LETTER TO THE EDITOR

Pitting Defect Detection of Multilayer Dissimilar Metal Materials Based on Electromagnetic Ultrasound Technology

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Multilayer multilayer dissimilar metal are widely used in aerospace, national defense, nuclear industry and other fields. Because of the particularity and complexity of multilayer dissimilar metal, their internal defects are prone to occur, which challenges the traditional non-destructive testing technology.In order to improve the detection ability of the internal defects of the structure, a detection technology based on electromagnetic ultrasonic technology is proposed. The pipeline made of multi-layer multilayer dissimilar metal was taken as the research object. The electromagnetic ultrasonic probe was used to excite the vertical incident wave or surface wave, and the corrosion was detected by measuring the thickness of the pipeline wall or the reflection wave of the defect of the pipeline wall.The instrument consists of an electromagnetic ultrasonic probe, a transmitting and receiving circuit, a digital signal processing circuit and a corrosion detection and analysis software. The test results are displayed by "B" scan chart or "C" scan chart and analyzed quantitatively, which can help the inspectors to judge the defects in multi-layer heterogeneous metal specimens intuitively.
Electromagnetic Ultrasound Technology; Multilayer multilayer dissimilar metal; Pitting Defects

1 INTRODUCTION

Multi-layer heterogeneous metal bonded structures have many advantages, such as high specific strength, high specific modulus, strong anti-fatigue and anti-vibration performance, and are widely used in aerospace, national defense, nuclear industry and other fields. Due to the influence of manufacturing methods and production environment, debonding and bubbles are easy to occur at the laminate bond. In the process of production, assembly and practical use, there will be cracks, scratches and other defects. Most of these defects are sub-surface defects, which easily lead to changes in the physical properties of components, and gradually affect the reliability and safety of components without any awareness. Therefore, it is of great significance to detect and ensure the quality and safety of such structures.

Longfei Dang, Miao Yang, Baohua Teng, Chun Yang published an article entitled “Study on

Heavy Metal Content and Microbial Ecology of Soil in Coal Mining Area and Application Prospect of UWB Radar” on Ekoloji's Issue 107 in 2019 (Dang et al. 2019). This paper aims at the study of heavy metal content in coal mine soils, microbial ecology and the application prospect of UWB Radar.The transformation and migration of heavy metals in subsidence area were clarified. The effects of heavy metals pollution on soil enzyme activity and soil microbial characteristics in subsidence area and surrounding farmland were analyzed. The interaction between microorganisms and heavy metals and its mechanism were studied.

Although the current research has achieved some results, the research on electromagnetic ultrasound technology is far from enough. Therefore, the pitting defect detection of multi-layer multilayer dissimilar metal based on electromagnetic ultrasound technology is proposed.

2 IDEA DESCRIPTION

Electromagnetic ultrasound and traditional piezoelectric ultrasound belong to the category of ultrasound. The principle of EMA exciting ultrasound is as follows:A coil is placed on a conductive metal surface, and a high-voltage pulse is loaded into the coil to excite an alternating electromagnetic field, resulting in the induced eddy current (Khan et al. 2017) in the surface layer of the object under test. If a stable magnetic field is applied on the coil at the same time, it will interact with the eddy current inside the metal and produce Lorentz force. Under the action of the force, the particle of the measured object will produce the ultrasonic radiation along the measured object or along the surface.The receiving of electromagnetic ultrasound is an inverse process of excitation. When the surface of the object is projected by ultrasound, the particle displaces, the lattice is forced by the biased magnetic field, which generates alternating current, which results in alternating magnetic field on the surface of the conductor under test. The alternating magnetic field leaks out of the conductor, which makes the detection coil disposed on the surface of the conductor generate inductive potential, its frequency and the received ultrasound. Waves have the same frequency and their amplitude is related to the energy of the reflected wave (Gao et al. 2017).In the electromagnetic ultrasonic testing, the measured object is a part of the electromagnetic ultrasonic sensor, and must be an electric conductor or a magnetic conductor. If the measured object is a ferromagnetic material, besides Lorentz force, it is also affected by magnetostrictive force.

