A New Testing Method Combining EMAT with Eddy Current

Fengying HUANG [1], Zhenggan ZHOU [1], Junming LIN [2]

1. School of Mechanical Engineering and Automation, Beijing University of Aeronautics and Astronautics，Beijing 100083, P. R. China

Email: hfyfeng@163.com, zzhenggan@buaa.edu.cn

2. EddySun (XiaMen) Electronic Co. Ltd., Xiamen 361001, P. R. China

Email: lin_0592@126.com

Abstract

A new testing method，which combines EMAT (Electromagnetic Acoustic Transducer) with eddy current testing technology, is presented. The method aims to achieve testing the inside and surface defection simultaneously, increasing the efficient, lower the cost, and getting more information of the material to yield the reliable result than using one testing method of them separately. The implementary procedure of the method is that the signal in the combination probe is sent to the EMAT testing channel and the eddy current testing channel separately, passing through signal processing, and analyzed, finally the result analysis by synthesize. In the paper, the principle of the combination method is analyzed, and the combination probe and the system are designed. Three different steel samples are experimented with the combination measurement method. The result of the experiment indicates that the new method is feasible.

Keywords: Electromagnetic acoustic transducer, Eddy current testing, Lorentz force

1 Introduction

It’s a very important issue to improve the integrity and reliability of the testing result in nondestructive testing procedure. However, it always cost the testing time and expense. Every nondestructive method has different advantage and disadvantage characteristics and adapts to different situation. The application of the combination method can synthesize the advantage of the different testing method, to achieve more reliable testing and save the testing time, lower the cost and increase the location accuracy capability of the defection than using one testing method of them separately [1].

EMAT is a non-contact testing method based on electromagnetic induction theory. It has many advantages different from piezoelectricity transducer such as no couplant, working in a wide range of temperature, testing the crude surface or oxide scaled surface or curved surface material directly, and can excite a wide variety of ultrasonic wave mode. Eddy current testing method is also a non-contact method based on the electromagnetic induction theory. EMAT and eddy current testing method both need induct the eddy current on the surface to realize the test. That gives the foundation for combination. The aim of the method combination

EMAT and eddy current make use of the EMAT which is sensitivity to the inside defection and the eddy current testing method which is sensitivity to the surface or sub-surface defection. The combination method can find the defection inside and on the surface of the metal simultaneity. Combining the two methods can take the advantage of them to complete the inspection and get more reliable result than using one testing method of them.

2 Analyze the mechanism of the method combination EMAT with eddy current testing

Maxwell's equations are the theory of the eddy current induction. When the coil is imposed alternation current above the sample it will produce alternation magnetic field, which induct eddy current on the metal surface. The density of eddy current lies on the change velocity of the magnetic field and the intension of the exciting current. The frequency is the same as the changes of the current in the coil [2]. Based on the Len 'z law the magnetic field which is induced by eddy current will prevent the change of the magnetic field produced by induced current (increase or decrease) [3]. The magnetic field will change the resistance of the coil. If there are some in-continuous on the surface will effect the distribution of the eddy current, the magnetic field produced by the induct current will also be changed, then it will change the resistance of the testing coil. It will complete the test by getting the changes of the resistance.

In the EMAT transmitting mode, high frequency eddy currents are induced by an alternating high current in the excitation coil interact with the static magnetic field to yield a Lorentz force. The force changes with the eddy current. This force can generate elastic waves, namely ultrasonic, which propagates through the metal. On the surface of the sample, the ultrasonic echo wave produces a particle velocity in the sample under the receiver coil. In the presence of a static magnetic field, the interaction between the particle velocity and the field establishes current densities in the material. These current densities generate a time varying magnetic field inside and outside of the sample, which can be detected as an induced voltage in a receive coil above the sample. This process is receiving mode of the EMAT. In the magnetic conducting material, magnetostriction is also contributing to generate the ultrasonic. The alternating magnetic field makes the volume of the magnetic material change to produce the libration propagation inside of the material. Magnetostriction is the same as piezoelectricity that it can translate the magnetic field energies to the mechanism striction and also feasible conversely [4].

