Simulation and Analysis of Electromagnetic Field of Eddy Current Sensor

Jing Shu

Southwest Petroleum University, School of Mechanical and Electrical Engineering,
No. 8 Road, Xindu District of Chengdu city, Sichuan Province, China

Abstract: ***Eddy current sensor is widely used in industrial production and scientific research, and it is a kind of nondestructive and non-contact testing instrument. In the detection process, eddy current sensors are often subject to the size of the probe coil (diameter and outside diameter), detection frequency and other factors. Therefore, it is very important to study the influence of the above factors on the performance of eddy current sensor by electromagnetic field simulation analysis of the coil of eddy current sensor. In this paper, the electromagnetic field simulation of eddy current sensor coil is analyzed, and the variation law of the electromagnetic field in the eddy current sensor coil in the air is understood, which has a certain reference value.***

Keywords: Eddy Current Sensor; Finite Element Method; Electromagnetic Field Analysis

1. Introduction

With China's oil, natural gas, the development of electric power engineering construction, of metal pipeline detection has been more and more attention is paid to and eddy current testing as a new detection technology, with non-contact, no pollution, convenient operation and so on. The eddy current sensor is the main instrument in eddy current testing, which is based on the principle of electromagnetic induction, when the metal conductor near a high frequency alternating current carrying coil, as shown in Figure 1, the space around the coil produces alternating magnetic field H_1, the alternating magnetic field is detected through the adjacent metal conductor in the detected the conductor produces eddy current induction, and the electric eddy current generated by the alternating magnetic field H_2, H_2 direction and H_1 in the opposite direction, because the anti-magnetic field of H_2, the phase and the current in the coil has been changed, change is the equivalent impedance of the coil, so it can be used for change the equivalent impedance of the coil to reflect the eddy current effect in metal conductors[1].

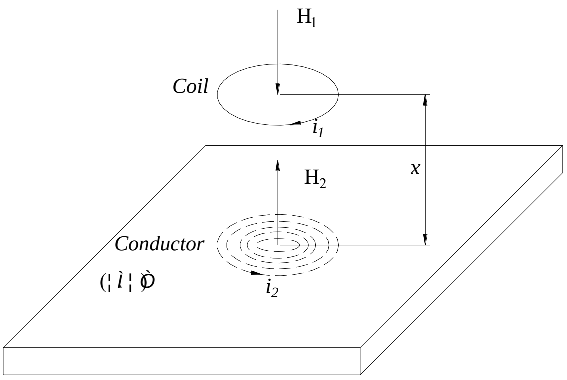

Figure 1: Principle diagram of eddy current sensor

The detecting coil impedance changes are related not only with eddy current effect and metal conductor permeability μ, resistivity σ, incentive current I, radius of the coil, the frequency omega and the detection coil to be detected metal conductor of the distance *x*. Impedance and electrical resistivity, permeability, line circle radius and excitation current, frequency and coil and detect the distance between conductors can represented by the following relationship:

$$z = f(\mu, \sigma, \omega, i, r, x) \tag{1}$$

When detecting the conductor permeability μ, sigma resistivity, incentive current I, coil radius r, ω frequency control constant resistance can become the detection coil to be detected between conductors on a single valued function of the distance, only:

$$z = f(x) \tag{2}$$

At this time, the impedance Z only with the coil to the change of distance of the conductor to be measured. In this way, we can convert the impedance change of output voltage or current, so that it can detect coil to detected changes in the distance between the conductors. Similarly, when we control other variables constant resistance can become a factor of single valued functions.

2. Basic theory of electromagnetic field

Whatever the problem of boundary value problem of electromagnetic field, it must be based on Maxwell electromagnetic field equations, material constitutive relations and boundary conditions.

Differential form of Maxwell equations[2]:

$$\nabla \times H = J + \frac{\partial \vec{D}}{\partial t} \tag{3}$$

$$\nabla \times E = -\frac{\partial \vec{B}}{\partial t} \tag{4}$$

$$\nabla \cdot \vec{D} = \rho \tag{5}$$

$$\nabla \cdot \vec{B} = 0 \tag{6}$$

H for the magnetic field intensity (A / m); D as potential shift vector (C/m^2); E electric field strength (V / m); B for the magnetic induction intensity (Wb/m^2); J for the conduction current density (A/m^2); $\partial \vec{D}/\partial t$ displacement current density; P for the free charge density (C/m^3).

