Study on the Lift-off Effect of EMAT

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Abstract

Noncontact with the test specimen is the advantage of Electromagnetic Acoustic Transducer（EMAT）, but it lowers the efficiency of EMAT, because the lift-off of transducer reduces the magnitude of alternating magnetic field in the specimen which has close relationship with exciting and receiving ultrasonic signals. The distribution and intensity of the alternating magnetic field at different lift-off values are simulated with the software of ANSOFT, and the relationship between lift-off and received signals is analyzed by experiments. Results show that the lift-off of transmitter should be about 2mm.

Key words: EMAT; lift-off; magnetostriction;

1. Introduction

Using conventional piezoelectric ultrasonic transducer to test cracks in metals, coupling medium is necessary, which makes it inconvenient in some occasions. So electromagnetic acoustic transducer(EMAT), which generates ultrasonic waves in metals directly, has received more attention. EMAT uses a combination of static and alternating magnetic fields to convert electrical energy to acoustic energy. Compared to piezoelectric transducer, EMAT has features, such as noncontact with the specimen when operating, high speeds, no coupling medium etc[1]. Noncontact with the specimen is its advantage, but the efficiency of the transducer becomes much lower as the increase of the lift-off (the distance between the transducer and the specimen).On the other hand, if the lift-off is small, the property of the transducer is not stable, because a slight variation of lift-off which is inevitable in engineering, will make its response change dramatically. So it is necessary to find an appropriate lift-off value for optimal signal response.

2. Principle of magnetostrictive EMAT

EMAT is mainly based on the theory of Lorentz force and magnetostriction. For ferromagnetic materials, the magnetization leads to the dimensional change in the magnetization direction, which is called magnetostriction[2]. The magnetostrictive force makes elastic deformation which will generate ultrasonic waves in the metal. When EMAT is used for ferromagnetic materials, the magnetostriction becomes important, especially in the low magnetic field situation[3]. So the EMAT designed in this paper is based on magnetostrictive mechanism.

The magnetostrictive EMAT consists of a magnet that produces a bias magnetic field, and a sensor coil excited by a high frequency sinusoidal electric current that produces alternating magnetic field. The driving force of ultrasonic uses a high frequency vibration of magnetostriction generated by the compound magnetic field. Magnetostriction is a nonlinear effect, when the bias magnetic field is much stronger than the alternating magnetic field, the magnetostriction function follows that[4]

$$\varepsilon = S^H T + d_t H \quad (1)$$

Where ε is strain, T is stress, S^H is the elastic constant measured for H=0, d_t is the inverse magnetostrictive stress constant, H is the alternating magnetic field. When T=0, it represents the relation between ε and H. The inverse magnetostrictive stress constant d_t is function of the frequency, the magnitude of H, the bias magnetic field H_0 and the magnetic history of the material.[5] As ε is the base of ultrasonic, and it is function of H, so we can estimate the ultrasonic by H.

3. Analysis of lift-off effect by simulation

Because H has close relation with ultrasonic, and lift-off will reduce its intensity in the specimen, we first analysis the relation between H and lift-off. To test the effects of lift-off, a sensor coil configuration is simulated as shown in Fig.1. The coil is located near the surface of a steel plane with lift-off G, and driven by 20A sinusoidal current at the frequency of 250KHz.

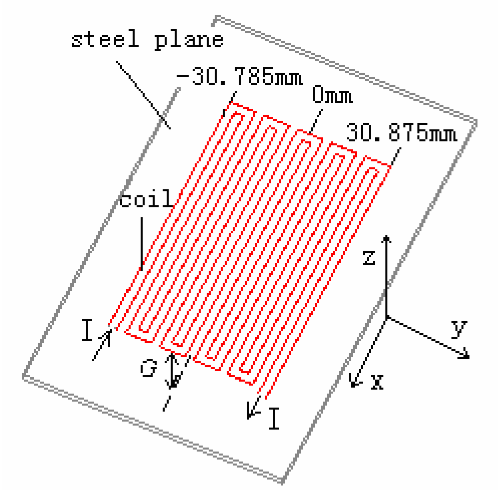

Fig.1 sensor coil configuration

When the high frequency electric current drives the sensor coil, the current in the coil wire is not distributed equably, but concentrates at the edge of the wire because of skin and proximity effects. When G is small, the distribution of alternating magnetic field induced in the steel plane is similar to the current in the wire, so the alternating magnetic field is stronger under the edges of the wire. As the increase of G, the interaction of the currents in the edges of the wire makes the alternating magnetic field distribute mainly under the middle of the wire. At the same time, the alternating magnetic field in the steel plane becomes smaller as the increase of G. To testify the analysis, we use the software of ANSOFT to simulate the induced magnetic field distribution in the steel, and the calculation results are shown in Fig.2.

