Numerical Value Analysis of Eddy Current Probe Coil of Placement Model Based on ANSYS

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Abstract

Eddy Current Testing（ECT）is a universal testing method, which is widely used in many fields. Thickness measurement is an important application of ECT. In this paper, numerical simulating by ANSYS finite element analysis software, the two-dimension model of ECT probe coil is built, the impedance variation of probe coil is acquired, and normalization to the impedance value of the probe coil is realized, according to the variation of thickness of nonconductive cladding over nonmagnetic metal substrate and thickness of metal substrate. The calculated simulative result is coincident with the traits of the real transducer. Thus, an effective analysis method and reference basis is consequently offered for the research of ECT theory, transducer design and practical application.

Keywords: Eddy current testing， ANSYS，Finite element，Thickness，Impedance

1．Foreword

Eddy current testing [1-2] (ECT) is a detecting method, which making use of the coupling between the substrate and probe coil. Some of influencing factors, such as the trait, Figure and crack in substrate, can be reflected by the change of impedance of probe coil. Meanwhile, ECT is based on electromagnetic-induction. Thereby, the influencing factors concerning electromagnetic-induction, such as the conductivity, magneto-conductivity, size, flaw, thickness of the substrate and life-off distance (the distance between the probe and the substrate), can also be the testing targets in ECT [3]. ECT is so sensitive that many unimportant parameters will generate some disturbing signals, while we are testing one parameter. If only one parameter is varying, while others are keeping fixed in testing process, the impedance of this probe coil will simultaneously change with it, and then a linear relationship is obtained. Taking the life-off distance as example, we fix the conductivity, magneto-conductivity of the substrate and the frequency, only vary the life-off distance, and then the relationship between life-off distance and the impedance of this probe coil is acquired, they are linear. We build the two-dimension model of the probe coil based on ANSYS (a kind of finite element analysis software). Then we get the normalized plane impedance diagram by simulating the substrate of different material and working frequency, which indicates the impedance changes with the thickness of nonconductive cladding over nonmagnetic metal substrate and thickness of substrate. The authors expect that it offers a practicable and credible theory for analysis method of impedance of probe coil and practical application of ECT.

2. the Principle of Finite Element Analysis in Electromagnetic Field

It is thought that the first thing of ECT analysis and research is to analyze the questions on the Maxwell equations, including solving and validating these equations. The Maxwell equations can be described as below:

$$\nabla \times E + \frac{\partial B}{\partial t} = 0 \qquad \text{Faraday's Law} \qquad (2\text{-}1)$$

$$\nabla \times H - \frac{\partial D}{\partial t} = J \qquad \text{Maxwell-Ampere's law} \qquad (2\text{-}2)$$

$$\nabla \bullet J = -\frac{\partial \rho}{\partial t} \qquad \text{Charge conservation Law} \qquad (2\text{-}3)$$

In these equations, E is the electric field intensity, H is the magnetic field intensity, D is the electric flux density, J is current density, and ρ is electric charge density.

The question of boundary values with regard to the two-dimension electromagnetic field:

$$-\frac{\partial}{\partial x}\left(\alpha_x \frac{\partial \Phi}{\partial x}\right) - \frac{\partial}{\partial y}\left(\alpha_y \frac{\partial \Phi}{\partial y}\right) + \beta\Phi = f \quad (x,y) \in \Omega \qquad (2\text{-}4)$$

In this equation, Φ is the unknown function, ∂_x、∂_y、β is known parameters about physical trait of the field, f is fountain or inspirit function. The boundary item is :

$$\Phi = p \qquad (\text{on } \Gamma_1)\ ;$$

$$\left(\alpha_x \frac{\partial \Phi}{\partial x}\hat{x} + \alpha_y \frac{\partial \Phi}{\partial y}\hat{y}\right) \bullet \hat{n} + \gamma\Phi = q \qquad (\text{on } \Gamma_2)$$

In the equations, Γ ($=\Gamma_1 + \Gamma_2$) is the boundary of Ω, $\hat{n}$ is the unit vector, γ、 p and q are known parameters concerning physical trait [4].