Due to the electromagnetic field motion, change, disappear always with a specific medium contact together, so just use the above equations to describe the physical is not complete, must also add the following three media to describe the constitutive relation equation.

In a linear, isotropic medium:

$$D = \varepsilon E \quad (7)$$

$$B = \mu H \quad (8)$$

$$J = \sigma E \quad (9)$$

3. Parametric finite element modeling of eddy current sensor coils

3.1 Problem description

The eddy current sensor coil simulation is to calculate the electromagnetic field distribution on the coil excited by the AC voltage in the free space. The parameters of the coil are as follows:

Table 1: Parameter description

Material properties	*Geometrical characteristics*	*Load*
Relative permeability (coil) =1	*Coil turn number =500 turn*	$V = V_0 \cos \omega t$
Relative permeability (air) =1	*Coil width s=0.02m*	$V_0 = 12V$
Resistivity =3E-8 Ω.m	*Coil average radius r=3x S/2m*	$\omega = 60Hz$

Coil for circular symmetry, the electromagnetic fields generated in any vertical coil face is the same, and for interface of the electromagnetic field is symmetric, so calculation interface of one quarter of the region can be[3]. Assuming great circle has almost no electromagnetic field, as is the area revising the great circle with a small round of far field region, namely the electromagnetic field inside the smaller.

3.2 Geometry Modeling

In the analysis of the geometric model of, the establishment of the top-down approach and combined with the overlap operation to complete.

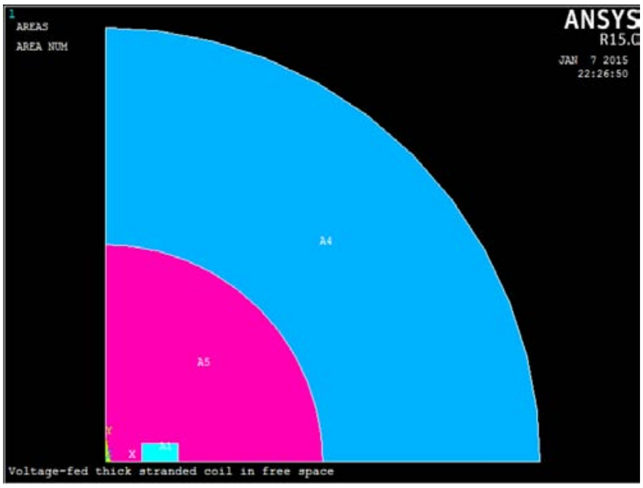

Figure 2: Coil geometry model

3.3 Select cell types and options

Table 2: Cell types and options

Unit type	*Function area*	*Unit options*
PLANE 53	*air*	*K1=0；k3=1*
PLANE 53	*coil*	*K1=2；k3=1*
INFIN10	*Far field unit*	*K1=0；k3=1*

Because of the need to input voltage in the probe coil, it is needed to couple the current degree of freedom, so the coil is located in the coil, so the choice of K1=2[4].

3.4 Define real constant and material properties

In this paper, the real constant is defined as the cross-sectional area of the coil, the number of turns, the current direction and the fill factor of the coil. The material properties that need to be defined are permeability and resistivity.

3.5 Dividing Mesh

The number of units on the far field line is divided into "1", and the number of all the regions on the model is "8", then the coil is mapped to the grid, and the air region is divided into a free grid.

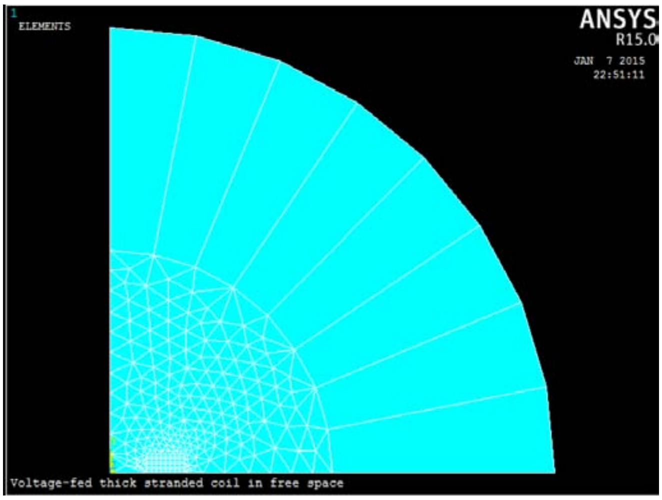

Figure 3: Mesh division of model

3.6 Boundary conditions and loads

On this model is applied to the magnetic field lines parallel to the boundary conditions, constraints in addition in the analysis must be applied: To probe coil all node coupling current degrees of freedom, to the coil voltage is applied in reducing the load, finally to the coil set excitation voltage and frequency.