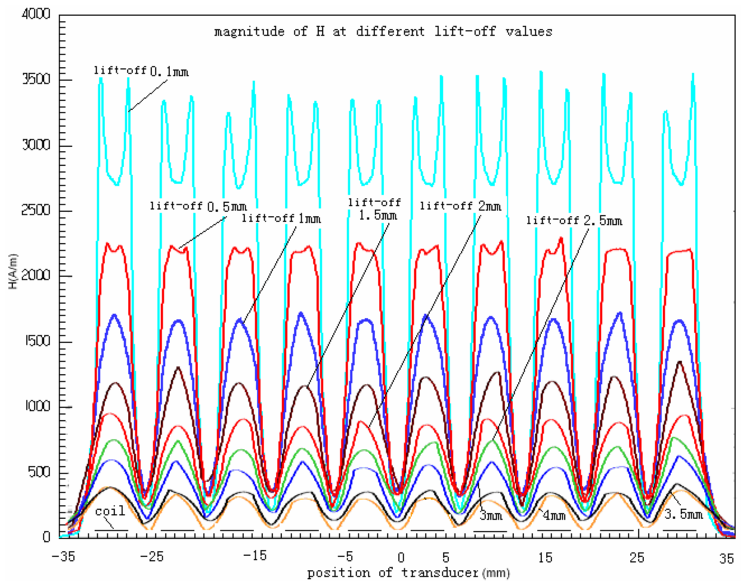

Fig.2 The calculation results of the induced magnetic field distribution

From the results, we can see that the magnetic intensity decays exponentially with G. When G is 0.1mm, the magnetic intensity is more than 3000A/m, when G is 1mm, it becomes 1700 A/m. Using linear least-squares fitting method to approximate the function between H and G, the results can be expressed as formula (2):

$$H = 1386 * \exp(-2.336 * G) + 2413 * \exp(-0.4883 * G) \qquad (2)$$

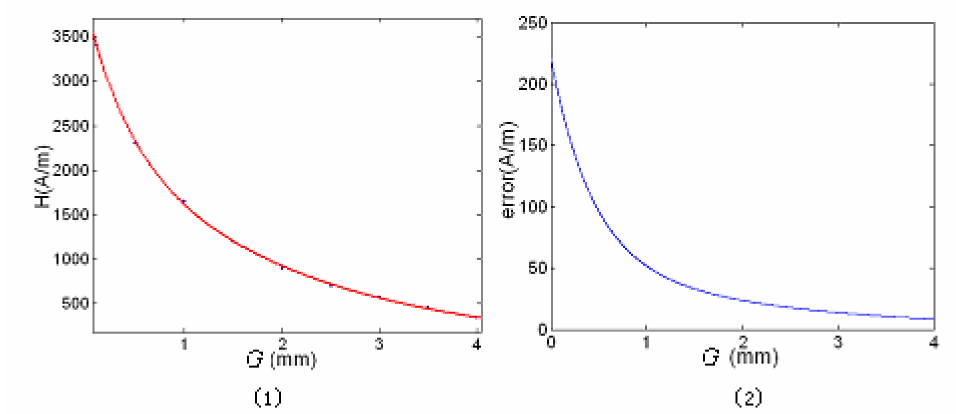

Fig.3 intensity of H and average error versus G

Fig.3-(1) describes the relation between H and G. Fig.3-(2) shows the average error of H with a 0.05mm shake of G. It can be concluded that if G is small, a slight shake of G will cause great change of H, and as the increase of G, H changes gently. The average error is about 13% when G is 2mm compared to 0.1mm. So in order to reduce the error of transducers, G should not be too small. But as the increase of G, the intensity of H drops quickly, which will make the efficiency of transducers low. So we should balance the stability and efficiency to select the appropriate value of G.

4. Experimental Procedure

To verify the analysis of lift-off effect, experiments are performed. Fig. 4 shows the block diagram of the experimental setup. The static magnetic field is provided by an electromagnet. Plate of low carbon steel is 8 mm thick. A sinusoidal burst current of 250 KHz drives the EMAT to generate ultrasonic waves in the steel. The transmitter and receiver are placed 300 mm apart.

