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A Large Lift-Off Nondestructive Testing Method Based on the Interaction Between AC Magnetic Field and MFL Field

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Abstract. The magnetic leakage field of the crack gets weaker rapidly as the lift-off value increases, which makes the detection more difficult, especially for many insulated pipes. On the other hand, for eddy current testing, the AC magnetic flux of the excitation coil decreases exponentially with respect to the probe lift-off value, meanwhile, the surface eddy current density decreases rapidly according to the law of electromagnetic induction. To achieve the inspection in a large lift-off, a large life-off NDT method based on the interaction between AC Magnetic field and MFL field is proposed. A series of simulations and experiments are conducted to verify its feasibility.

Keywords. Large lift-off, Eddy Current Probes, MFL

1. Introduction

Non-destructive testing technology has been widely used in various engineering fields to ensure the structural safety of components [1-3]. Among electromagnetic detection methods, Magnetic flux leakage testing and eddy current testing are the most commonly employed in non-destructive testing technology [4-6]. For these two detection methods, the lift-off value is a key factor in the inspection. In the case of small lift-off, first, under the rough surface state, a large interference signal is easy to be brought, and the signal-to-noise ratio is relatively low [7]. On the other hand, the probe tracking system is close to the pipe wall, which not only increases the equipment cost, but also causes the probe to be worn and vibration noise signal. In addition, considering the inspection of tubes covered with a thick coating layer, the probes cannot directly contact the pipe wall. Therefore, it is necessary to implement the detection in a large lift-off.

However, the MFL signal induced by the external crack of the steel pipe in the detection space decreases rapidly as the lift-off distance increases. At the same time, due to the compression of the background magnetization field in the space, the MFL is further reduced [8], so it is difficult to obtain an effective signal. And the magnetic flux leakage induction signal is used as a low frequency signal and is susceptible to the interference of various low frequency noise signal. For eddy current testing, the eddy current density induced in the sample is rapidly attenuated with the increase of the lift-off, and the detection sensitivity is also reduced.

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In order to implement detection in a large lift-off, some scholars have made research about the approach of increasing the inspection lift-off previously. Wu et al. [9] used ferrite core coil as the MFL sensor and conducted a series of experiments to compare the sensitivity between air core sensor and ferrite core coil. Sun et al. [10] proposed a new MFL principle based on near-zero background magnetic field. Without the influence of background noise signal. The MFL testing can be accomplished in a larger lift-off. Some scholars have studied the application of signal modulation in pulsed eddy current testing [11-12]. Based on the above research, a weak magnetic field measurement method based on the interaction between AC magnetic field and MFL field is proposed. In the large lift-off space, a high-frequency AC magnetic field signal is generated by the excitation coil, and the DC MFL signal is modulated on the high-frequency signal. The detection coil is influenced by the modulated signal that has the variation characteristic of the DC MFL. After amplification and demodulation, the low frequency leakage magnetic field signal is demodulated. The method can realize the defect detection under the large lift-off, effectively suppress the noise signal and improve the signal to noise ratio.

2. Mechanism

According to the magnetic dipole model, the outer wall defect of the ferromagnetic steel tube generates a magnetic leakage field in the space, which decreases with the increase of the lift-off. The energy of conventional magnetic flux leakage signal is mainly concentrated on its DC component and low frequency harmonic component. During the inspection in the large lift-off, the detection coil is scanned along the path in space, and the magnetic flux passing through the coil changes, so a very small electromotive force is induced in the coil which causes the detection coil to have a weak response to the surface crack of the ferromagnetic material.

In this method, the high-frequency magnetic field excited by the excitation coil is used as the carrier signal, and the DC leakage magnetic field is used as the modulation signal, as shown in Fig. 1. After the signal modulation is performed, the modulated high-frequency modulated magnetic field signal has all the information of the original spatial MFL signal, and its amplitude changes with the variation of the characteristics of original MFL signal. According to Faraday's law of electromagnetic induction, an induced electromotive force is generated in the circuit as long as the magnetic flux passing through the induction coil changes. The essence of modulation is the multiplication of two magnetic field signals, and the original DC leakage magnetic field signal and the high frequency mutual inductance magnetic field signal act together on the induction coil, so the form is reflected in the superposition of the magnetic field signal in the induction coil. From the perspective of frequency, it is the high-frequency magnetic field signal generated by mutual inductance plays a decisive role.

The sensor picks up the information of the above field source, and the modulated magnetic field generates an induced electromotive force in the coil. After amplification, the MFL information of the crack is modulated on the carrier wave, and then the MFL information is directly obtained through the demodulation circuit. After amplification, the detection signal is obtained in a large lift-off. In this method, the weak DC leakage magnetic field signal is moved to the high frequency band, and the signal strength is improved to facilitate acquisition and subsequent processing. The effect of low-frequency noise is weakened, and the inspection in a large lift-off can be achieved.

