal, which is to obtain the damage situation of the wire rope. The leakage magnetic detection principle is shown in Figure 1. It can be seen that the size and shape of the leakage magnetic field at the defect depends on the strength of the magnetic excitation, the size and shape of the defect.

On the basis of vacuum magnetic conductivity, the relative magnetic conductivity of ferromagnetic substances can reach hundreds to thousands. When the external strong magnetic field is exerted to ferromagnetic components, the high density magnetic line overflows at the defect location, and it passed to the magnetic medium. In the interface of magnetic medium, the leaking magnetic field is formed. The leakage magnetic distribution at the defect location is shown in Figure 2. Where Bx is the horizontal component of flux density, and it parallel to the magnetization direction; By is the vertical component of flux density, and it is perpendicular to the magnetization direction. Bx is the maximization in the center of the defect, and its curve presents as bell shape; By is the maximization on both sides of the defect, a curve is as bipolar shape crossing the over-center point. The synthesis of horizontal and vertical components forms the distribution of the leakage magnetic field at the defect.
The test was conducted using the leakage magnetic detection equipment of LRM-XXI Diagnostic System No. 53 with the Hall component. Hall element produces the Hall Effect, that is, the charged particles move in the magnetic field under Lorenz force, its motion trajectory is deflected, and then the electric potential is produced in the direction perpendicular to the motion trajectory. It can sensed the space magnetic field at static situation, and converts the magnetic field signal linearly into a voltage signal, as shown in the Hall potential expression (Equation 1).

\[ U_H = K_H IB \]  

Where \( K_H \) is the sensitivity coefficient of Hall element; \( I \) denotes electricity; \( B \) represents the magnetic strength, and it is affected by the length, width, depth of the defects, removal distance of the Hall component.

3. The cable non-destructive testing scheme

The cable specimen is formed with 1 x 7 (seven wires) steel strands (equivalent diameter of 15.2mm). It is made with four layers steel strands of 18, 12, 6, 1 root respectively from the outside to the inside of the cross section as shown in Figure 3. The diameter of the cable is 106.4mm, and the effective length is 12m; the cable is covered with PVC cube; the thickness and diameter of PVC tube is about 5mm and 140mm respectively. The cable specimen is shown in Figure 4. In this testing, the parameters such as depth and height of the defect, defect spacing, the removal height of the sensor and the output sensitivity coefficient were considered. The test case is presents as Table 1.
respectively. The defects arrangement program is shown in Figure 3 and Figure 5. In which ①②③ denotes the sample wire with the diameter of 4mm, 5mm, 6mm. The length of the sample wire is 0.5m. The sample wires spacing is 0.8m and 1.5m along the cable.

The middle steel strand
First layer (surface) Second layer Third layer
1m 1.5m 2m 1.5m 1m

15m 12m 1m
(a) wires spacing of 0.8m

The middle steel strand
First layer Third layer Second layer
① or ① or
① ① ① ①
①
Middle of the cable
①

(b) wires spacing of 1.5m

Figure 5 Sample wires arrangement along the cable

| Case number | Defect thickness (mm) | Defect height (mm) | Layer of defect arrangement | Defect spacing (m) | Output sensitive coefficient (mv/div²) |
|-------------|-----------------------|--------------------|----------------------------|-------------------|---------------------------------------|
| 1           | 4 5 6                 | 15.2               | 2                          | 0.8               | 10                                    |
| 2           | 4 5 6                 | 30.4               | 3                          | 0.8               | 25                                    |
| 3           | 4 5 6                 | 15.2               | 2                          | 0.8               | 10                                    |
| 4           | 4 0 0                 | 0                  | 1                          | 1.5               | 25                                    |
| 5           | 4 5 6                 | 15.2               | 2                          | 1.5               | 10                                    |
| 6           | 0 5 0                 | 0                  | 1                          | 1.5               | 25                                    |
| 7           | 4 5 6                 | 15.2               | 2                          | 1.5               | 10                                    |
| 8           | 0 0 6                 | 0                  | 1                          | 1.5               | 25                                    |

4. Experimental results analysis
The leakage magnetic testing equipment with diameter of 160mm and 200mm were used to the cable specimen. Firstly, the test cable is fully magnetized by the magnetization of three cycles, and then the more accurate output was extracted and analyzed.
4.1. Removal height of sensor

The non-destructive testing equipment with diameter of 200mm and 160mm were used respectively, and the test results were shown in Figure 6(a), 6(b). Combined with the defect arrangement scheme, the test results in Figure 6 show that (1) when the testing equipment starts, stops and jumps, the test electrical signal is disturbed, and it will affect the volatility of the defect at adjacent location; (2) according to the distribution type of the defect, the arranged defects were detected in the tested electrical signal curves. Furthermore, the electrical signal at defects position is more obviously with the increase of diameter and reduction of the height of the sample wire. (3) When the removal distance of the sensor is reduced, the electrical signal is more significantly for the non-destructive testing equipment with diameter of 160mm. (4) the leakage magnetic signal of the cable with steel strands is readily affected by factors such as the wave signal, the uneven surface of the steel strand, the vibration of the steel strand, etc., which can result in the uncertainty of the test signal, especially for small defect.

