Simulation Analysis of Magnetic Flux Leakage (MFL) testing for Wire Rope Based on Multilayer Helical Structure

Xiaoyuan JIANG, Yanhua SUN, Mengqi LIU, Lingsong HE

School of Mechanical Science and Engineering, Huazhong University of Science and Technology, 430074, Wuhan, China

Abstract

For magnetic flux leakage testing, various variants of the same-diameter steel wire rope were developed respectively, and the simulation results show that different modeling structures of wire rope result in different distributions of internal magnetic field and defect leakage magnetic field. Therefore, a comprehensive study on the magnetic field transmission and defect leakage magnetic field characteristics of steel wire rope is required.

1 Introduction

A wire rope is a helical winding structure composed of multiple strands of steel wire[1]. Its overall composition consists of a bundle of wires and air-filled interstices. When conducting finite element simulation studies on magnetic flux leakage testing of wire rope, the model of wire rope is typically simplified to that of a steel rod with the same diameter. In fact, due to the presence of air gaps between the multiple layers of spirally twisted steel wires, the magnetic state and distribution of magnetic field lines within the steel wire rope will change when it is magnetized. This results in differences in the magnetic field distribution of defective areas such as single or multiple broken wires, and internal or external wire breaks. Various steel wire rope structures with identical diameters were established and analyzed using finite element analysis. The results indicate that the defect magnetic leakage fields caused by various structures differ significantly. Consequently, it is vital to investigate the spatial propagation mechanism of magnetic fields in helical winding structures.

2 Finite element simulation analysis of different wire rope structures

Magnetic flux leakage (MFL) testing as one of the most reliable nondestructive evaluation techniques for inspecting wire rope, we magnetize the wire rope using a magnetizer that consists of two axially magnetized circular magnets and a center yoke, and we simulate and analyze the leakage magnetic field of defects on wire ropes of the same diameter with varying structures.

2.1 *Wire rope structural modeling*

As shown in Fig. 1(a), (b) and (c), three models of wire rope with identical diameters were established, including a steel rod, untwisted multifilament wire rope and twisted multifilament wire rope.

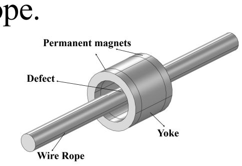

Fig. 1(a): Steel rod

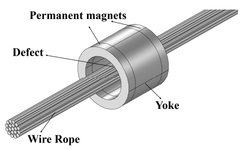

Fig. 1(b): Untwisted wire rope

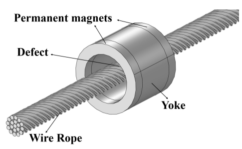

Fig. 1(c): Twisted wire rope

According to the principle of magnetic field refraction and the boundary conditions of the electromagnetic field, the direction of the magnetic field will change at the interface of the two media[2]. As shown in Figure 2, there is an air gap between the multi-layer steel wire and a discontinuity of magnetic permeability. When the exciting magnetic field enters the steel wire rope, the magnetic field lines will be diffracted and refracted many times in the interface between the steel wires and air, resulting in a change in the transmission path of the magnetic field lines into the steel wire rope, so that the magnetization state in the wire rope of different structures is also different.

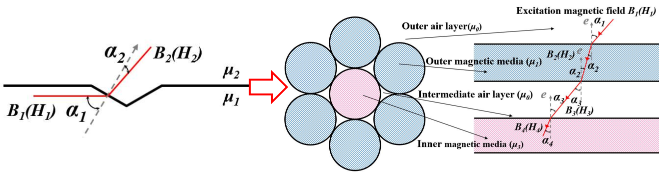

Fig. 2: Magnetic refraction at the interface

2.2 *Simulation analysis*

At the same point on the surface of these three structures and on the second layer of steel wire, create 5mm-long inner and outer wire breaks. Perform finite element simulation on them and evaluate the results. As shown in figures 3(a) and 3(b), the magnetic leakage fields of defects located directly above the same path of internal and external wire breaks in different wire ropes are presented. Figure 4 depicts the internal magnetization state of steel wire ropes with different structures near the broken wire location, as well as the magnetic field leakage in the air domain, where the red vector represents the direction of the magnetic field line inside the wire rope, and the blue vector represents the direction of the magnetic leakage field in the air domain above the broken wire. The results indicate that the magnitude of the magnetic leakage field generated varies depending on the structure of the wire rope. In addition, the distribution of magnetic fields within the wire rope, as well as the distribution of magnetic fields in the air domain, are affected by the structure of the wire rope near the broken wire. The magnetic flux flows in the direction of the wire rope's winding.

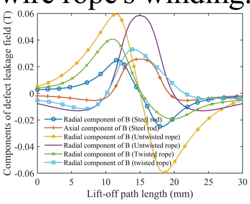

Fig. 3(a): Leakage field characteristic signal of external broken wire

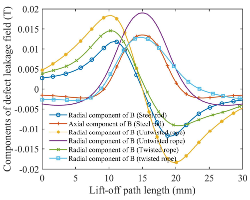

Fig. 3(b): Leakage field characteristic signal of internal broken wire

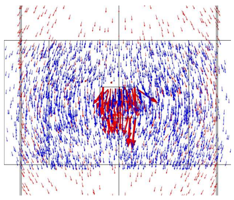

Fig. 4(a): Steel rods

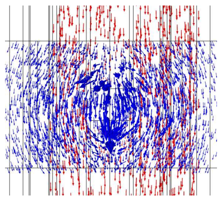

Fig. 4(b): Untwisted wire rope

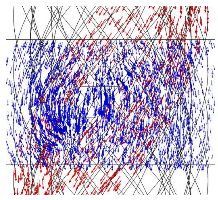

Fig. 4(c): Twisted wire rope

3 Conclusion

The magnetization state and detection signal of a multi-layer helically wound wire rope are influenced by the structure of the wire rope. Therefore, it is necessary to study the effect of physical and geometric parameters on the spatial magnetic field and detection signal of the wire rope.

References

[1] Velinsky S A. On the design of wire rope[C]//International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers, 1988, 26584: 315-322.

[2] Sun Y, Kang Y. Magnetic mechanisms of magnetic flux leakage nondestructive testing[J]. Applied Physics Letters, 2013, 103(18).