These equations can be solved by numerical calculation. The finite element algorithm, boundary algorithm, discrete cell algorithm and finite difference algorithm are all commonly used in engineering field. Generally, the finite element algorithm is the most common method. Its principle is transforming the infinite degree of freedom in continuous field into the preference degree of freedom in discrete field. ANSYS is a sort of usual finite element analysis software, which can be used to solve many questions: structure, liquid, electric power, and electromagnetism and so on. It includes pretreatment, program of settle and post processing modules, combining with the analysis of finite element, GUI and optimizing technique. Therefore, ANSYS is quite useful tool to solve engineering problems.

The principle of electromagnetic field analysis is: firstly dividing the object into finite elements, including some of nodes; secondly calculating magnetic potential and electric potential on every node in the some conditions, according to the vector magnetic potential or the scalar quantity electric potential; then other relative qualities obtained, for example magnetic flux density, electromagnetic field stored power and so on; finally inputting the result and analyzing the relevant parameters [5].

3 Finite Element Analysis on Impedance of Probe Coil Effected Thickness of Cladding

The thickness of cladding [6] on metal material is an important index in many industry application environments. Accordingly, the accurate measure of thickness of cladding is a hot research issue. ECT is an effective method to measure the thickness of nonconductive cladding over nonmagnetic substrate. According to the theory of ECT, this kind of measure is actually the same to that of life-off distance. Thus we simulate the impedance of the probe coil by ANSYS, and know the rule of the impedance in different frequency and material. Finally, we get the normative impedance diagrams, which offer effective reference for research on measure thickness by ECT.

The analysis process can be divided into six steps [7]: parameter defined; model built; meshing; data loaded; solving; result analyzed.

Some parameters are defined before simulative analysis. The coil is rolled 400 circles by copper thread (diameter is 0.16mm); the relative permeability is 1 (μ_r=1); the inside diameter is 1.5mm; the outside diameter is 4.8mm, and the height is 5mm. Then the conductivity of substrate needs to be confirmed (aluminum), the loaded voltage (maximum is 24V) and the frequency (2000Hz) also need to be defined. The lift-off distance is increased by 0.5mm to 6.2mm (Factly, the thickness becomes to thicker and thicker).The model of the probe coil is showed in Figure 3-1.

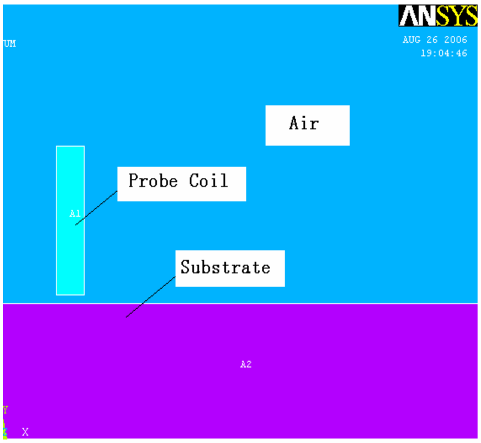

Figure 3-2 Geometry model

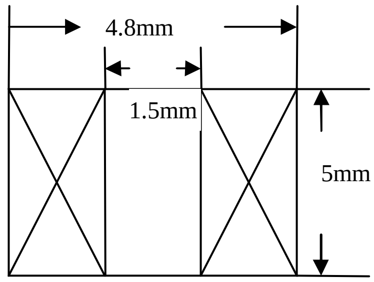

Figure 3-1 Model of the coil

According to the question above, the geometry model is built in ANSYS surrounding. The model is described as the probe coil loaded the AC voltage is placed on a no defect metal flat. Considering the symmetry, the model is only designed for the half. It simplified the model, and save time. Meanwhile, we must ensure that the diameter of flat is longer than the diameter of the probe coil 5 times, the thickness of metal flat is deeper than skin depth 4 times. Therefore, the impedance affected by the metal flat is the same as the infinite big flat [8].

When the model was set up, according to the actual issue, we do not distribute the model by lattice, until the element type of the lattice, the degrees of freedom and behavior is selected.

