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Development of EMA Guided Wave Technique for Testing of Wires

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Abstract

A new technology using electromagnetic acoustic testing to detect the defect in wire is given in the paper. The principle and methods to excite ultrasonic guided wave in wire by adopting electromagnetic acoustic technology, the component and feature of electromagnetic acoustic testing for wire and the experimental effect of the system are mainly described herein.

Keywords: wire, electromagnetic acoustic testing, guided wave, electromagnetic acoustic transducer (EMAT), nondestructive testing (NDT).

1. Introduction

Wire is one of main type materials used in engineering construction and mechanical manufacturing, which contains various types and is used in wide application and has about 10% occupying in domestic steel production. Modern industry and building industry bring high and high demands for the quality of wires, especially for high strength pre-stress reinforcing bar and steel strand used for railroad bridge, long span cable-stayed bridge and other large buildings, and the raw materials to manufacture wires specially used in mobile industry and mechanical industry. At present it is still required to import large amount of high quality wires, the main reasons rely on the poor quality and reliability of domestic products. Effective NDT is just an important means to solve the problem. Therefore it is necessary to carry out NDT for wires used in important application.

2. Analysis on ultrasonic guided wave defect testing for wire

Compared with ultrasonic bilk wave, guided wave has features of long spread distance and fast testing. Testing sensitivity of ultrasonic guided wave depends on the size of detected object (it is different from the testing sensitivity of bulk wave which relates to the wavelength of ultrasonic wave). Guided wave has capacity of effectively detecting fault of across section S/1000 in spreading approach of ultrasonic wave, furthermore it has more testing sensitivity for small piece. In general, wire has small across section and the production speed is fast, which are especially suitable for the testing with ultrasonic guide wave.

As known, by means of properly selecting frequency of piezoelectric crystal and adjusting the incidence angle of piezoelectric probe, guide waves can be generated (e.g. Lamb wave, Rayleigh wave and rod wave) in detected pieces in traditional piezoelectric ultrasonic testing technology. However, in consideration of much complex impure wave mode of ultrasonic wave given by piezoelectric technology plus couplant is necessary during spreading of ultrasonic wave, therefore, piezoelectric ultrasonic testing is unsuitable for the detecting of wire.

As a new NDT technology in recent years, EMA testing can excite and receive acoustic wave with the help of electromagnetic induction between the high frequency coil in EMAT and the surface of detected piece, thus no couplant is required, and unnecessary to contact the detected piece. By designing EMAT and selecting exciting frequency properly, high pure ultrasonic guided wave can be excited out with EMA method. Hence applicable prospect can be expected to use the EMA technology in defect testing of wire to ensure product quality.

3. EMA guided wave exciting in wire

Guided wave is generated owning to the multi reflection of acoustic wave between the discontinuous interface of medium which can generate complex interference and geometric dispersion. Guided wave mainly contains the guide wave in cylinder and the SH wave, SV wave, Lamb wave and leaky Lamb wave[1] and etc. Based on the theory of Silk and Bainton, guided wave in cylinder can be: a. axisymmetric longitudinal mode $L(0,m)$, m=1,2,3,□□; b. axisymmetric torsion mode $T(0,m)$, m=1,2,3,□□; c. non-axisymmetric bending mode $F(0,m)$,n,m=1,2,3,□□. In various modes, variable m expresses the vibration type in radius of cylinder, variable n expresses the spiral spreading type around cylinder. In which mode $L(0,m)$ and mode $T(0,m)$ are both particular cases of mode $F(n,m)$ when n=0.

Two methods generating acoustic wave with EMA technology are available in generally, i.e. Lorentz force effect and Magnetostriction effect. Method generating ultrasonic guided wave with the aid of Lorentz force effect is to move a coil applied with high frequency current closely to surface of detected metal, eddy current with corresponding frequency will be induced in the superficial surface of metal. If a magnetic field is applied in the detected metal at the same time, a force with the same frequency as eddy current will be generated under the magnetic field effect, i.e. Lorentz force. The spreading of Lorentz force in piece can excite acoustic wave. Method generating ultrasonic guided wave with the aid of Magnetostriction effect is to apply a magnetic field generating from high frequency current on detected piece. Ferromagnetic material consists of many self-magnetized domains, which are arranged in disorder without magnetizing effect and the magnetism will be counteracted mutually, thus it appears neutral magnetism in macro. If it is applied with external magnetic field, magnetic domains will be rotated and transferred to cause macro transformation of metal, i.e. magnetostriction effect. Acoustic wave is generated with the spreading of magnetostriction effect.