Electromagnetic ultrasonic probe (EMAT) consists of magnet, transmitting and receiving coil and specimen (Ramasamy et al. 2017). Compared with piezoelectric probe, EMAT has many advantages in pipeline wall corrosion detection: (1) Without coupling agent, it is suitable for high temperature detection and creeping detection in gas pipeline. (2) In non-contact measurement, the influence of coating, contamination and rough surface is very small. (3) It has a strong ability to detect natural defects, and can detect the cracks and holes on the surface of steel pipe (Vidyarthy et al. 2017). (4) Ultrasound guided waves generated in the steel tube can spread far away. When the longitudinal defect of the steel tube is detected, the probe and the workpiece need not rotate. (5) When measuring thickness, EMAT uses shear wave, and its longitudinal resolution is twice as high as that of piezoelectric probe.

EMAT uses different coils, magnetic fields and excitation frequencies to produce various types of ultrasound (Hajideh et al. 2017, Xue and Geng 2015; Amouzgar et al. 2017). For corrosion detection of metal pipelines, bulk wave thickness measurement method and surface wave defect detection method are mainly used. EMAT is used to measure the thickness of the body wave designed by the instrument. The permanent magnet generates a vertical static bias magnetic field. The coil is helical and the frequency is 2.5 MHz. It can excite the vertical incident shear wave in the metal tube wall. When testing, the corrosion of pipeline can be judged by measuring the propagation time (T) of ultrasonic wave in the pipe wall, calculating the thickness (H) of the pipe wall and comparing the thickness changes

Surface wave flaw detection EMAT uses permanent magnet to generate vertical static bias magnetic field. The coil is tortuous structure and its frequency is 1.5MHz. It can detect corrosion defects on the inner and outer surface of metal pipe wall and sub-surface. When there is no discontinuity in the tube wall, the surface wave emitted by EMAT only has one echo around the tube wall; If there are defects or welds in the propagation path, there will be multiple reflection waves. The method of defect detection and location is the same as that of piezoelectric ultrasonic surface wave detection, as shown in Figure 1. It can also rotate the probe 90 degrees to make the surface wave propagate along the radial direction, so that the defects of circumferential extension can be easily found. If the probe is placed on the inner wall, the same method can be used to detect the inner wall defects.

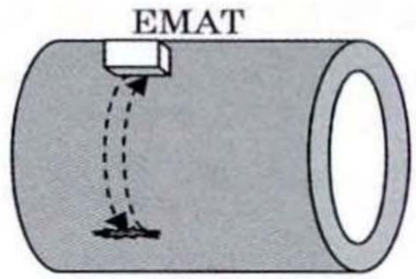

Fig. 1 Surface wave detection simulation of electromagnetic ultrasonic probe

3 RESULTS

3.1 System Composition

The difference between electromagnetic ultrasonic metal pipeline corrosion detector and piezoelectric ultrasonic detector is that the probe is different, the defect analysis software is different, the transmitting and receiving circuits are different, and the others are basically the same. The system mainly consists of electromagnetic ultrasonic probe (EMAT), transmitting and receiving circuit, analog signal processing circuit, digital signal processing circuit, human-machine interface (HMI) and corrosion detection software package.

The man-machine interface is an embedded terminal based on Windows XPe, with built-in corrosion analysis software package. Data acquisition and processing circuit communicates with HMI through USB interface, which is completed by FPGA, MCU and A/D conversion circuit. The burst wave circuit receives the trigger signal of the digital processing circuit and generates the burst signal according to the number and frequency of the set pulses. After isolation drive, the signal is boosted by transformer to form a high-voltage and high-power coil driving signal to drive the EMAT excitation coil. Coils with different frequencies need different tuning matching circuits to achieve maximum power output and relatively pure sinusoidal wave. The excitation coil and the receiving coil can be the same coil or can be separated. The receiving sensitivity of the separated coil is slightly lower, but the receiving circuit can be isolated from the high voltage pulse and reduce the width of the initial pulse. The EMAT of a single coil is a spontaneous self-turning probe. There is no inconsistency between the structure of two coils and the parameters of the circuit. It is widely used. After impedance matching, protection and drive, the weak voltage signal received by the receiving coil enters the analog signal processing circuit. Its magnification is controlled by the host computer and can be set in the human-machine interface.