The EMAT energy transform process happens in the skin depth. Despite the eddy current and EMAT realized the testing making use of the induction eddy current, eddy current testing method picks up the change of the eddy current induced by the surface situation and EMAT excites the ultrasonic due to the eddy current, then induct eddy current by the ultrasonic vibration. Their signals are different in time and space. The eddy current receiving probe picks up the signal response by the surface and sub-surface condition of the material. Ultrasonic will echo when meet the inside of the defection. The particle velocity in present the bias magnetic fields will induct eddy current above the receiving probe. Then the echo signal reflecting the inside defection can be picked by EMAT channel. EMAT is hard to discriminate the surface defection by bulk wave for the testing dead zone.

3 Combination testing system of EMAT and eddy current

3.1 Design of the combination probe

The testing method combination EMAT and eddy current use one probe to implement the two testing methods simultaneity. The probe integrates the common characteristic of eddy current and EMAT probe. The coil of probe is spiral coil include of inside and outside circle. Fig.1 is the structure of the probe. The probe composes of the spiral coil, Nd-Fe-B permanent magnet, the probe shell shield, wear-protection layer and BNC head. The outside coil is as transmit and receive coil of EMAT. The inside of the coil is as the eddy current testing coil. The high voltage pulse generator output several continuous pulses as the exciting signal of the probe.

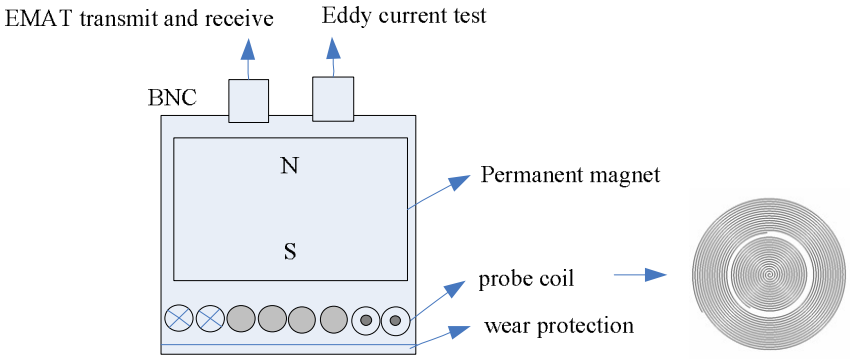


Fig. 1. Structure of the combination probe

One channel of the probe connects to transmit and receive circuit of EMAT; another channel connects to the eddy current receiver circuit to implement signal processing. The capacitance is paralleled to the coil for impedance matching to increase the transmit power.

3.2 Framework of EMAT and eddy current combination testing system

The combination method can be described by Fig.2. The signal of the probe can be sent to the EMAT channel and eddy current channel simultaneously. The system can get the data of the deep layer from the EMAT channel after signal processing and get the surface and sub-surface data from the eddy current channel to analysis, and then the testing data is analyzed synthetically to achieve the full and reliable evaluation.

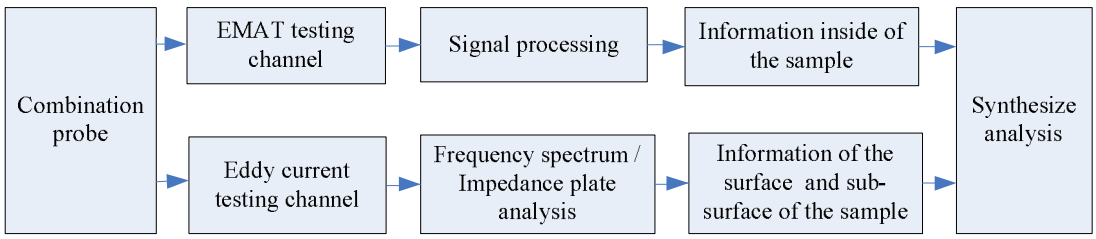


Fig.2. System framework of the combination testing method

For the EMAT channel, the transform power is lower than the piezoelectricity transducer, the signal of the receiving is very small, needing multi amplified. The amplify circuit should

be capable of prevention the noise for it is disturbed by electromagnetic easily. The following signal processing is the same as the conventional piezoelectricity after amplifying enough and passing through some filters.

The exciting signal to implement the eddy current test is several continuous pulses not the continuous sine signal as the conventional eddy current test. It can be analysis by time domain and frequency domain or the resistance plane analysis for the signal in eddy current channel.

4 Experiment with combination probe for steel sample

The combination method of EMAT and eddy current make use of the high voltage pulse exciting signal to induct eddy current on the surface of the detecting material. One channel of the probe connects to the eddy current testing channel to time and frequency domain analysis, and the other connects to the EMAT channel to corresponding signal process. The signal in the EMAT channel is recorded using oscilloscope. The probe of the inside circle is 40 turns of 0.15mm diameter copper wire. The outside circle is 50 turns of 0.3mm diameter copper wire.

