Signals Analysis of Fluxgate Array for Wire Rope Defaults

Gu Wei, Chu Jianxin
Institute of Electrical Automation, Shanghai Maritime University, Shanghai 200135, China
E-mail: puppygu@sh163.net
E-mail: jxzhu@msc.shmtu.edu.cn

Abstract. In order to detecting the magnetic leakage fields of the wire rope defaults, a transducer made up of the fluxgate array is designed, and a series of the characteristic values of wire rope defaults signals are defined. By processing the characteristic signals, the LF or LMA of wire rope are distinguished, and the default extent is estimated. The experiment results of the new method for detecting the wire rope faults are introduced.

1. Introduction
It is generally adopted the magnetic leakage testing method for wire rope faults in NDT at present. The signals process is quite complex because of the complexity in wire rope default status [1][2][3].

The paper presents a new method for the process of the magnetic leakage signals from wire rope fault. The main principles of the new method are: a transducer of fluxgate array is developed to detect the wire rope in all directions, and a group of characteristic value based on the three dimension distribution of the flaw signals are founded.

2. A transducer made up of the fluxgate array
In the magnetic leakage testing; the wire is saturatively magnetized by outer DC magnetic fields in the axial direction and a leakage field will be produced at the surface of the wire rope. Because of the difference between defective place and non-defective place in permeability, the correlative information of wire rope fault can be attained, when magnetic sensor is used to test the density and the distribution of magnetic leakage of the wire rope.

We developed a single-winding and single-core fluxgate as the magnetic sensing unit, and designed a new type of non-destructive testing transducer made up of the fluxgate array, shown in Fig.1. The transducer is composed of two half nylon cylinders, and a group of six fluxgate units are putted along the inner wall of cylinder in the same round angle. When the magnetized wire rope passed through the internal hole of the cylinder along the oriented ring, it resulted in the relative movement between the wire rope and the magnetic sensing unit, and the information of magnetic leakage can be obtained [4][5].

After the filtering pretreatment of the testing signals of the fluxgate array, the flaw signals of wire rope are produced. The signals are a group of six component signals and three dimension signals.
3. The characteristic values of magnetic leakage signals of wire rope faults

For the sake of quantitative analysis, we develop a plane-columnar coordinate system: $\rho$ — radial vector of rope; $\phi$ — circle vector of rope; $z$ — longitudinal vector of rope, as shown in Fig.1.

![Fig.1 The testing transducer made up of the fluxgate array](image)

Because the direction of $\rho$ is the testing direction of the magnetic sensor, the scalar of $\rho$ can reflect the amplitude of fault signal. Because the direction of $\phi$ is the circle distributed direction of the magnetic sensor, the scalar of $\phi$ can reflect the circle direction width of the flaw signal distribution. Because the direction of $z$ is the length direction of wire rope, the scalar of $z$ can reflect the longitudinal direction breadth of the flaw signal distribution.

Extending the plane-columnar coordinate system along the direction of $\phi$, the six-channel signal waveform can be obtained, shown in Fig.2. In the graph, the corresponding round angle location of 1#, 2#, …, 6# fluxgate unit is 0, 60, …, 300 degree respectively.

![Fig.2 The signal waveform of six-channel of the fluxgate array](image)

It is different that the shape of the flaw signal in each channel of the fluxgate array, shown in the Fig.2, which reflect the fault status in a certain longitudinal section and neighborhood of the tested wire rope separately. In order to show the integral status of the wire rope fault—the distributing status in three-dimension space, we should find one way by which all the changes of signals in six-channel can be considered, so the following three comprehensive characteristic values were set up:
3.1. Signal average magnitude

\[
\overline{\rho} = \frac{1}{N} \sum_{i=1}^{N} \rho_i = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{1}{M} \sum_{j=1}^{M} \rho_{i,j} \right)
\]

where \( N \) presents the number of testing channel, and the \( N = 6 \) for the transducer shown in the Fig.1; \( M \) presents the sampling times of the flaw signal in the given region, and let \( M = 3 \), more smooth waveform can be obtained; \( \rho_i = \frac{1}{M} \sum_{j=1}^{M} \rho_{i,j} \) presents the average magnitude of the \( i \)th channel flaw signal along the \( z \) axis direction, and \( \rho_{i,j} \) is the \( j \)th sampling value in the \( i \)th channel flaw signals; \( \overline{\rho} \) presents the distribution of the N-channels flaw signals along the rope circle direction, which reflects the comprehensive strength of the wire rope flaw signal in a certain cross section, including neighbor cross section.