3.2 Hardware Circuit Design

In the circuit of electromagnetic ultrasonic metal pipeline corrosion detector, the circuit of burst wave generator, boost conversion and driving circuit are quite different from that of piezoelectric ultrasonic.

3.2.1 Sudden Wave Generator

The burst wave generator is realized by programmable gate array (FPGA). The clock signal of 100 MHz is generated by PLL in the FPGA. As the global clock source, the clock source is provided for A/D conversion, address signal generation, burst wave generator and other circuits. The clock source divides frequency through a preset frequency divider to generate the frequency signal (Sf) needed for EMAT excitation. After Sf enters the high-level pulse width counter, every rising edge makes the counter output high-level, and at the same time begins to count the clock source at 100 MHz. After counting the preset value, the output becomes lower, so that the periodic signal with adjustable high-level pulse width and Sf frequency can be produced. The delay counter is used to generate another burst wave with the same frequency and a certain delay compared with the first one. The delay is 10 ns, and the delay is generated according to the preset count value. The method is that there are two registers in the delay counter. The first register is the delay number register and the second one is the pulse width register. Every time the Sf signal rises, counting begins. After counting the specified delay number, the counter outputs a high level; After that, the pulse width counting is started, and after reaching the pulse width counting value, the counter outputs low level. In this way, a second signal with dead time control and the same frequency as the first one is generated. In order to achieve a specified number of burst waves, the pulse counter is output to a high level at the rising edge of each trigger signal. At the same time, the pulse output of the delay counter is counted. After counting the set number of pulses, the pulse counter is output to a low level. When the signal and the two signals are operated logically and operatively, a set frequency and a specified number of burst waves can be generated. The generator is implemented in Verilog HDL language. In addition to the frequencies of 1.5 MHz and 2.5 MHz, it can generate other frequencies as needed

3.2.2 Driving Circuit and Boost Conversion

The driving circuit uses high-voltage and high-speed MOS devices and full-bridge inverters to generate the required high-current pulse wave. The pulse wave is boosted by transformer and connected with EMAT coil by tuning matching circuit to excite electromagnetic ultrasound.

The tuning circuit is mainly based on different probe frequencies, using appropriate capacitance value and the probe coil in parallel to make it resonant, so that the energy output is optimal, and the output waveform is closer to sinusoidal.

3.2.3 Receiving Circuit

The receiving circuit of the piezoelectric flaw detector is basically the same as that of the receiving circuit of the piezoelectric flaw detector. The difference is that the EMAT coil is equivalent to a weak inductive voltage source, and the matching of the front stage is very important. Through a variety of comparative tests, the use of transformers for coupling matching has achieved good results.

3.2.4 Digital Signal Processing

The FPGA includes digital bandpass filter, average filter, detection, alarm processing circuit, etc. In addition to alarm processing circuits, other circuits are general digital processing circuits, which can be directly generated by the development tools of FPGA. The alarm circuit mainly analyses the phase, amplitude and width of the waveform. After eliminating the interference clutter, the waveform data that crosses the set alarm threshold is added into the buffer and the defect location is recorded. Finally, the waveform data is sent to the host through the USB interface.

After digital signal processing, power frequency interference and surge interference are effectively eliminated, and high frequency random noise is attenuated by about 20 dB. To further increase the processing effect of digital signals, larger capacity of FPGA devices is needed.

3.3 Software Design

Electromagnetic ultrasonic metal pipeline corrosion detector is based on Windows XP system. The development tool is Microsoft Visual Studio software. The detection software is designed with three layers: the hardware driver and communication software of the bottom USB interface, the data analysis and processing software of the middle layer, the human-computer interaction interface of the top layer and the storage software of the detection results

The hardware driver functions of USB interface include the detection, enumeration, determination, reading and writing test, state detection and other functions of USB devices. The USB interface chip FT232H with core driver and SDK library can directly call the functions provided to achieve the above functions without studying the USB protocol. USB communication software completes data exchange between host and FPGA and MCU. Its main functions include transmitting control commands and reading detection data to MCU and FPGA, and using multi-threading technology.