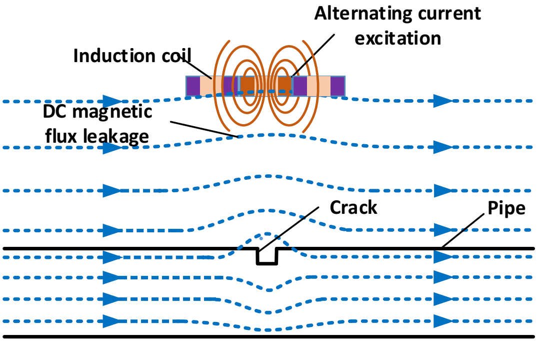


Figure 1. Mechanism of the method.

3. Simulation

In this section, a non-linear three-dimensional FEA model was built in ANSYS to analyze the detection limit of eddy current testing and MFL testing, as shown in Fig. 2. First, the semi-steel pipe model is selected to verify that the eddy current density generated by the excitation coil in the steel pipe is exponentially attenuated as the lift distance increases, as shown in Fig. 3. This shows that the excitation of eddy current testing is not applicable in the case of large lift-off.

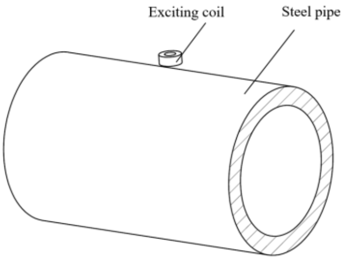


Figure 2. eddy current ANSYS model

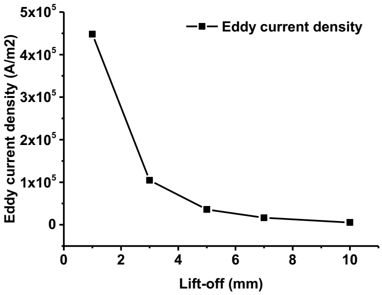


Figure 3. eddy current density changes with lift-off

Then, a simulation model was conducted to analyze the MFL field in different lift-offs, as shown in Fig. 4, the encircling coil was used as the DC magnetizer, generating the DC longitudinal magnetization field. The size of the defect in the tube is 10 mm in length, 1 mm in depth and 0.5 mm in width. Under the saturation magnetization, the change of the normal magnetic field component under each lift-off value exists when the outer surface defect exists.

The background field and the MFL field at 10 mm above the defect were extracted separately, and Fig. 5 shows that the normal component for the defect was smaller than the normal component of the background field. The 0.002mT MFL field is difficult to detect by the sensor in the background field.

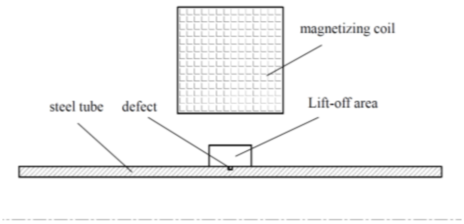


Figure 4. MFL ANSYS model

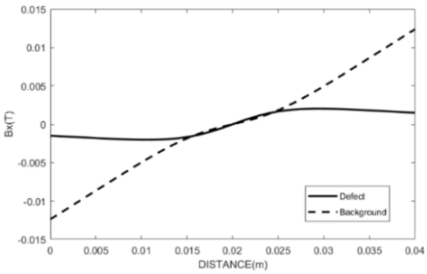


Figure 5. Defect signal and background signal

4. Results and discussion

Based on the above mechanism and simulation, the testing system for this work was built to validate the feasibility of this new method, as show in Fig. 6. The encircling magnetizer was employed to magnetize the specimen with a rectangular notch which was machined by electric discharge machining(EDM). The size of the notch is 10 mm in length, 1 mm in depth and 0.5 mm in width, as displayed in Fig. 9. The DC magnetizing power provided 16A current to ensure the specimen is in the saturation magnetization state. The exciting coil was used to excite eddy current in the specimen which was driven by the power signal generator that provided an 80 kHz sine voltage waveform signal. The detecting coils picked up the induction magnetic field intensity components above the surface of the specimens, as displayed in Fig. 7. The slide can make sure that the sensor moved horizontally.

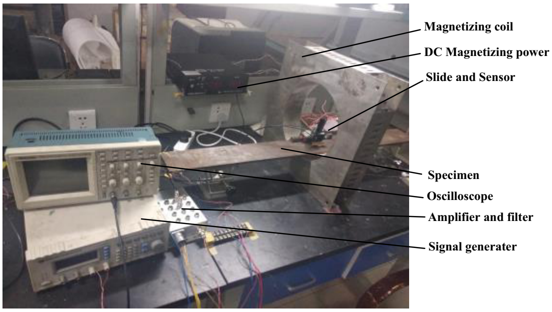


Figure 6. Experiment setup.

