High Accuracy Tiny Crack Detection in Metal by Low Frequency Electromagnetic Technique

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Abstract. A low frequency testing technology based on eddy current technique is proposed for detecting defects in some special equipment surface. A two-dimension model is built to simulate the distribution of low frequency (10 Hz) magnetic flux density nearby the surface of a metal plate. The influence of lift-off effect, coil diameter, crack shape on the measurement are discussed. And the crack measurement sensitivity of 0.6μm was obtained.

1. Introduction
Nondestructive testing technology [1] has been widely applied in industry for detecting defects in some special equipment. Compared to other detecting technologies, low frequency electromagnetic technique [2] has many advantages. For example, the deeper skin depth can be obtained, checkout equipment is convenient to take and the inspection result can be obtained quickly. The low frequency electromagnetic technique derived from eddy current technique [3] is based on the theory of Faraday’s law of electromagnetic induction. In this paper, a two-dimension model is built in COMSOL Multiphysics. Some interesting results are obtained by the finite element analysis.

Figure 1. Eddy current technique

The principle of eddy current technique is illustrated in Figure1. Alternating electromagnetic field is aroused after alternating current is applied on the exciting coil. Since the metal plate is the conductive material, some eddy current appears and mainly distributes in the plate surface due to the skin effect. When there is a crack nearby the plate surface, the flow direction of eddy current will change and its induced magnetic field will also change. Hence, we can know if defect exists nearby the plate surface by putting a detector near the sample plate.
2. Simulation
With the help of COMSOL Multiphysics, we use the finite element analysis method to simulate a series of experiments to know the properties of the low frequency testing technology. And our simulation is totally under a two-dimension model. Since the experiment is carried out by the software and simulation results can be easily obtained, the search coil needn’t be set. The simulation parameters are shown in Table 1. The simulation model is illustrated in Figure 2.

![Figure 2. Two-dimension model](image)

The exciting coil is made of copper and is put near the sample plate. There is a rectangular groove nearby the plate surface. By changing the coil diameter, lift-off value, defect size, defect shape and so on, we can find some interesting results.

| Parameter | Wire diameter | Turns | Current | Frequency | $\sigma$ (plate) | $\mu_r$ (plate) |
|-----------|---------------|-------|---------|-----------|-----------------|----------------|
| Value     | 0.2mm         | 500   | 10A     | 10Hz      | $5.727 \times 10^5 \text{ S/m}$ | 2000          |

3. Results and Discussion
As shown in Figure 3, the lift-off value changed, the distribution of magnetic flux density nearby plate surface is different. The curve dip means there is a crack. The depth of curve dip decreases with the increase of lift-off value. From Figure 4, we can know that the curve span increases with the increase of coil diameter.

![Figure 3. Effect of the coil lift-off value](image)  
![Figure 4. Effect of the coil diameter](image)
The effects of rectangular groove, V-groove, dovetail groove and combination groove (rectangle+V) are illustrated in Figure 5 and the accuracy of measurement is shown in Figure 6.

![Figure 5. Effect of the defect shape](image1)

![Figure 6. Accuracy of measurement](image2)

The sequence of magnetic flux density from strong to week is as follows: combination groove, rectangular groove, dovetail groove, V-groove. The minimum fractional error of 0.03% (0.6μm) was obtained as the separation distance is rightly equal to the crack width.

4. Conclusion
On the condition of our given parameters, we gain the minimum accuracy of measurement when crack spacing is rightly equal to the crack width. For the future work, we will develop an intelligent algorithm to do the optimum work under the different conditions. And also, experiments will be done to verify our simulation results.

5. References
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