Research on Bearing Eddy Current Testing Based on ANSYS

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Abstract. In order to quantitatively analyze the eddy current flaw detection of bearing parts, the eddy current testing model is established by ANSYS finite element simulation software. The simulation analysis object selects a self-inductance eddy current probe. There is only one coil in the probe, which is both an excitation coil and a detection coil, and the detection signal is reflected by the change of the impedance of the coil. Through the simulation experiment, the influence of the structure size of the probe coil and the lift-off distance excitation signal of the probe on the detection effect when using the eddy current detection method for non-destructive testing of the bearing parts is explored. Study and analyze the influence of the change of the defect size on the detected object on the detection signal in the eddy current simulation.

1. Introduction
As a commonly used component in mechanical equipment, the bearing is mainly used to support the rotating body mechanism to reduce the friction coefficient when rotating, and has high requirements for the machining accuracy and quality of the bearing. Therefore, in the production of bearings, the detection of flaw detection of bearing parts is particularly important [1]. In the practical application of bearing flaw detection, magnetic particle inspection is a relatively mature flaw detection technology, but the method of magnetic particle inspection needs to manually identify the presence or absence of workpiece flaws, and the production process is difficult to automate. Eddy current testing is suitable for the detection of ferromagnetic workpieces. Today, eddy current non-destructive testing technology has been widely used in aerospace, machinery manufacturing, construction engineering and other fields [2]. In the non-destructive testing of bearings, eddy current testing techniques can be used to detect defects near the surface of the bearing.

2. Eddy Current Testing Principle
The eddy current test is based on the principle of electromagnetic induction, and an alternating magnetic field is generated around the excitation coil to which the alternating current signal is applied. When approaching the conductor test piece, the alternating magnetic field causes eddy currents on the surface of the test piece. The magnetic field generated by the eddy current reacts to the detecting coil, and the complex impedance of the detecting coil changes. The conductivity and defects of the test piece affect the distribution of the eddy current, which affects the impedance variation on the detection coil. The impedance consists of the real part and the imaginary part, the real part is the resistance, and the imaginary part is the reactance.

The eddy current detecting sensor can be divided into two types: self-inductive and mutual-inductive. The self-inductive detecting coil is the exciting coil. The eddy current signal on the measured object directly affects the impedance of the exciting coil. The output signal is on the coil.
Impedance change; the mutual inductance has an excitation coil for applying an excitation signal, and a detection coil for picking up an eddy current signal on the object to be measured, and the detection coil generates an induced voltage under the reaction of the magnetic field of the eddy current, when the object is measured. When the eddy current changes, the impedance of the coil is detected to change, thereby affecting the detected voltage value [3-4].

In the detection of bearing parts, because of the small detection surface and the detection of the annular surface, it is more suitable to use the pen test eddy current probe. The test end of the eddy current probe is smaller, and it is more suitable for the design method of the absolute coil, that is, the self-inductive probe. As shown in Fig. 1, it is a schematic diagram of self-inductive probe eddy current detection, the upper part is the excitation coil of the probe, the lower part is the measured body, R1 is the inner diameter of the coil, R2 is the outer diameter of the coil, L is the length of the coil, h is the lift distance of the probe coil, d is the thickness of the measured body [8].

3. Simulation Model Establishment

Finite element analysis is to simulate a real system by simplification of complex problems by replacing an infinite number of systems with finite approximations. According to the eddy current detection principle, the finite element analysis model is established by ANSYS software to analyze the change of the detection signal in the eddy current detection system. The simulation model is established as shown in the figure. After determining the material structure size of the model, create the physical environment, build the model, assign the model characteristics, model the mesh, load the boundary conditions and loads, model solve, post-process and view the processing results [5-6].

3.1. Simulation model structure

The eddy current simulation model can be simplified to an axisymmetric two-dimensional eddy current field model. In eddy current testing, the change of the eddy current field on the measured object affects the impedance value in the detection coil. Therefore, the self-inductive eddy current probe model is used in the simulation, and the measurement signal can be obtained by calculating the impedance of the coil. In the two-dimensional eddy current field simulation, the unit PLANE53 can be used. The unit type is a magnetic entity vector with degrees of freedom such as AZ, AZ-VOLT, AZ-CURR, AZ-CURR-EMF [7].

As shown in Fig. 2, a two-dimensional simulation model of eddy current detection is established, the blue area is the probe coil, the purple area is the measured object, and the red area is the surrounding air area.
3.2. Main process of simulation

Figure 3 shows the modeling and analysis process of ANSYS finite element analysis software. The following is the main flow of eddy current testing finite element analysis:

- Select Magnetic-Nodel in the preferences of ANSYS software to filter the graphical interface, and then define the work title and unit type. The two-dimensional electromagnetic analysis uses PLANE53 unit to define the material properties according to the relative magnetic permeability and resistivity of the materials in the table. Define the coil real constant, the coil cross-sectional area, the number of coil turns, the coil fill factor, and so on.

| Table 1. Material properties of the simulated model. |
|-----------------------------------------------|
| Material properties | Coil | the measured object |
|---------------------|------|---------------------|
| Relative permeability | 1 | 300 |
| Resistivity $(10^{-7})$ | 0.1724 | 1.69 |

- The geometric model that needs to be built is axisymmetric, so the model uses a two-dimensional model of 1/2. Assume that the measured body is 5mm wide and 10mm high, the inner radius of the probe coil is $R_1=1mm$, the outer radius is $R_2=2mm$, the length is $L=3mm$, the lifting distance between the coil and the measured object is $h=2mm$, and the number of turns of the coil is 100. Hey. According to the model size, the model is drawn using the Modeling module under Preprocessor in the software.