In ambient temperature, wire made of ferromagnetic metal has much strong magnetism, therefore magnetostriction effect can be the main means to excite ultrasonic guided wave. A method using magnetostriction effect is adopted to generate ultrasonic guided wave is given in figure 1. A longitudinal stable magnetic field B is applied on detected wire, longitudinal alternate magnetic field B_L can be generated on wire surface by using the high frequency coil wound around the circumference of wire. Because coils are periodically arranged in the longitudinal direction of wire, the magnetostriction effect F_M generated under the common effect of stable

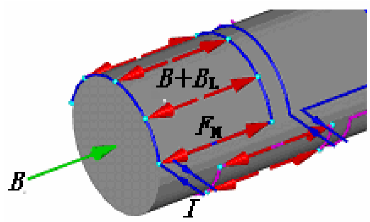


Fig. 1 Principle of exciting EMA guided wave

magnetic field B and alternate magnetic field B_L will spread in longitudinal, and the guided wave pattern is called as axisymmetric longitudinal mode L(0,m).

4. EMA guided wave defect testing system for wires

EMA guided wave defect testing system developed for ferromagnetic metal wires by Central Iron & Steel Research Institute is showed in figure 2, which consists of EMAT,

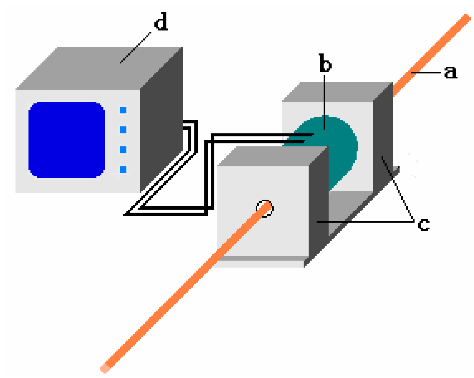


Fig. 2 EMA guided wave detect testing system for wires

a. wire b. transducer c. magnetizing unit d. EMA defect detector

magnetizing unit and EMA defect detector.

Magnetizing unit in the system consists of two coils in serial, a stable magnetic field in longitudinal direction of wire can be generated to realize the longitudinal magnetism when coils are energized with direct current.

EMAT consists of two coils of transmitting coil and receiving coil, which are made of multi-windings surrounding wire with interval 1/2 wavelength of acoustic wave, and windings are periodically arranged in longitudinal. Alternate magnetic field with corresponding frequency will be generated in detected wires.

EMA defect detector used for defect testing of wire is showed in figure 3 and the block diagram is showed in figure 4. Repeated pulse train will be generated by electromagnetic acoustic defect detector to control D/A with the aid of computer system, which can be fed back to EMAT via the power amplification. At first, testing signal containing wire quality information, which obtained by EMAT will be amplified via preamplifier, then it will be transmitted to computer system via A/D conversion after adjustable gain and demodulating treatment. Computer system will distinguish the signals and diagnose if defect exists, and carry out treatments such as display, classification, statistic and store for testing results.

Fig. 3 EMA defect detector

In general of SNR of testing signal is rather weak which may hamper to find out minor defect, owning to the coarse surface and iron scale of rolled wire when EMA guided wave testing system is used for automatic defect testing. Furthermore, accuracy of detected result may be impaired by the electromagnetic radiation generated from welding machine, overhead crane, frequency converter and etc. owning to the severe environment of industrial field. It can be seen from above that increasing SNR is the key to ensure testing reliability of wires. In general echo signal of guided wave defect testing for wires has certain frequency scope, while the bandwidth of noise induced from coarse surface and disturb induced from