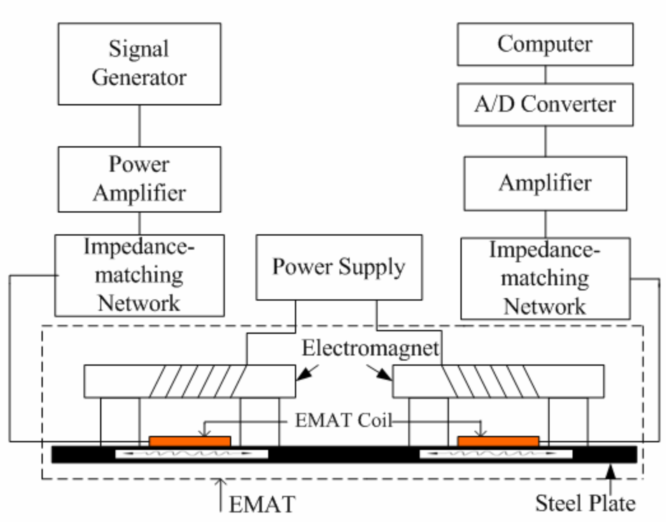

Fig. 4 block diagram of the experimental setup

To study the lift-off effect of the transmitter and receiver, two procedures are performed. First, put the transmitter on the plane, adjust the lift-off of the receiver; then, put the receiver on the plane, adjust the lift-off of the transmitter. The results are shown in Fig.5. From the received signal, it can be concluded that lift-off reduces the efficiency of EMAT. In accord with the theory analyses, if the lift-off is small, the peak value of signal (P) changes observably, and the signal becomes weaker as the increase of lift-off. The transmitter is affected by the lift-off more evidently. If the lift-off of transmitter is higher than 3mm, the noise is stronger than the signal. So in order to get better signal to noise ratio(SNR), the lift-off should be less than 3mm. If lift-off is less than 1.6mm, the slope is big, and the transducer is not stable as the shake of lift-off. So to balance the stability and SNR, the lift-off value should be between 1.8mm to 2.5mm.

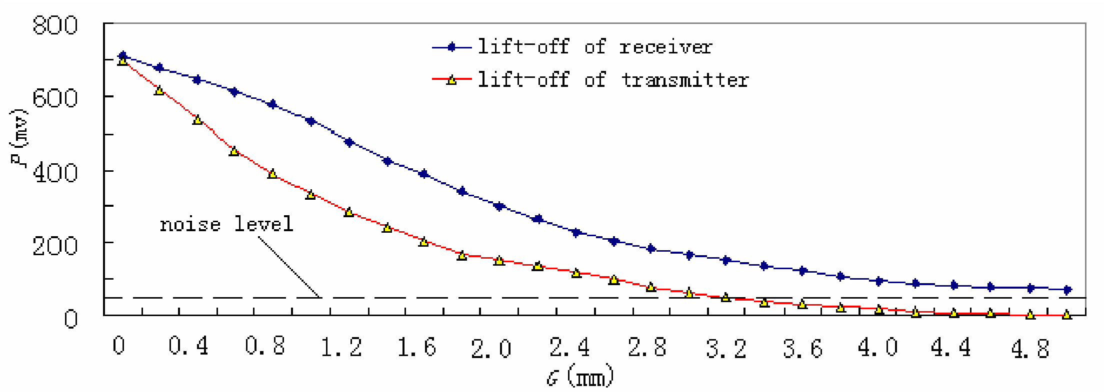

Fig.5 received signal at different lift-off values of transducers

Keeping the lift-off of transmitter and receiver 2mm individually, and increasing the lift-off of the other, the results are shown in Fig.6. It is concluded that 2mm lift-off of transmitter is more stable, and the signal changes little no matter the lift-off of the receiver. So in order to make the transducers work stably in complex environment, the lift-off of transmitter should be about 2mm.

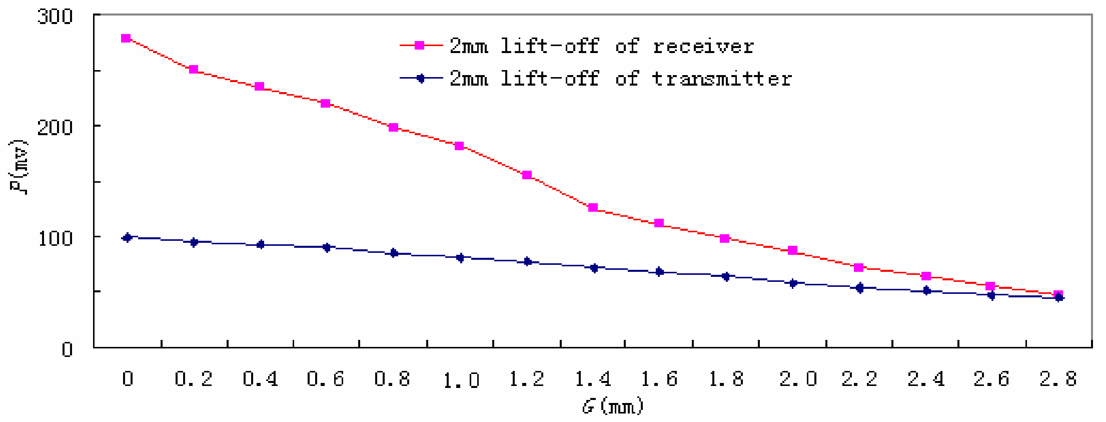

Fig.6 results of 2mm lift-off for transducers

5. Conclusion

(1) Both the transmitter and the receiver are affected by lift-off, as the increase of lift-off, the efficiency of EMAT decays exponentially.

(2) The transmitter is affected by the lift-off more evidently than the receiver, if the lift-off is small, the performance of EMAT will be instable as the shake of lift-off.

(3) Considered the stability and efficiency of EMAT, the lift-off of transmitter should be about 2mm.

Acknowledgements

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