Three different samples are used to validate the feasible of the combination method. The first is the steel which has different deep crack on the surface. The second is the steel plate to simulate the thickness reduction. The third is the steel sample with holes inside of the material. The signal in the eddy current channel which is response of the crack on the surface and the signal in EMAT channel response of the thickness and the hole inside of the sample are got by these experiments.

4.1 Experiment of steel sample with different depth surface crack using combination probe

Fig.3 is a diagram of testing the cast steel sample whose thickness is 10mm with 5mm, 3mm, 1mm, 0.5mm depth, 0.15mm wide manual flaw on the surface. Fig.4a (1), (2), (3), (4) are the testing result with combination probe in time domain from eddy current channel, 5mm, 3mm, 1mm, 0.5mm depth crack, respectively. The maximum amplitude in the fig. can be seen increased with the deeper of the crack. It also gets the detecting result from frequency domain analysis. The amplitude of the signal changes very visible with the depth of the crack deeper in frequency spectrum analysis. The EMAT channel can’t get changes for the surface crack because of the testing dead zone.

Fig.4b is a diagram of the echo wave from the EMAT channel with the combination probe in the oscilloscope through amplifying 60dB. There is only the echo wave from the bottom side. S1, s2, s3 shown in the fig. 4(b) are the echo waves from the bottom of the sample firstly, secondly, thirdly, respectively. The ultrasonic is shear wave whose velocity is 3250m/s. The thickness is 10.01mm yielded from the time 6.16 μs between the echo waves and the sound velocity of the shear wave. The error is 0.1%. The thickness of the sample can be yielded from the EMAT channel. The eddy current channel has no signal about the bottom side due to the skin effect.

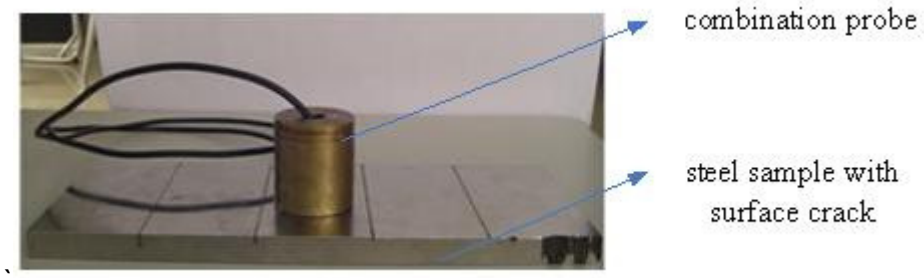
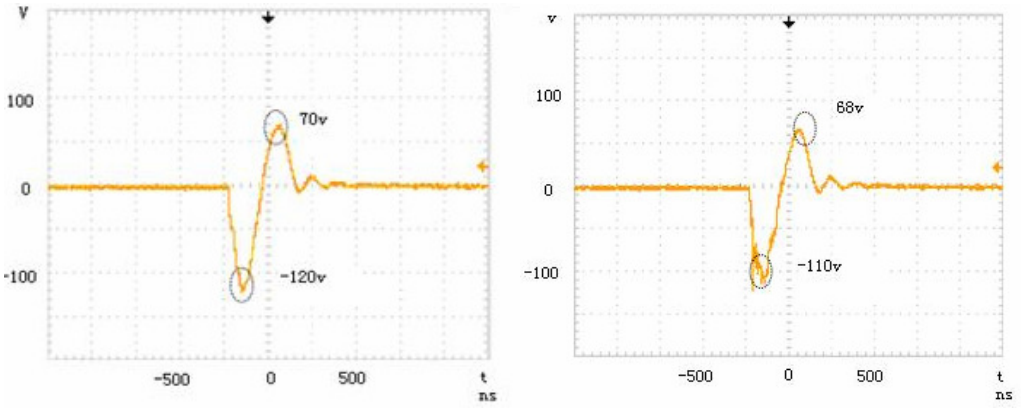
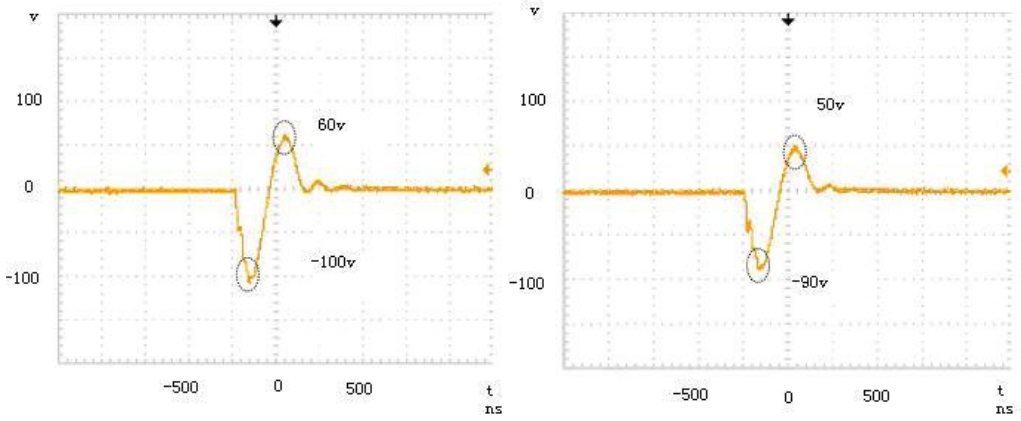


