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Defects Detection System for Steel Tubes Based on Electromagnetic Acoustic Technology

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Abstract

Based on the electromagnetic acoustic technology (EMAT), a system for detecting the defects of steel tubes has been constructed. Through analyzing the principle of detecting the defects of steel tubes by EMAT, an electromagnetic acoustic transducer is designed to transmit and receive the electromagnetic acoustic signals. After the data are acquired by the high-speed data acquisition card, they are transferred to computer and are processed. In addition, the selective frequency and amplification technology was used to process the weak received signal, which improved the anti-jamming ability of the system. Experimental results of different diameter through-hole steel tubes showed that this system can automatically detect the defects in steel tubes.

Keywords: Defect detection system; EMAT; steel tube

1. Introduction

Steel tubes have been widely used in petroleum, natural gas, water treatment and other fields [1,2]. It is well known that the quality of steel tubes is affected by many factors. So, high-quality steel tubes must meet the requirements of the continuity and uniformity in chemical composition, physical properties and shape [3]. What's more, during the use of steel tubes, many defects, such as cracks and holes, often occur because of heat, corrosion and stress concentration and so on [4]. Therefore, in order to ensure the quality and continuity, various kinds of methods are used to detect the defects in steel tubes. Among them, acoustic detection technology is most commonly used [5].

The piezoelectric ultrasonic technique has the merit of high sensitivity to cracks and holes. However, there must be a good acoustic coupling between the transducer and steel tube, which limits its online application [6]. To solve this problem, the electromagnetic acoustic transducer (EMAT) had been

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developed, and it can directly generate and receive the acoustic signals in metals without the acoustic coupling. But the efficiency of EMAT is too low. Generally speaking, when the circuits achieve a good match and the current peak-to-peak value of the excitation coil is 50A, the voltage of the receiver coil can only reach tens of microvolts [7,8]. Furthermore, the high-power transmitter will generate intense electromagnetic interference, which leads to serious noise. Therefore, when the system is designed, the receiving unit must have the ability of extracting the weak desired signals from the heavy noise.

Base on above these, an automatic system for detecting the defects of steel tubes has been constructed according to the EMAT. Because the selective frequency and amplification technology is used to process the weak wanted signal, the anti-jamming ability of this system is improved dramatically.

2. Detection Principle

2.1. Principle of transmission and receive of EMAT

When a coil is supplied with the alternating current, an alternating magnetic field will generate. If the coil is close to the metal surface, an eddy current will be induced near the metal surface, and it complies with Faraday electromagnetic induction law [9]. The density depends on the change rate of the alternating magnetic field produced by the coil, and the frequency is equal to that of the alternating current.

As we all known, any current under the magnetic field is subject to the stress, and the eddy current is not exclusive. Under the alternating stress, the stress wave is prone to be generated in the metals. When the frequency is over 20kHz, it will be considered as the ultrasonic wave. On the other hand, the reflected ultrasonic wave will affect the wave vibration, and thus it will cause the voltage change in the excitation coil. The ultrasonic wave generated by this method is commonly called electromagnetic ultrasonic wave [10, 11]. By changing the magnet and the coil structure, different types of waves including the longitudinal wave, shear wave and surface wave can be got. By changing the frequency of the alternating current, the propagation direction of the ultrasonic wave can be altered. Therefore, it is easy to achieve different wave.

2.2. Principle of detecting defects in steel tubes

Fig.1 shows the model of EMAT probe for detecting the defects in steel tubes. It is composed of high-frequency coil, electromagnet and steel tube. It can be seen that the transducer includes high-frequency coil, electromagnet and steel tube. That is to say, the steel tube is an important part of the transducer, and the conversion between electric field, magnetic field and acoustic field is done near the tube surface.