Currently, the whole model could be measured off by the small grids. After that, it was the process in the software interface that the different elements have been coupled the relevant parameters 、got limit terms、and loaded the power. These were all based on the defined parameters and the attribute. Finally, we solved in “Solution” [9], and then got the current of real and imaginary part of the probe coil in “General Postproc” [9]. The value of impedance can be calculated by the formula ($Z = \frac{\dot{U}}{\dot{I}}$). Before studying the results, the group of values of the impedance should be normalized, so that the normalized plane impedance graph about the influence on thickness variation based on certain metal substrate and frequency is available. Meanwhile, the authors change the metal under testing and the frequency. In this way, we could get a series of impedance Figures concerning the different materials (Figures 4-1to4-4). As Figures showed, we can get the information: the curves represent different materials in loading some frequency samples.

When the material is nonmagnetic and the cladding increases, the resistance of the probe declines as the reactance rise. It shows that the corresponding relationship between the thickness of the cladding and the impedance of the probe coil [10]. So, we can measure the thickness indirectly by the impedance. By the Figure, when the frequency is fixed, the curves about the kinds of metals of different conductivity are different. The precision of the measure is directly influenced by the different materials. Comparing these four graphs, however, all curves are becoming cliffy and closer with the frequency increasing. Therefore, the authors realized that higher frequency can effectively restrain the adverse factor which can disturb the measure of the thickness on different kinds of materials.