Fig.3. Steel sample with different depth surface crack testing with combination probe



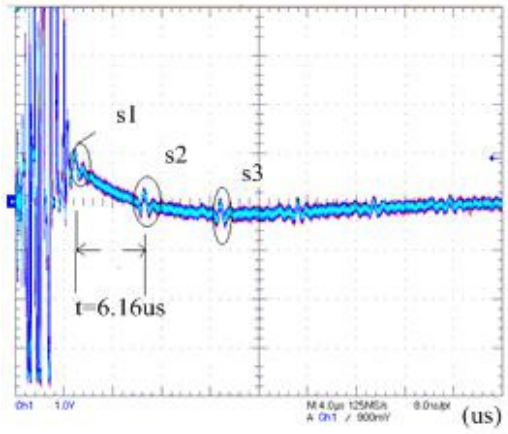
(1)

(2)



(3) (4)

(a)

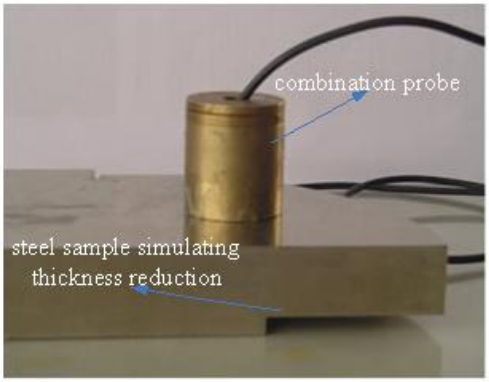


(b)

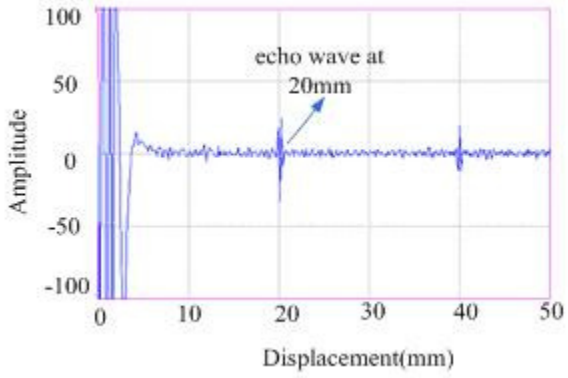
Fig.4. Testing result of the object shown in fig.3 with combination method (a). Result in eddy current channel testing the steel sample with surface crack in time domain with combination probe: (1) With 5mm depth surface crack (2) With 3mm depth surface crack (3) With 1mm depth surface crack (4) With 0.5mm depth surface crack (b). Echo wave in EMAT channel testing the steel sample with combination probe

4.2 Experiment of steel sample simulating the thickness reduction with combination probe

Fig.5 (a) is a testing diagram of the experiment simulating the thickness reduction with the combination method. The thickness of the sample is 25mm, and is milled 5mm from the bottom of the sample. Adjust the amplifier to 95dB, fig.5 (b), 5(c), 5(d) are the result of the echo wave of the bottom side of 25mm, location of 20mm and the location of the thickness decrease, respectively.