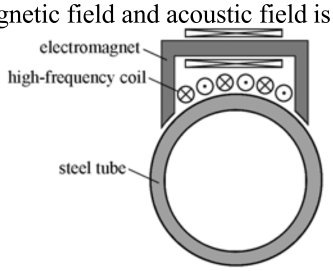

Fig.1. Model of EMAT probe for detecting the defects in steel tubes

When steel tubes are detected, EMAT probe will generate two beams of ultrasonic surface waves with opposite propagation direction. These two surface waves will transmit along the tube surface, and in the end the overall tube surface will covered. During the propagation, when the ultrasonic surface waves encounter the defects, it will be reflected back. If the defect location is different, the properties of the response waves will differ. So, by analyzing the different response waves, the defects can be detected.

3. Structure of Detection System

The system structure of detecting the defects in steel tubes is shown in Fig.2. It is made up of EMAT probe, hardware unit and software unit. Hardware circuit includes the transmitting and receiving coil, transmitter unit, receiver unit and high-speed A/D conversion card. The tuning pulse signals generated by the arbitrary signal generator are amplified by the power amplifier and then are supplied to the EMAT probe. Under the static magnetic field, ultrasonic waves are generated in the steel tube. After propagation and reflection, the weak response signals are received by the receiver coil, and then they are filtered and amplified by the selective frequency and amplifier circuit. Finally, the data containing the desired information are acquired by the high-speed A/D conversion card, and sent to computer by PCI bus.

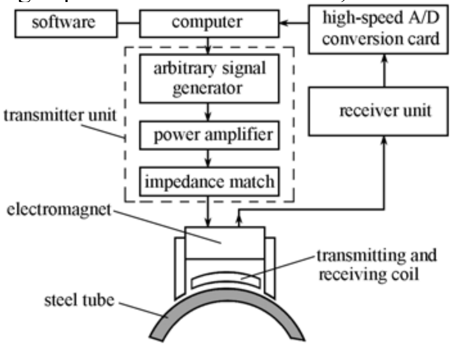

Fig.2. System structure of detecting the defects in steel tubes

3.1. Transmitting and receiving coil

Transmitting and receiving coils usually include the spiral coil and the winding coil. Because the electromagnetic ultrasonic wave can be easily generated by the winding coil, and the longitudinal and shear waves can be got by changing the frequency, the winding coil is used to generate the ultrasonic wave in this system. When this coil is designed, the phase matching conditions should be met, namely:

$$n\lambda = 2L \tag{1}$$

where λ is the wavelength of the surface wave, L is the distance of adjacent turns in coil, and n is an odd number, n=1, 3, 5….

In order to simplify the design, the coil is manufactured according to the law of $L = \lambda/2$, which can make the ultrasonic energy maximum.

The wavelength λ is inversely proportional to the alternating current frequency f in the coil. Therefore, the choice of the acoustic wavelength λ must take account of these factors, such as the EMAT probe structure and the lift-off effect. It is generally believed that the minimum defect that can be defected by the ultrasonic wave is about $\lambda/2$. So, the optimal frequency of detecting the defects in this system is f = 500kHz.

3.2. Transmitter unit

As an inductive load, the EMAT differs from the piezoelectric ultrasonic transducer that is a capacitive load. Thus, in order to maximize the conversion of sound energy and to optimize the time domain response, many factors different from piezoelectric transducer must be taken account into. For the EMAT probe with the relatively low efficiency, the high-power narrowband pulse group is usually used. It can not only improve the SNR, also play very important roles in the choice of ultrasonic guided wave modes. In this system, the narrowband pulse modulated by Hanning window is used to drive the winding coil. As a result, it will generate a narrowband response which frequency is 20% of the center frequency.

We adopted the D-type power amplifier. Different from C-type, its base and collector voltage shapes are rectangular, which can reduce the voltage loss of the collector and improve the output power.

Because of the low impedance of the coil, the mismatch of the impedance between the transmitting unit and the receiver unit usually becomes serious. In order to improve the SNR, the appropriate impedance match must be made. The series capacitor narrowband match is used in the transmitting unit while the parallel capacitor broadband match is used in the receiver unit.

3.3. Receiver unit

Because the desired signal is very weak while the noise and interference is very strong, the weak desired signal is usually submerged by the noise. So, the signal should be amplified and filtered in order to filter out the noise outside the passband.

