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Improve the signal to noise ratio and installation convenience of the inductive coil for wire rope nondestructive testing

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ABSTRACT

Inductive coil is used as the nondestructive testing sensor of a wire rope or a pipe, because of its low cost and high durability. However, the winding structure is complex and difficult to design during the field test. Hundreds or even thousands of turns are needed to improve the signal to noise ratio (SNR) and the data processing is cumbersome. In this paper, based on the theoretical analysis and 3D transient magnetic field simulation, a kind of iron core is presented as coil winding skeleton for the wire rope nondestructive testing. Additional iron core plays a role of magnetism concentration, where the magnetic flux leakage (MFL) path is changed and the MFL of the defect is converged to the core. Therefore, the SNR of the coil which is wound on the iron core is improved, and the coil winding skeleton is simplified with the iron core structure optimization. Meanwhile, the influence of the coil cross-section area on the test result analysis is eliminated, and the influence of the lift-off distance between coil and wire rope on the detection result is also reduced. Finally, it is proved by experiment that the SNR of coil with the iron core proposed in this paper is increased almost six times, which makes it easier for defect analysis.

1. Introduction

Main methods for wire rope nondestructive testing include eddy current testing, acoustic testing, radiographic testing, magnetostrictive testing, optical testing and electromagnetic testing. The eddy current testing device is simple and lightweight with high detection resolution [1], but it is not sensitive to the internal defects. The sensitivity of acoustic testing is relatively high, which can propagate a long distance, but easy to be affected by the detection environment [2]. The radiographic testing has high accuracy and the results are intuitive [3,4], while it has a heavy weight, a high maintenance cost and a certain degree of radiation hazards to the human body. The magnetostrictive testing has the advantage of single point excitation and detection, sensor without relative movement with the detection object, but the detection distance, SNR of echo signal and defects resolution are limited and influenced by the factors of attenuation rate and multiple mode of guide wave [5,6]. The optical testing results are intuitive, but can not detect internal defects [7]. In addition, the oil and mud stains on the wire rope surface have a great impact on the test result. Wire rope is a ferromagnetic component, with the application of electromagnetic excitation, the electromagnetic characteristics of the defects are different from the intact wire rope, where magnetic sensors can be used for data acquisition for defect detection. The electromagnetic testing is not affected by the oil or mud stains on the wire rope surface, so the internal and external defects can be detected, and various types of magnetic sensors can be chosen for defect detection. In conclusion, the electromagnetic testing is considered to be a most reliable method for the inspection of wire ropes in service [8].

The magnetic sensors for electromagnetic testing [9,10] include inductive coil, hall [11], anisotropic magneto-resistive (AMR), giant magneto-resistive (GMR), fluxgate and tunnel magneto-resistive (TMR) [12]. The sensor of the world's first advent wire rope nondestructive device is inductive coil [13]. After more than 100 years development, because of its low cost and durable, inductive coil is still used as the detection sensor by some well-known wire rope nondestructive testing manufactures [14], such as: NDT Technologies (USA), DMT (Germany), British Coal (British), AGH (Poland), and Halec SA (France). There are four structures for wire rope nondestructive testing using inductive coil, as shown in Fig. 1.

The main flux method uses an annular coil encircled the rope. Since it measures the magnetic flux inside the rope, the performance of this annular coil is considered as the gold standard by which all the other methods are utilized. Unfortunately, it is topologically impossible to implement a hinged annular coil with a large number of turns that can be opened and conveniently attached to the wire rope. The modified main flux method [15] and radial flux method adopt separate structures, which makes it easy to attach the sensor head to the wire rope even under

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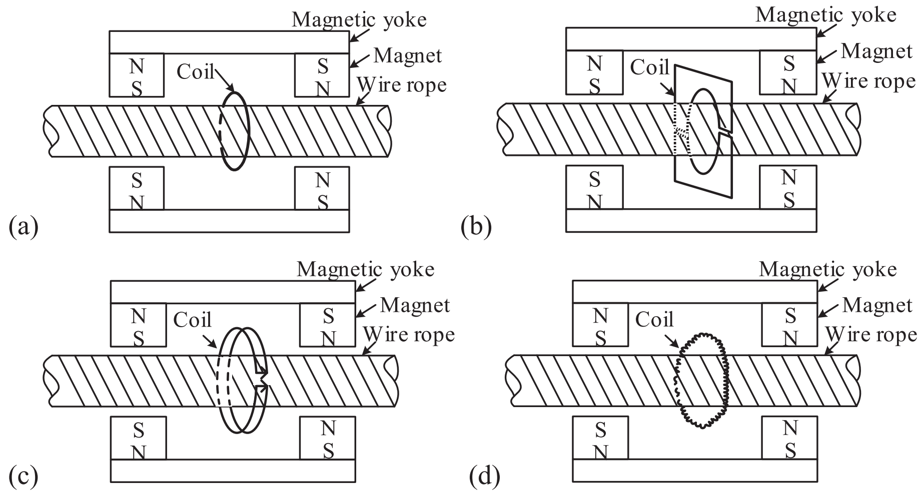

