A Methodology for Identifying Defects in Wire Rope Based on Permanent Magnet Excitation

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Abstract: A wire rope defects detection method based on permanent magnet excitation is proposed. A detection system, mainly composed of permanent magnet excitation, distance detection, multi-sensor magnetic flux leakage signal acquisition and data analysis device, is set up. According to the different characteristics of the multi-sensor magnetic flux leakage signal, the localized fault (LF) and loss of metallic cross-sectional area (LMA) signal is separated, and then the two defects can be detected. The experiments show that the method can effectively detect the two defects when they appear simultaneously on the wire rope.

Key words: wire rope; defect; cross-sectional area loss

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0 Introduction

As an important load-bearing part, wire rope is widely used in industrial production, scientific research and other fields. However, a fracture on a wire rope will cause a great threat to human life and property safety, especially for elevators, bridges, ropeways and liftings. Therefore, it is particularly important to detect conditions of wire ropes.

In general, wire rope defects are mainly divided into two kinds: One is localized fault (LF), and the other is loss of metallic cross-sectional area (LMA). Numerous methods have been developed to detect them, such as ultrasonic method[1], vibration method[2], eddy current method[3-5], and acoustic emission test method[6-7], etc. Among them, the electromagnetic technique is the most widely used one.

Mccann et al. invented the earliest instrument for nondestructive testing of wire rope based on AC excitation, but it was not suitable for practical industry because of its low detection efficiency and huge volume[8]. Weischedel proposed a practical separation coil and introduced the integral circuit to improve the detection performance[9-10]. Kalwa et al. used the permanent magnet excitation and the hall element to detect the main magnetic flux and magnetic flux leakage signals change, and found the quantitative relationship between some defects and the signals[11-12]. Jomdecha et al. designed a modified electromagnetic main-flux equipment for wire rope inspection[13]. In China, the first wire rope detector was developed in the 1970′s. Yang et al. studied the quantitative detection of broken wire defects in wire ropes by using permanent magnet and hall effect sensor[14-15]. Tan et al. improved incentive device design and signal detection method based on broken wires leakage magnetic field[16]. Zhang et al. designed a magnetic flux leakage detection equipment with a hall sensor array to detect the wire rope defects[17]. Han adopted the leakage magnetic field method to carry out the fault detection of wire rope, and analyzed different numbers and types of broken wires[18]. Wu used leakage magnetic flux to detect the LF defect, and used the main magnetic flux to conduct the LMA

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defect of steel wire rope[19]. Zhang et al. designed a giant magneto-resistance sensor array collection system to collect the remanence signal to acquire two-dimensional magnetic flux leakage data on the surface of wire ropes, and detected defects in various types of wire rope[20-21]. Liu et al. developed the tunnel magnetoresistive systems to form a circular magnetic flux leakage sensor for the detection of flaws in hoist and slight wire ropes[22-23].

In a nutshell, some methods have been developed to detect the two typical defects of wire ropes, but most of them can only detect one defect, and there is still no effective method to simultaneously measure LF and LMA defects. Therefore, we designed a wire rope defect detecting system to simultaneously detect the two defects based on permanent magnet excitation, multi-sensor data acquisition, and computer data analysis technology.

1 System Architecture

The testing principle is shown in Fig. 1. When uniform magnetic field pass through the wire rope, the local magnetic permeability will decline because of the defect, and the internal conduction magnetic field will leak to the external space. The magneto-dependent sensor can be used to test the magnetic flux leakage signal, and the defect can be detected.

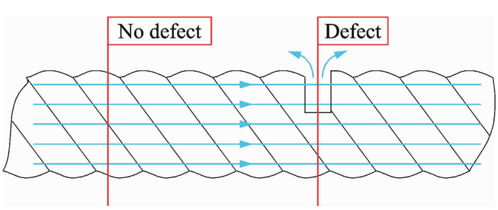

Fig. 1 Principle of magnetic flux leakage detection

Based on the testing principle, the wire rope defect detection system was built. It was mainly composed of a permanent magnet excitation sensing module, a distance detection module, a signal sampling and preprocessing module, a wireless data transmission module and a personal computer(PC). The schematic diagram of detection system is shown in Fig. 2. Axial uniform magnetization was realized by using permanent magnet excitation device. The magnetic sensor elements embedded in the excitation device could get the magnetic flux leakage signal of defect, and transmit it to the signal sampling and preprocessing module. Then, the processed signal would be transmitted to a computer by the wireless data transmission module. And the assessment and analysis of the defects could be achieved by the computer. Some of the key parts of the detection system are described as follows.