The data transmitted by sending thread includes trigger mode, period, burst wave parameters, A/D conversion frequency, acquisition length, band-pass filtering, detection, gain and suppression parameters, gate, alarm parameters, etc. Receiving threads are used to read echo data and alarm data, which requires high reading speed. For this reason, a 4kB FIFO is set up in the FPGA and bonded with the FIFO of the USB chip. The actual reading speed can reach more than 20 MB/s.Data analysis and processing software mainly includes: data cache, A scan data processing, B scan data processing, C scan data processing, corrosion evaluation and so on.

A-scan data processing flow: sound speed setting, temperature compensation; thickness calculation in body wave mode, corrosion depth calculation; circumference calculation in circumferential detection in surface wave mode, arc length calculation between defect position and probe position, the equivalent size of defect is calculated according to wave amplitude. The thickness calculation method and the defect equivalent calculation method in piezoelectric ultrasound can be used in the algorithm.

B-scan data processing flow: measurement of scanning step size, calculation of corrosion location and size, generation of radial and circumferential defect distribution data table; scanning step size can be measured by external trigger mode, each external trigger pulse corresponds to a fixed interval, which can be generated by encoder, grating ruler, or position signal feedback from stepping motor or servo motor. When triggered internally, a default value close to the scan speed can be set instead. The data processing of B scan depends on the result of A scan

C-scan data processing flow: According to the predicted shape and geometric size of the pipe or tank and the results of B-scan processing, three-view data of corrosion distribution are generated, and the area, location, thinnest wall thickness and corrosion depth of the maximum corrosion defects are calculated.

Corrosion evaluation: The main factors for comprehensive analysis of pipeline safety are the results of C-scan treatment, physical and chemical properties of materials, size of stress analysis, service environment of pipelines and working conditions. Among the above factors, except for the field detection data, other factors can be stored in the database and directly invoked in the analysis and processing. The instrument adopts minimum wall thickness measurement and safety evaluation method of corroded pipeline.

Human-computer interaction interface software includes shift parameters, workpiece parameters, instrument parameters, evaluation standard parameters, etc. The contents displayed include pipe wall thickness, defect depth, location, size, A, B, C scan views, etc. Storage software is used to record the above contents into database or parameter files, and also has the function of generating test reports.

4 DISCUSSION

In order to test the technical specifications of the electromagnetic ultrasonic metal pipeline corrosion detector, the piezoelectric ultrasonic detection method and test block were used to test the instrument.

Firstly, the test pieces are compared in the thickness range of 3-200 mm. When the thickness is less than 80 mm, the detection error does not exceed 0.05 mm; when the thickness is 80-200 mm, the detection error does not exceed 0.2 mm. Secondly, by testing flat bottom hole, defects of 2 mm artificial flat bottom hole can be found in the range of 50 mm thickness. Finally, the surface wave is used to detect the small holes at the distance of 100 mm from the probe.

From the test results, it is necessary to improve the signal-to-noise ratio (SNR) to detect the defect of 2mm artificial flat bottom hole. This can be solved by increasing the transmission power, improving the signal-to-noise ratio of the amplifier circuit, and using a larger capacity of the FPGA to increase the number of digital filter nodes and average times.

5 CONCLUSION

The pulse emission voltage of the electromagnetic ultrasonic metal pipeline corrosion detector is 1300 V, the number of pulses is adjustable in the range of 1-10, the pulse frequency is adjustable in the range of 50 kHz-5 MHz, and the detection repetition frequency can reach 1000 Hz. Its thickness and defect detection meet the requirements of metal pipeline corrosion detection. For the detection of cryogenic frozen places and high temperature pipelines above 100 C, the electromagnetic ultrasonic metal pipeline corrosion detector has incomparable advantages compared with piezoelectric ultrasound. After cooperating with the automatic scanner, it can also realize the automatic corrosion detection outside the pipeline and inside the pipeline.

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