Fig. 1. Wire rope nondestructive detection using induction coil: (a) main flux method; (b) modified main flux method; (c) radial flux method; (d) circumferential flux method.

adverse field conditions. However, in order to improve the SNR of the detection signal, the coil needs to be designed as arc-shaped winding according to the wire rope diameter, which is not easy to make and necessary for complex signal processing [16]. The detection principle of circumferential flux method is similar to the Rogowski coil [17]. This method also has the drawback that the winding is not convenient and the SNR is low. In Ref. [18], a modified electromagnetic main flux method is proposed, the coil sensors are installed surrounding the inner carrying case, and this coil can detect the leakage field in all the axial, radial and tangential directions. The resolution of the system is defined by the size of the sensor.

In order to solve the problem of coil winding and installation complexity, and improve the SNR of the coil output signal. The advantages of adding the iron core and optimization of the core structure in terms of theoretical analysis, simulation verification and experiment [19] will be presented in this paper.

2. Theory analysis

2.1. Basic principle of inductive coil detection

For the wire rope nondestructive testing using inductive coil, in order to detect the internal and external defects, proper design of magnets and yoke are chosen to excite the rope to near saturation. The excitation structure and the distribution of defect MFL are shown in Fig. 2(a) and (b), respectively.

In Fig. 2(a), F_m is the magnetomotive force of the permanent magnet. R_m is the magnetoresistance of the permanent magnet. R_y is the magnetoresistance of the yoke. R_w is the magnetoresistance of the tested wire rope. R_{wq} is the magnetoresistance of the air gap between the magnet and wire rope. The equivalent magnetic circuit model of the wire rope excitation structure is shown in Fig. 3.

According to the Kirchhoff voltage and current law, the magnetic flux passing though the iron core is:

$$\Phi_s = \frac{4F_m}{2R_m + 2R_{wq} + R_y + R_w} \tag{1}$$

When there is a defect on the wire rope, R_w changes and some of the magnetic flux that pass through the rope leaks into the air. Due to the low permeability of the air, the MFL of the defect is dispersed in the surface of the wire rope, as shown in Fig. 2(b). Therefore, to improve the signal intensity, the lift-off distance of the coil which is used for defect detection needs to be designed as small as possible, and the coil cross-section area needs to be designed large enough to cover the MFL.

2.2. Principle of coil with iron core detection

In order to improve the SNR and installation convenience of the coil, an iron core for winding the inductive coil is brought out as a part of the excitation circuit. The core is selected as a material with high permeability, such as pure iron or permalloy. The improved excitation structure

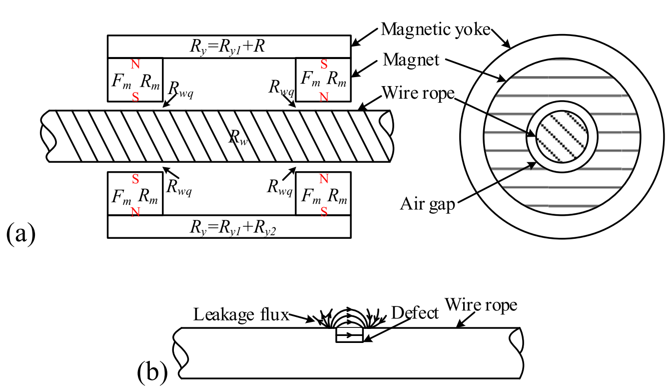

Fig. 2. The traditional excitation structure and distribution of defect MFL: (a) the excitation structure; (b) the distribution of defect MFL.

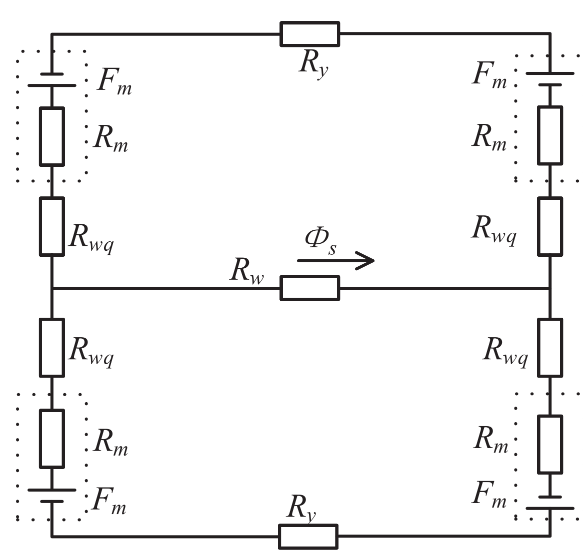

Fig. 3. The equivalent magnetic circuit.