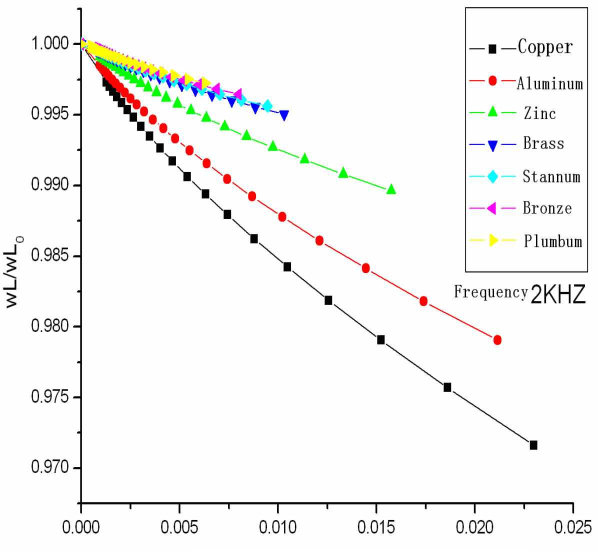

Figure 4-1 2 kHz

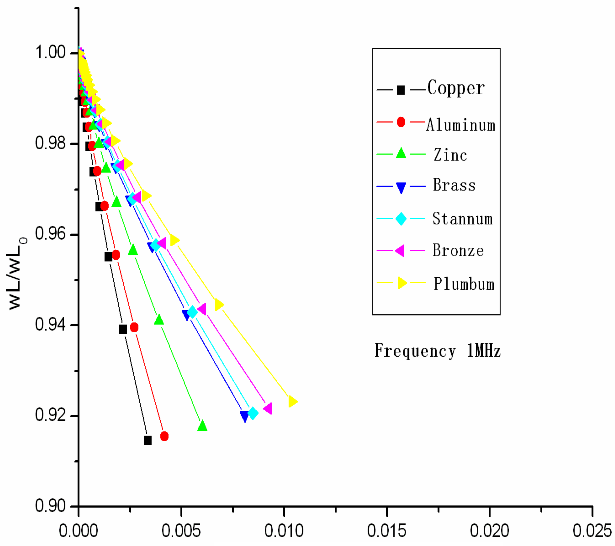

Figure 4-3 1M kHz

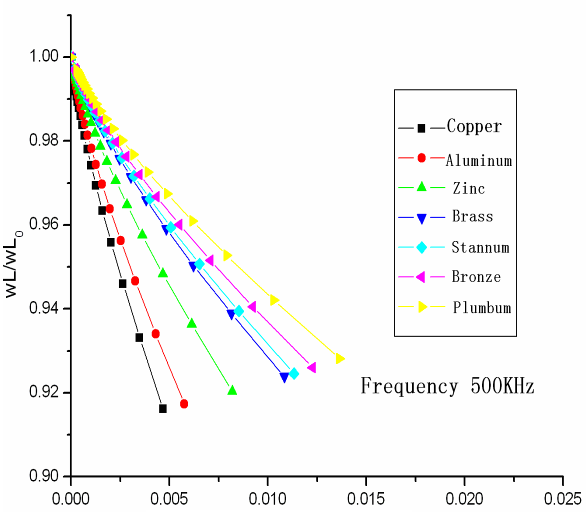

Figure 4-2 500k Hz

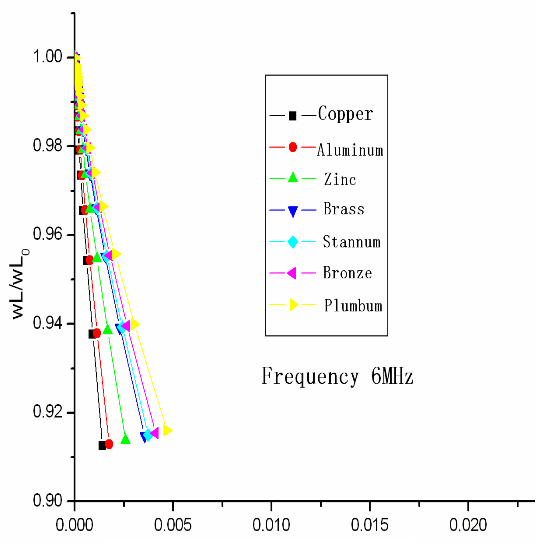

Figure 4-4 6M Hz

4. Finite Element Analyses on Impedance of Coil Affected the Thickness of Substrate

Analysis of the impedance of the probe coil affected by the changing of the thickness of metal substrate is also available by ANSYS. The mainly the processing is the same as the analysis on the thickness of the cladding. However, the incorrect result will emerge when the position of the metal is as that of the model in FIGURE 3-2. The depth of the plane magnetic-field infiltration probably exceeds the thickness of the metal when the thickness of the metal becomes thinner and thinner, so that the magnetism loop will be crabbed by the boundary term when the loop is able to extend downwards through the substrate. Therefore, it is necessary to hanging the model as the FIGURE 5-1, in which the metal substrate was put on the center of the y-axis. And then, the researcher did some simulation respectively on four kinds of material , cuprum、aluminum、plumbum and titanium, in different frequency,2kHz、5kHz、10kHz、20kHz. At last, the series of the impedance plane Figures were drawn as the Figure 5-2 to 5-4.