3.2. Signal average width

\[
z = \frac{1}{N} \sum_{i=1}^{N} z_i
\]

Where \( z_i \) presents the flaw signal width of \( i \)th channel; The \( z \) presents the distribution of N-channels flaw signals along the wire rope axis direction, which reflects the comprehensive span of the flaw signal in a certain segment of wire rope.

3.3. Signal variance in circle direction

\[
\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} \left( \rho_i - \overline{\rho} \right)^2
\]

Where \( \sigma^2 \) presents the different status of each flaw signal channel in circle direction, which reflects the concentrating or scattering extension of the wire rope fault in a certain cross section.

4. The fundament of discernment for wire rope flaw signals

In order to test the wire rope default, the first thing is to distinguish the defect type qualitatively. According to the status of wire rope faults, it can be classified into two categories:

a) localized fault, LF in short, mainly includes broken silk, point corrosion, etc. faults in local region. It has larger value of \( \sigma \), smaller value of \( z \) in characteristic values, the flaw region shown in \([z_1, z_2]\) of the Fig.2.

b) loss of metallic area, LMA in short, mainly includes wearing, lamellar corrosion, drawing transformation etc. defects to make the cross section decreased. It has larger value of \( z \), smaller value of \( \sigma \) in characteristic values, the defect region shown in \([z_3, z_4]\) of the Fig.2.

The second procedure is to judge the extent of fault quantitatively, such as the number of broken silks in LF and the percentage of cross section loss in LMA. The characteristic values \( \overline{\rho} \) and \( z \) are the judging reference.
5. Experiment Results

By an interface circuit connecting the transducer of the fluxgate array shown in the Fig.1 with the micro-computer instrument system, a device for wire rope fault diagnosis will be built up. The software of the fuzzy discernment for the signals process is running in the device\(^\text{[6][7]}\).

Adapting the device to detect 100 times repeatedly on the \(24\text{mm}^2, 6 \times 37 + FC\) type wire rope, the experiment results are shown in the table 3.

| No. | Fault type | Fault extent | The times of non-error detecting | The times of one-silk error in LF, 3% cross section loss error in LMA |
|-----|------------|--------------|----------------------------------|---------------------------------------------------------------|
| 1   | LF         | 1 silk       | 72                               | 98                                                            |
| 2   | LF         | 2 silks      | 77                               | 86                                                            |
| 3   | LF         | 2 silks      | 78                               | 88                                                            |
| 4   | LF         | 7 silks      | 74                               | 82                                                            |
| 5   | LF         | 4 silks      | 74                               | 87                                                            |
| 6   | LMA        | 6% cross section | 67                               | 81                                                            |
| 7   | LMA        | 14% cross section | 64                               | 77                                                            |

From the table 3, it can be seen that the average non-error detecting rate of the LF is 75%, and detecting rate of the average one-silk error is 88.2%. As for the LMA defect, the average non-error detecting rate is 65.5%, and the average 3% cross section loss error detecting rate is 79%. Correspondingly, the detecting accuracy of the LF is a little higher than that of the LMA.

The transducer made up of the fluxgate array and characteristic values analysis is a new method for detecting wire rope default. The location of the fluxgate array, the extraction of characteristic values, and the determination of basic strategy for signal processing, all are needed to be improved in the experiment and the theory.

References

[1] H. R. Weischedel and R. P. Ramsey: Electromagnetic Testing—A Real Method for the Inspection of Wire Ropes in Service, *NDT international*, Vol.22, No.3, 1989, 151-161
[2] Yang Shuzi, Kang Yihua: Quantitative Inspection for Broken Wires of Wire Ropes Principle and Technique, *National defense industrial press*, 1995
[3] Chu jianxin, Gu Wei: Testing the Field of Wire Defects with Fluxgate Sensors, *Chinese journal of scientific instrument*, Vol.18, No.4, 1997, 437-440
[4] Gu Wei, Chu Jianxin: The Principle and Application of a New Technique for Detecting Wire Rope Defects, *Proceedings of the IEEE ICIT’96*, IEEE Inc. Dec, 1996, 445-449
[5] Gu Wei, Chu Jianxin, A Transducer Made up of Fluxgate Sensors for Testing Wire Rope Defects. *IEEE transactions on IM*, Vol.51, No.1, 2002, 120-124.
[6] Chu Jianxin, Gu Wei. Study on the Quantitative Inspection of Wire Rope Faults Based on the Fuzzy Recognition, *Chinese journal of scientific instrument*, Vol.20, No.6, 1999, 556-559
[7] Gu Wei, Chu Jianxin, Characteristic Values Analysis and Fuzzy Discernment for the Fault Status of the Wire Rope, *Chinese journal of mechanical engineering*, Vol.38, No.5, 2002, 122-125