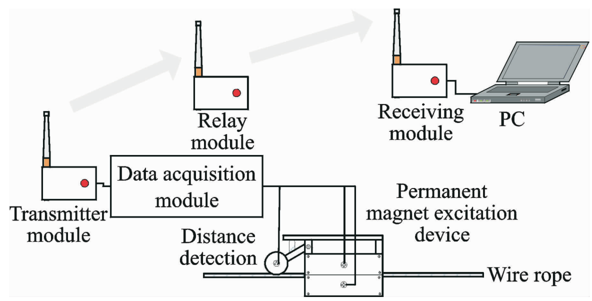

Fig. 2 Schematic of wire rope defect detection system

(1) Permanent magnet excitation device

The design of permanent magnetization device must meet two conditions. First, it is able to meet the requirements of the saturation magnetization, closer to it or exceed it. Second, it is able to ensure a long steady magnetization distance to arrange the sensor. Compared with DC excitation and AC excitation, permanent magnet excitation has a less interference factor. Therefore, we shortened the distance between the N and the S poles to increase rope magnetization. Fig. 3 shows the internal structure of permanent magnet excitation sensing probe.

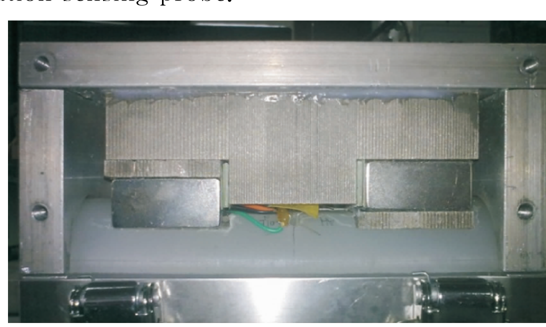

Fig. 3 Permanent magnet excitation sensing probe

In the probe, Ndfeb rare-earth permanent magnet was chosen as the excitation source, and several excitation devices were arranged symmetrically along the wire rope to uniformly magnetize the wire rope. Armature, which is made of soft magnetic materials with high magnetic permeability and low coercive force, were used to guide the magnetic field to avoid the magnetic flux leaking to the space outside of the main magnetic flux path. Some embedded magnetic sensor elements (Hall sensor A1302) were arranged uniformly to measure the magnetic flux leakage signal in the axial direction.

(2) Data acquisition and distance detection module

The detection system needs to establish the correspondence between the multi-channel magnetic flux leakage signals and the distance information. Distance detection was realized by using the incremental photoelectric encoder. The probe moved along the wire rope to promote the encoder rotating, and the distance information was converted to electrical pulses. Then, the relative motion distance between the probe and the rope could be calculated by counting the number of pulses. The selection of the encoder mainly depended on the output waveform, encoder specifications and the number of lines.

For the sake of practical industries, high-speed high-precision multi-channel data acquisition is needed. Low acquisition speed will affect the number of collected points per unit time, and fast movement of the probe relative to wire rope can not guarantee that the necessary number of points is acquired on a particular length, which will limit the speed of detection. Therefore, spatial domain sampling was employed in our system. Besides, due to the existence of the bottom wave signal and the static output of the Hall element, signals of wire rope defects were extremely weak. The multi-channel data collection was used to obtain rope leakage magnetic information of different radial orientations. Signal of one sample point on the axial rope can be analyzed by arranging several sensors to collect several different points in the radial direction at the same time. Based on the above mentioned, we chose A/D conversion chip MAX186 with the sampling rate of 133 kHz and conversion resolution 12 bit.