It can be seen that, when the leakage magnetic detection equipment is closed to the cable, that is, the removal distance of the sensor is reduced, and then the electrical signal is detected clearly for the defect with the area less than 1% of the cross-section area of the cable, and it is more obviously with the depth increase and the distance reduction of the defects.

![Comparison of testing result under different removal height of sensor](image)

(a) Testing equipment with the diameter of 200mm

(b) Testing equipment with the diameter of 160mm

Figure 6 Comparison of testing result under different removal height of sensor
4.2 The output sensitivity coefficient
Under output sensitive parameters of 10mv/div, 25 mv/div, the compared electrical signal result is shown in Figure 7 (a), 7 (b). Combined with the defect arrangement scheme, the results in Figure 7 show that (1) When the leakage magnetic testing equipment with the diameter of 200mm is used to the cable specimen and the removal distance of magnetic sensor is higher, the tested electrical signal is affected by the output sensitive parameters. In which the electrical signal is stronger for the magnetic sensitive parameter of 10mv/div; (2) When the leakage magnetic testing equipment with the diameter of 160mm is used and the removal distance of magnetic sensor is less, the tested electrical signal is basically consistent under the different output sensitive parameters. It can be seen that the reasonable size of non-destructive testing equipment and signal output sensitive parameters can improve the detection accuracy of defects in the cable.

4.3 Defect spacing
For the cable with defect (sample wire) spacing of 0.8m and 1.5m respectively, the corresponding test results are compared as shown in Figure 8(a), 8(b). Combined with the defect arrangement scheme, the results in Figure 8 show that (1) the leakage magnetic detection equipment can determine the defect location of the cable with defect spacing of 0.8m and 1.5m. At the ends and joints of the cable, and the situations for the distance from defect to the above position and the defect spacing less than the length of testing equipment, the test electrical signal is disturbed easily, so the test results may be inaccurate. Therefore, the leakage magnetic testing technology is applied to the actual cable, the type of test
equipment, output sensitivity coefficient and signal analysis method should be reasonably selected.

![Diagram](image)

(a) output sensitive coefficient of 10mv/div

(b) output sensitive coefficient of 25mv/div

Figure 8 Comparison of testing result under different defect spacing

5. Conclusions
A cable specimen with local defects was designed and fabricated, and then the NDT technique based on the leakage magnetic principle was applied to the cable specimen. By comparing and analyzing the test results and the characteristics of actual defects, the conclusions are obtained as follows.

(1) the leakage magnetic testing equipment with diameter of 160mm and 200mm is used to the cable specimen, the removal distance of magnetic sensor to the arranged defect in the cable is in the range of 0 to D (D is the diameter of detection instrument). When the cable is closed to and in the center of the detection instrument, the electrical signal is detected accurately for the defect with the area less than 1.0% of the cross-section area of the cable, and it is more obviously with the depth increase and the height reduction of the defects.

(2) In view of the effect of the removal height of internal sensor, the defect height and the geometry size of the detection instrument, the fluctuation of the electrical signal at the defect location is affected by the output sensitivity coefficient variety, especially for the leakage magnetic detection instrument with larger diameter than the cable (greater than 20mm).

(3) At the ends and joints of the cable and in the situations for the distance from the defect to the above position and the defect spacing less than the length of testing equipment, the electrical signal of the defect is disturbed, so it may be inaccurate.
In summary, the non-destructive testing equipment based on the leakage magnetic principle can be applied to detect the internal local defects of the cable. The detection results’ accuracy is strictly related to the geometry size characteristics of the detection instrument, internal defect depth, lifting height of the sensor, magnetically sensitivity coefficient, defect spacing, etc. Therefore, the non-destructive magnetic leakage testing technology is applied to the actual cable, the type of test equipment, output sensitivity coefficient, signal analysis method should be reasonably selected.

In this test, the factors such as the actual cable’s characteristics, forming process, the external protection device, the joint treatment, the internal corrosion, abrasion, wire broken weren’t considered, and then small amount of the qualitative evaluation index is given. Therefore, a large number of measured data of the factual cable should be accumulated, it is to provide technical and data support for the reasonable application of the NDT based on magnetic leakage.

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