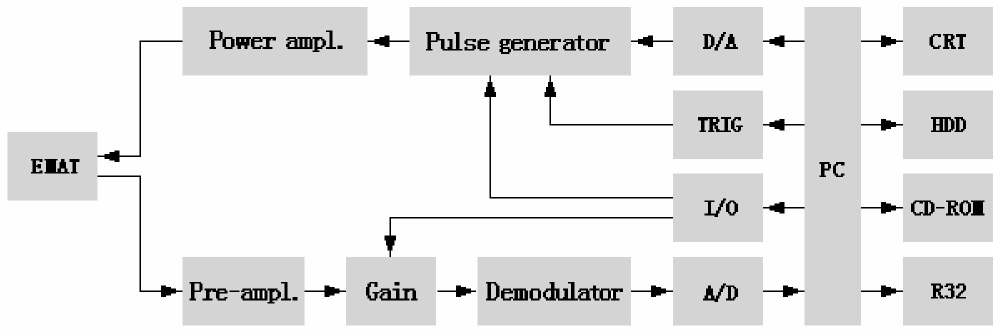


Fig. 4 Principle block diagram of EMA defect detector

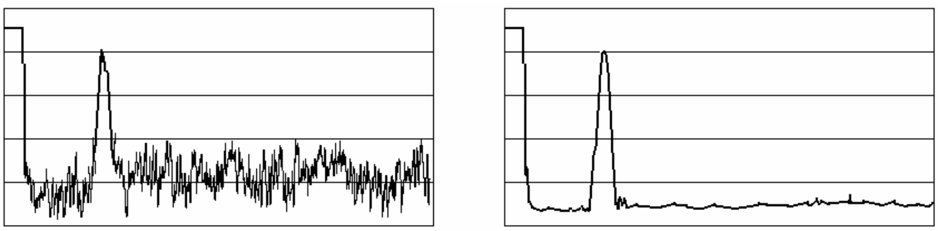
environmental electromagnetic radiation, therefore it is possible to eliminate interference noise of main frequency of echo signal with filtering method to improve SNR.

It is indicated from engineering that the IIR filter has a better frequency selecting characteristic than that of FIR when the same order is given, furthermore the operation speed is much fast and memory required is less. High order filtering can be realized with the of several two-order cascading filter of IIR filter, and the transfer function is:

$$H_n(z) = \frac{b_{0k} + b_{1k}z^{-1} + b_{2k}z^{-2}}{1 - a_{1k}z^{-1} - a_{2k}z^{-2}}$$

In which k=1,2,3 □□ n, n is the order of filter. Calculation speed can be accelerated by means of using repeated module command in designing of serial filtering software. By adopting the simple method, system resource required is less.

Impure noise in wire defect testing can be eliminated to clear the displayed waveform by carrying out digital filtering when operating the electromagnetic acoustic defect testing system, i.e. testing SNR is significantly increased, shown in figure 5.



Before filtering After filtering

Fig. 5 Digital treatment of wire testing signal

5. Experimental result of wire testing

By adopting the EMA guided wave testing system developed, favorable result had been obtained in the experiment of defect testing for wire with diameter 5～20mm, the system is capable of detecting defect of 0.1% across section of detected wires. In the experiment, detecting frequency 0.2～0.6MHz and acoustic wave pattern L(0,1-4) had been adopted. Furthermore, digital filtering treatment exerts an important role to increase testing SNR above 20dB.

Additionally, we can carry out testing experiment for various common natural faults in wires. Various defects, such as cracks, laps, inclusion, stomata and etc., may be occurred on surface and inside of wires in production due to the problems of smelting and rolling process. By performing proper test for wires with defects collected, favorable detecting result had

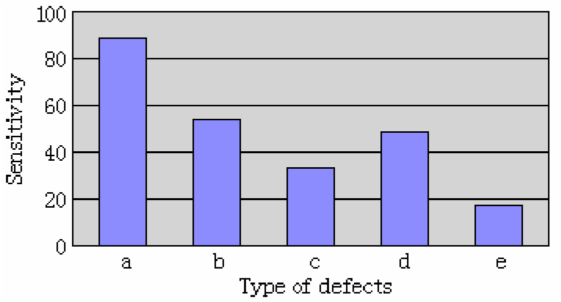


Fig. 6 Statistic of defect testing effect of wires

been obtained, as figure 6.

6. Conclusion

EMA guided wave defect testing is a new NDT technique for wires. Central Iron & Steel Research Institute had carried out the research and development for the technology jointly with Enterprise Research Institute (BFI), Germany with the methods of governmental international cooperation, and a series of progress and achievements had been obtained after a two years study. The technology can be used for the automatic in-line testing for high temperature high speed wire production, thus favorable application prospect can be expected, which has important significance to improve the development and application of EMA guided wave testing technology for wires.

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