Multi-channel magnetic flux leakage signal acquisition and distance detection circuit could be realized based on MCU STC89C52. The specific working process is described as follows. Firstly, relative moving of the probe and wire rope drove photoelectric encoder rotating, and a string of pulse signal would be output. Secondly, MCU counted the number of pulses through external interruption. When the count reached a certain threshold, the MCU would command multi-channel A/D to collect data; and the MCU could preprocess signals of the broken wire and the cross-sectional area loss defects, respectively. The preprocessing results would be sent to the upper computer by serial port for further processing, waveform displaying, and broken wires and cross-sectional area loss calculation etc.

(3) Wireless data transmission module

In order to transmit data easily, wireless data transmission network based on Zigbee technology was used in the wire rope defects detection system. It consisted of the transmitting node, the receiving node and some relay nodes. Each node used the same hardware, but can get different functions by changing the software setting. The transmitting node could process the detected data, and transfered to the receiving node by multiple-hop relay way. Finally, the data would be transmitted to computer through serial ports.

In our system, the wireless data transmission module was set up based on CC2430/CC2431 on-chip system. When using 2.4 GHz wireless sending and receiving antenna, the transmission distance would not be less than 70 m, and data transfer rate would not be less than 100 kbps. And the obstruction could be avoided by increasing the relay nodes.

2 Assessment of Cross-Sectional Area Loss

Wire rope cross-sectional area damage signals refer to effective metal cross-sectional area of wire rope decreasing slowly in a long range of axial direction, mainly including worn, corrosion, rope diameter shrinking, which eventually leads to the decline of carrying capacity of wire ropes. Rope cross-sectional area loss assessment is generally based on the detection of main magnetic flux, namely, by measuring the change of main flux to indirectly detect the change of cross-sectional area of the rope. The above-mentioned permanent magnet excitation magnetic flux leakage detection system can detect LF defect, characterized by broken wire, and LMA defect, represented as abrasion. Therefore, accurate identification and elimination of broken wire signal will improve the detection and evaluation of the cross-sectional area loss.

(1) Assessment of LF defect

The experiments were carried out by preparing homemade standard specimens of wire rope with broken wire defects. We produced different defects in every other strand wave of wire rope location to imitate the characteristics of the centralized broken wire on the surface of a single point. Fig. 4 gives the schematic diagram of the specimen.

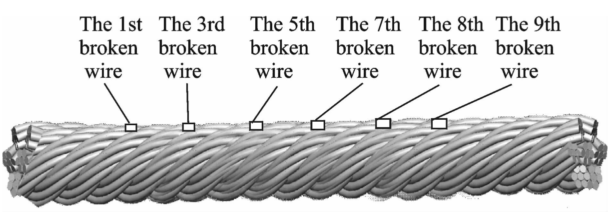

Fig. 4 Schematic of specimen

Using the wire rope defect detection system described above, we could obtain the wire rope magnetic flux leakage signal as shown in Fig. 5. It should to be noted that the signal in the figure is not the original signals that come from four Hall sensors, but the processed signal through data synthesis and A/D conversion, so it does not contain specific unit. The main features of the signal are: ① Peak-to-peak signal. It is an abnormal signal amplitude of the absolute difference value of between peak and valley, mainly involves the maximum value and the minimum value of the signal. And then the difference of the adjacent pair of extreme value can be obtained. ② Signal wave width. It is the distance between two points beside peak whose waveform value is down to a certain percentage of the peak value. The percentage is 50% in our system. The reason is that the magnetic flux leakage signal is not symmetric when rope is radially distributed evenly. As to the parts of over 50%, the front edge and the after edge of signal will be parallel approximately, which will hinder the elimination of broken wire signal.

Compared Fig. 4 with Fig. 5, we can find that there is a one-to-one relationship between the magnetic flux leakage signal and LF defect. Therefore, the LF defect can be detected according to the magnetic flux leakage signal, and the amount of broken wires can also be evaluated by using the features of the signal.