The selective frequency and amplifier technology is a common method of processing the weak signal. Because the energy of the random noise has the characteristics of evenly distribution in the frequency domain, the noise in the received signal can be reduced by constructing narrow-band filters. Therefore, the weak desired signal can be extracted from the heavy noise. The selective frequency and amplifier circuit, schematically shown in Fig.3, is designed by using the passive components. It includes the limiting circuit, the preamplifier circuit, the resonant circuit, the isolated circuit and the amplifier circuit.

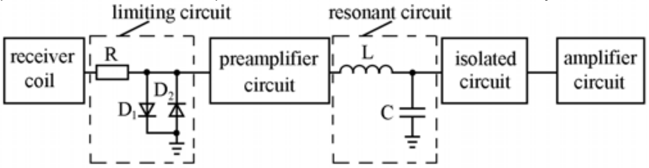

Fig.3. Schematic diagram of selective frequency and amplifier circuit

Due to the serious electromagnetic interference caused by the EMAT transmitter unit, the limiting circuit is added at the input of the receiver unit, and it is composed of a pair of inverse parallel diodes. The interference caused by the transmitter unit is about 10V while the received signal is only 10μV. Consequently, the received signal is not significantly reduced, but the electromagnetic interference will be shorted by diodes and rapidly damped.

Resonant circuit composed of inductor and capacitor is the core part of the selective frequency and amplifier circuit. By adjusting the resonant parameters, the resonant frequency can accord with the center frequency of the received signal. By maximizing the quality factor Q without distortion, a narrowband bandpass filter can be got. In addition, because the resonant voltage of the passive components is much higher than the input voltage, the resonant circuit can also amplify the signal. Therefore, the resonant circuit plays roles in frequency selection and signal amplification. However, the quality factor Q can not be infinite improved owing to limitations of signal bandwidth and device constraints. By frequency scanning experiment, the quality factor Q is about 30.

4. Experiments and result analysis

In order to verify the system, many experiments on the steel tubes with different diameter through-hole have been performed, respectively.

Fig.4 shows the waveform of response signals in steel tubes with and without the hole. When the tube is without through-hole, the relative amplitude of the wave is low. However, when there is a through hole, the relative amplitude significantly increased. By calculation, SNR is about 16dB, which shows that the system can effectively detect the defects in steel tubes.

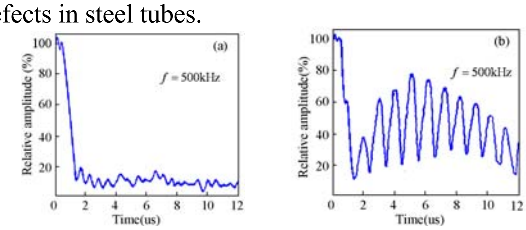

Fig.4. The waveform of steel tubes with and without the hole: (a) without through-hole; (b) with through-hole

Fig.5 shows the relationship between the amplitude of the response signals and the diameter of through holes. It can be seen that the response signal amplitude increases with the increase of hole diameter, which means that the system is sensitive to the through hole and it can be used to effectively detect the defects in the tubes.

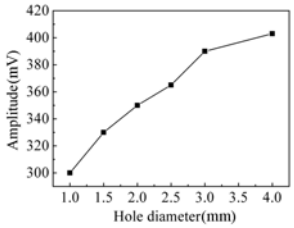

Fig.5. Relationship between response signal amplitude and the diameter of through holes

5. Conclusions

An automatic system for detecting the defects in steel tubes was developed according to the electromagnetic ultrasonic technique. This system is composed of the transmitting and receiving coil, transmitter unit, receiver unit, high-speed A/D conversion card and software. The selective frequency and amplifier technology is used to process the weak response waves, which greatly improves the ability of the anti-jamming. By using this system, many experiments on steel tubes with different through-hole are carried out, and the results show that the system can automatically detect the defects in the tubes, and that the hole diameter is proportional to the amplitude of response waves.

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