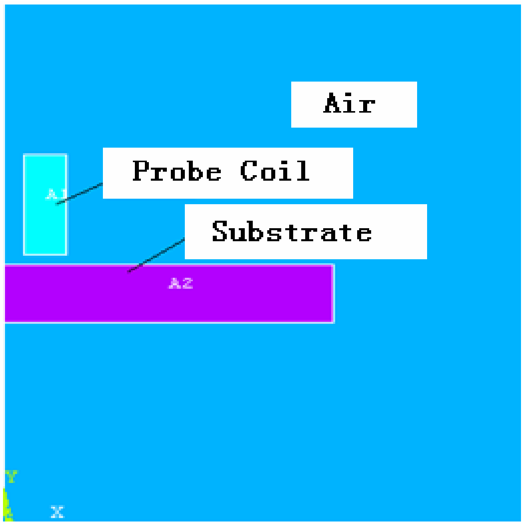

Figure 5-1 Model of the variation thickness of substrate

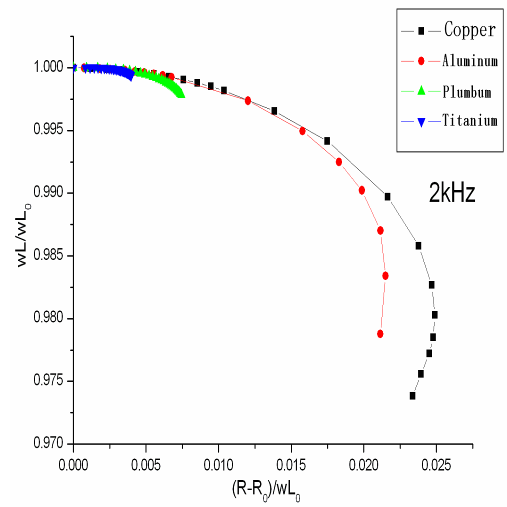

Figure 5-2 the impedance variation with changing substrate thickness under 2kHz

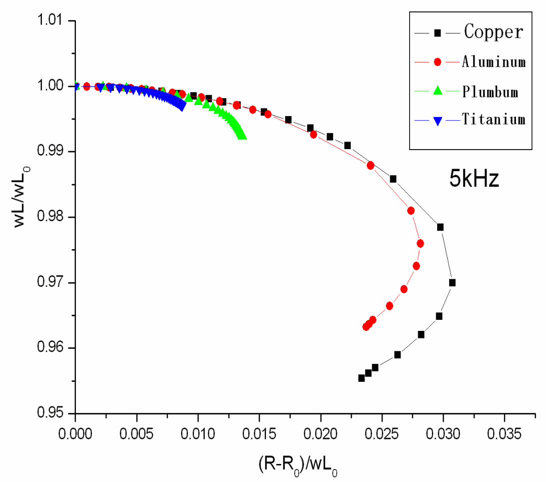

Figure 5-3 the impedance variation with changing substrate thickness under 5kHz

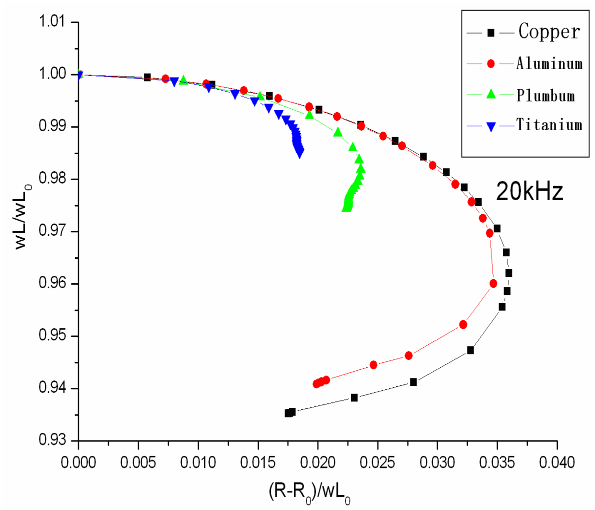

Figure 5-4 the impedance variation with changing substrate thickness under 20kHz

By the graphs, the inverse ration relationship between the thickness of the metal substrate and the impedance of the eddy current probe is obvious. So, the numerical value of the thickness is solved through this relationship. The variation of the thickness has great influence on the eddy-current distributing, when the thickness of the metal is thinner than the depth of the eddy-current infiltration. Meanwhile, the impedance about the probe coil is obviously varied. Furthermore, when the thickness of the substrate becomes thinner and thinner, the change of the impedance is very remarkable. In other words, it has the greater affect on measure when the thickness of the substrate is thinner.

5 Conclusions

Through the research of thickness of nonconductive cladding over nonmagnetic metal substrate and thickness of metal substrate by ANSYS, we built two-dimension model of the probe firstly, and know the variation rules by solving the value of its impedance. Moreover, we can draw a series of intuitionistic Figures about the normalized impedance. Finally, the conclusions can be generalized as below:

1) It has an approximate linear relationship between the thickness of the cladding on the metal substrate and the impedance of the eddy current probe. Therefore the value of the thickness can be gained indirectly through measuring the impedance of the probe.
2) Different conductivity of metals is the primary disturbing factor in the process of measuring the thickness of the cladding. However, it is found that enhancing the frequency is an effective way to restrain the disadvantageous factor.
3) It has an inverse ration relationship between the thickness of the metal substrate and the impedance of the eddy current probe. Similarly, the numerical value of this thickness is available through the connection. Besides, the thinner the metal is, the better effect of measuring with eddy-current method is.
4) It's feasible to simulate the placement eddy-current probe coil and calculate the numerical value by ANSYS software. An effective analysis method and reference basis for the research of ECT theory are consequently offered through this simulation process, then the data of our research support the transducer design and practical application, with good value.

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