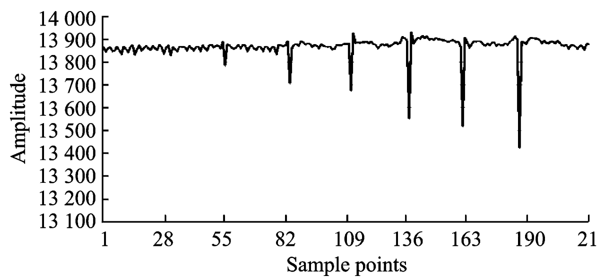

Fig. 5 Magnetic flux leakage signal of broken wires

(2) Assessment of the LMA defect

Abrasion detection was analyzed by using digital processing method. First, the magnetic flux leakage signal could be detected by using the wire rope defect detection system. And the signal consisted of two kinds of signals: LF local defect and LMA defect. Second, the magnetic flux leakage signal caused by LF defect should be eliminated, that is, some sudden change of waveform would be processed. Then, the processed waveform needed to be repaired according to the magnetic leakage signal reference level. Finally, the LMA defect could be evaluated by analyzing the reconstructed signal.

The specimen was homemade, too. First, an abrasion area was made on the wire rope. Then, some broken wires were produced on the abrasion area. Fig. 6 is the corresponding magnetic flux leakage signals. Considering the characteristics of

LF defect and LMA defect, it can be clearly seen that the abrasion exists from 130 points to 210 points, and there are three obvious breaks at the abrasion area, which are caused by the broken wires. Also the amplitude of signal increases after 210 points. These may be caused by the vibration of the wire rope. In the detection, the vibration of the wire rope will cause the change of the relative position between the probe and the rope, and the leakage magnetic signal will become bigger accordingly. Certainly, the specific reasons need to be analyzed in the future.

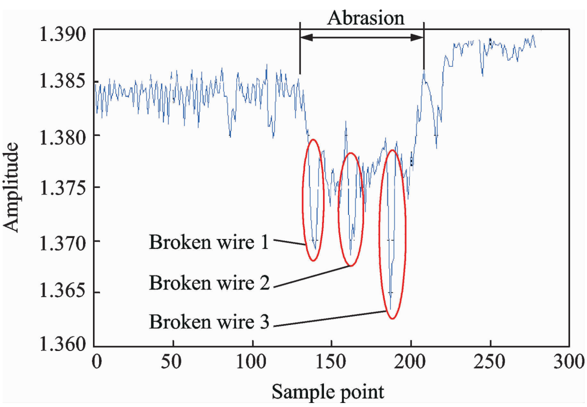

Fig. 6 Magnetic flux leakage signals of broken wires and abrasion

Further data processing is described as follows. First, LF signal was removed from the detected signal. Second, the mean of the maximum and the minimum before the LF defect, as well as the mean of the maximum and the minimum after the LF defect were calculted. The two means were connected to compensate the removed LF signal. Then, base value was subtracted from the compensation signal, which was then filtered by a low-pass filter. Fig. 7 shows the filtered signal by using a 32nd order FIR filter with window function Kaiser. We can see that LF and LMA defects

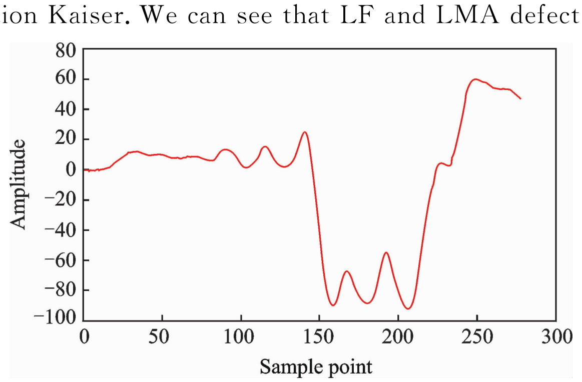

Fig. 7 The filtered magnetic flux leakage signals

have different forms of defect magnetic flux leakage signals. Based on these signals, the two defects can be assessed separately by using the above mentioned method.

3 Conclusions

A wire rope defects detection system was built to realize the detection of LF and LMA defects. The system was mainly composed of a permanent magnet excitation sensing module, a distance detection module, a signal sampling and preprocessing module, a wireless data transmission module and a PC. By analyzing different characteristics of the multi-sensor magnetic flux leakage signal, LF and LMA signals were separated. A 4 * 31SW+FC steel wire rope experiments showed that the system could effectively detect the two defects. The method is useful to evaluate LF and LMA defects, respectively, when the two defects simultaneously appear in wire ropes.

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