(a)



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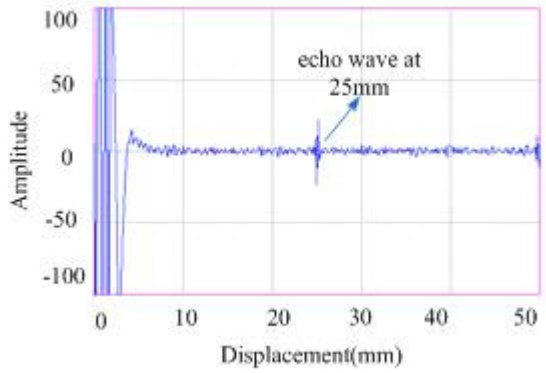
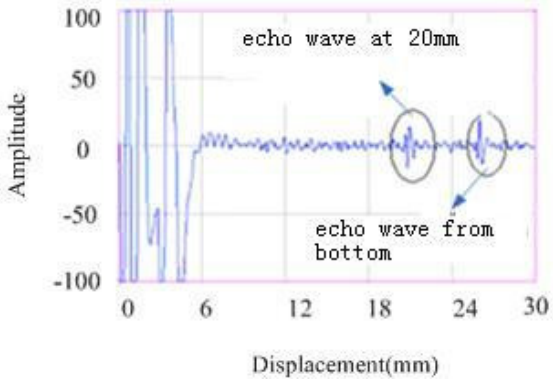


(c)

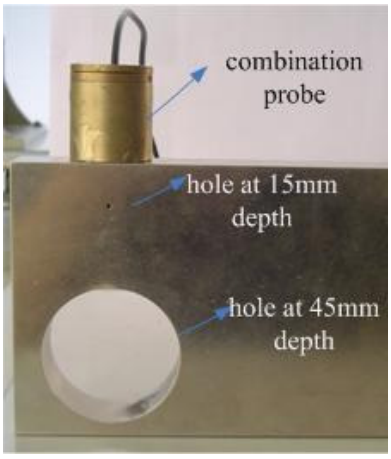


(d)

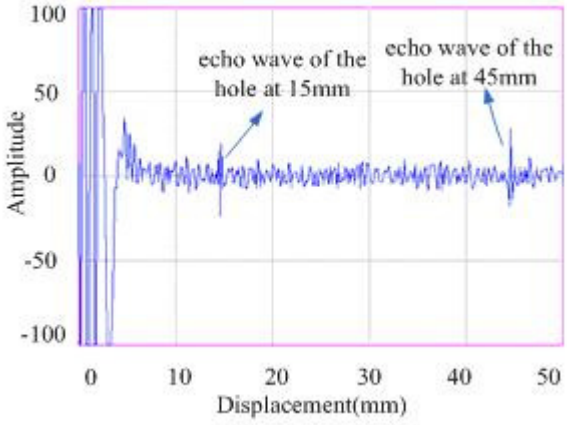
Fig.5. Result of testing the steel plate simulation of the thickness reduction in EMAT channel with combination probe. (a). Testing the steel sample simulation thickness reduction with combination probe. (b). Testing result from 20mm location in EMAT channel. (c). Testing result from 25mm location in EMAT channel. (d). Testing result from location of thickness reduction in EMAT channel.

4.3 Experiment of the steel sample with hole by using combination probe

Fig.6 (a) is a diagram testing the steel sample with hole inside of the material to validate the feasible of testing inside defection with the combination probe. There are two holes in the sample whose size is the 1.5mm diameter and 50mm diameter. Fig.6 (b) shows the result from EMAT channel by adjusting the amplifier to 103dB. The echo wave can be picked from the EMAT channel. But eddy current channel has no changes for the sample without surface defection. It is concluded that the method has the ability of testing the inside of the defection with the combination probe.



(a)



(b)

Fig.6 Result of testing the hole defection inside of the steel. (a) Sample with hole defection testing with combination probe. (b) Result of the measurement with combination probe in EMAT channel

5 Conclusions

In a general, the testing method combining EMAT and eddy current is feasible from the upwards experiment result. The method can be used to test the inside, surface and sub-surface defection of the metal material simultaneity. The combination method integrates the two

methods' advantages to analyze the testing result more integrity and more reliable than using each technique separately. It can reduce the cost of the testing and increase the testing efficiency. The method is studied initially and should be researched further in the signal processing; increasing the testing sensitivity and analyzing the testing result synthetically. But we are in faith that it will have the bright application future in nondestructive testing domain.

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