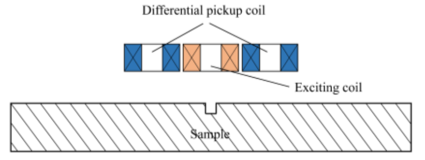


Figure 7. Probe.

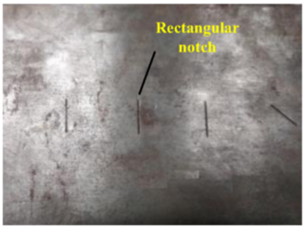


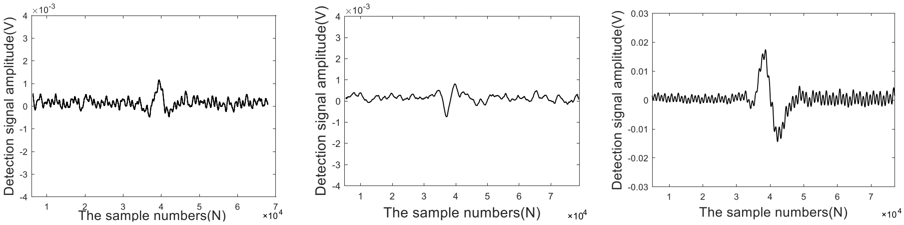
Figure 8. Specimen

Firstly, when only the AC excitation was applied, the surface defects of the steel pipe did not generate a local magnetic leakage field in space. When the distance between the probe and the surface are about 10 mm, the eddy current density generated in the steel pipe is rather weak, which attenuates to 1% of the eddy current density when the probe is to 1 mm above the steel pipe. Fig. 9 (a) shows that the signal corresponding to the defect in the test result was too small, and it can be concluded that if the signal can be obtained at this large lift-off, the MFL field is an indispensable factor.

Then, when only the DC magnetization was applied, the surface defects of the steel pipe generated a local MFL field in the space. At this time, due to the variation trend of the MFL field with the lift-off, the MFL field above 10mm is also very weak which is buried in the background noise. Fig. 9 (b) shows no detection signal of the defect was achieved by the detection coil. Therefore, under this detection system, there is no ability of the direct acquisition of the MFL field.

$$SNR = 20lg\frac{V_s}{V_n} \tag{4.1}$$

Finally, when DC magnetization and AC excitation were applied, according to the definition of SNR expressed as Eq(4.1), the signal SNR increased compared with the other two methods, and the MFL signal was modulated with the AC magnetic field as shown in the Fig. 9 (c). The MFL field is a spatial field, which distributes in a certain way. At a certain lift-off, the traditional MFL testing lose the ability to inspect the sample, because the MFL field is too weak. If the eddy current probe is put at the same lift-off with traditional MFL testing, the AC magnetic field generated by the driver coil will interact with MFL field. The MFL field will be modulated with the AC magnetic field. Therefore, the defect signal is generated in the pickup coil. The AC magnetic field acts as medium to transmit MFL field, which can realize the inspection of defects at a larger lift-off compared with traditional MFL testing.



(a) Eddy current signal (b) MFL signal (c) Signal of the new method

Figure 9. Experiment results.

In addition, to explore the change trend of the SNR of this new method with lift-off variation, a series of experiments was conducted under the same experimental condition except that the lift-off increased from 1mm to 10mm with 1mm step. The results are shown in Fig. 10. The SNR decreases linearly with the increase of lift-off.

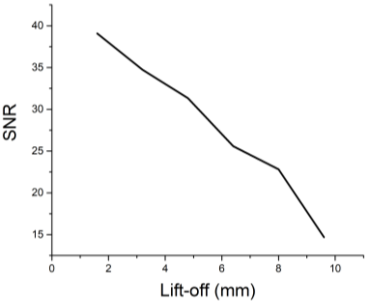


Figure 10. The change trend of Lift-off

In the experiment, it is found that when the DC magnetization and AC excitation are applied simultaneously, the detection capacity is improved compared with the other two magnetizing ways. The experimental results suggest that the detection can be accomplished in a larger lift-off with this method. Increasing the lift-off can guarantee the safety of sensors when detecting the steel tube online. There are different methods of increasing the lift-off, like utilizing the magnetic field focusing effect in sensors, avoiding the background signal, processing MFL signals, and others. The method proposed in this paper is based on the modulation of MFL signal. The main advantage of the proposed approach is its applicability to inspect the ferromagnetic materials at a large lift-off. However, like the eddy current testing which is sensitive to the variation of the lift-off, this approach is easily influenced by lift-off changes. Besides, a limitation of the method is that only ferromagnetic materials can be detected with this approach. Because the MFL field is an essential factor for the inspection, and only ferromagnetic materials can produce MFL field.

5. Conclusion

In this paper, it can be concluded that this method shows good performance in large lift-off detection based on the interaction between AC Magnetic field and MFL field. It is a new and promising NDT technology which is different from the commonly used MFL method. With the employment of this new method, the detection can be made in a larger lift-off.

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