3.7 Solve

Because the input voltage is alternating voltage, so the choice of analysis is harmonic analysis. Set the working frequency of 60Hz in harmonic analysis are generally used in the wave front solver.

3.8 Post treatment

In the post processing, we can get the distribution of the magnetic line of force of the coil, current value for the real part, the imaginary part of the current value, the lines in a three-dimensional distribution.

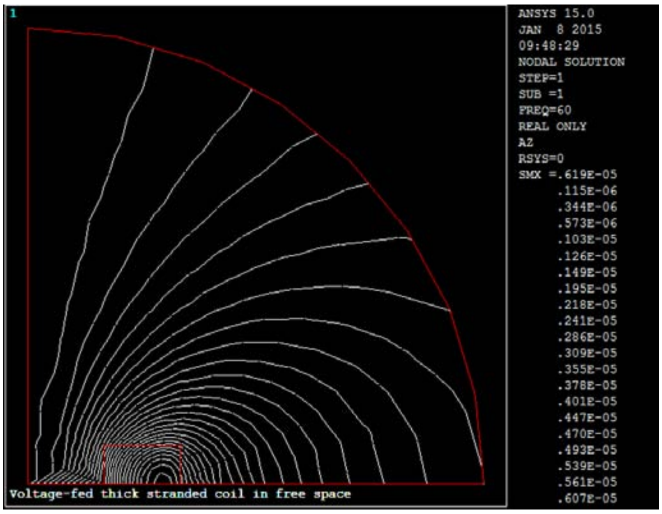

Figure 4: The real part of the coil magnetic field distribution

And the actual value of the current is 1.19235774, and the imaginary part of the current is -1.62071026.

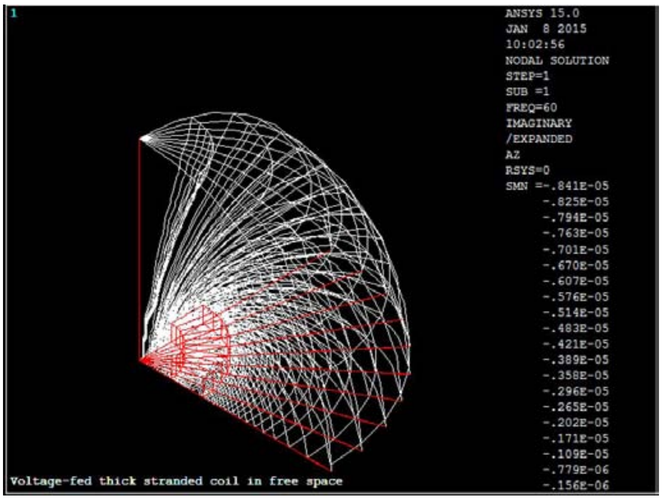

Figure 5: The 3D magnetic field distribution diagram

4. Conclusion

The process of finite element modeling of the coil in using the finite element method, combined with the characteristics of the probe coil itself, in the analysis of plane axial symmetry structure of two-dimensional analysis object is simplified, and maintain a characteristic analysis of the object itself. According to the characteristics of the simplified model of mesh mapping of the coil, free the grid division of the air region, both to ensure the accuracy and reduce the scale of the model. In this model, not only by the magnetic field distribution of the coil, also got the real part of the coil current in the air and the value of imaginary values, from simple to complex, laid the foundation for the subsequent analysis and Simulation of probe coil detection of the measured material model.

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Author Profile

Jing Shu received the College of mechanical and electrical engineering, Southwest Petroleum University, bachelor's degree, master's degree in reading, the main research direction for nondestructive testing, electromagnetic field simulation.