- Material attributes and unit types are assigned to the model of the coil, the measured object, and the air. Methtool is used to combine the mapping and free partitioning to mesh the model. The rectangular rule graphic can be mapped and divided, and other graphics are freely divided.

- Degrees of freedom are applied to the coil and the object to be tested, respectively; magnetic field line parallel conditions are applied to the periphery of the entire model and a voltage load is applied to the coil, and then solved. The current on the coil node, the eddy current distribution on the object to be measured, and the like are obtained by post-processing.

Obtain the current on the coil node and calculate the impedance value by current and voltage. The formula is shown as:

$$Z = Z_{\text{real}} + jZ_{\text{imag}}$$  \hspace{1cm} (1)

$$V_{\text{real}} = \sqrt{2} * V$$  \hspace{1cm} (2)

$$I_{\text{mag}} = I_{\text{real}}^2 + I_{\text{imag}}^2$$  \hspace{1cm} (3)

$$Z_{\text{imag}} = V_{\text{real}} * I_{\text{imag}} / I_{\text{mag}}$$  \hspace{1cm} (4)

$$Z_{\text{real}} = V_{\text{real}} * I_{\text{real}} / I_{\text{mag}}$$  \hspace{1cm} (5)

In the above formulas, $Z$ is the impedance, $V_{\text{real}}$ is the true voltage value, $I_{\text{mag}}$ is the sum of the squares of the real and imaginary parts of the current, $Z_{\text{real}}$ is the real part of the impedance, and $Z_{\text{imag}}$ is the imaginary part of the impedance.

3.3. Simulation Signal Analysis

In order to analyze the influence of excitation signal frequency, lift distance, coil turns and coil filling coefficient on the detection signal, the finite element model of different parameters is established to analyze the experimental data.

3.3.1. Excitation signal frequency. Under the condition that other conditions are kept unchanged, the frequency of the excitation signal is simulated from 80 Hz to 10000 Hz. As shown in Fig. 4 and Fig. 5, as the frequency increases, the maximum value of the eddy current intensity in the measured body gradually increases, but the red region (the concentrated point of the eddy current) gradually approaches the surface on the measured body. The higher the frequency of the excitation signal, the more obvious the skin effect of the eddy current and the shallower the detection depth.
3.3.2. Lifting Distance. The lift distance is the distance between the lowermost end of the eddy current probe and the measured object, and the change of the lift distance causes the eddy current generated in the measured body to change, thereby causing the detection signal to change. As shown in Fig. 6 and Fig. 7, when different lift distances are used, the eddy current intensity and distribution in the measured object will be different, and the impedance value of the probe coil will also change. At the same time, as the lift-off distance increases, the eddy current intensity on the surface of the measured object weakens, which may make the detection effect worse. Therefore, it is necessary to select a small lifting distance in the detection, and the lifting distance is fixed.

3.3.3. Coil Thickness. In the case where the cross-sectional area of the coil unit and the coil filling factor are constant, the cross-sectional area of the coil increases proportionally as the number of turns of the coil increases. Assuming that the inner radius and length of the coil are constant, the outer radius of the coil is proportional to the number of turns of the coil. As shown in Fig. 8 and Fig. 9, as the number of turns of the coil increases, the outer radius of the coil increases proportionally, and the eddy current intensity of the surface of the measured object increases, and the impedance of the coil also gradually increases. Under the condition that the size of the detection surface of the measured object is allowed, increasing the number of turns of the excitation coil can enhance the intensity of the detection signal and improve the detection effect.

3.3.4. Coil inner radius. In the case where only the inner radius of the coil is changed, the number of turns of the coil, the filling factor, and the thickness are constant, and the total length of the coil changes. If the inner radius of the coil is increased, the cross-sectional area of the coil unit is constant, the total length of the coil becomes long, and the impedance of the coil increases. And because the coil

Figure 4. Eddy current intensity distribution at different frequencies.

Figure 5. Frequency - maximum eddy current intensity trend chart.

Figure 6. Eddy current intensity distribution at different lift distances.

Figure 7. Lifting distance - maximum eddy current intensity trend chart.

Figure 8. Coil thickness - maximum eddy current intensity trend.

Figure 9. Coil thickness - coil impedance trend chart.
thickness does not change, the outer radius of the coil also increases. As shown in Fig. 10 and Fig. 11, the strongest region of the eddy current gradually approaches the Y-axis, and the maximum eddy current intensity also increases as the inner radius of the coil increases.

Figure 10. Eddy current intensity distribution at different inner radius of coil.

Figure 11. Inner radius of the coil - maximum eddy current intensity trend.

3.4. Simulation analysis of bearing defects

3.4.1. Effect of Defect Width on Detection Signal. In the simulation experiment to study the influence of the defect width on the detection signal, only the width of the defect is changed and the defect position is located in the center of the model to be tested. As shown in Fig. 12, the eddy current intensity distribution on the measured body with different defect widths will change somewhat; as shown in Fig. 13, the resistance of the probe coil gradually decreases as the defect width increases, and it can be distinguished from the coil resistance when the measured object has no defects.

Figure 12. Eddy current intensity distribution when the width of the defect is different.

Figure 13. Defect width - coil impedance map.

3.4.2. The effect of defect depth on the detection signal. In the simulation experiment to study the influence of defect depth on the detection signal, only the depth of the defect is changed and the defect position is located in the center of the measured body model. As shown in Fig. 14, the eddy current intensity distribution on the measured body with different defect depths will change; as shown in Fig. 15, the resistance of the probe coil gradually increases with the increase of the defect depth, and it can be distinguished from the coil resistance when the measured object has no defects.

Figure 14. Eddy current intensity distribution when the depth of defects is different.

Figure 15. Defect depth - coil impedance map.

3.4.3. The influence of the defect position on the detection signal. It is assumed that the defect section is a rectangle having a width and a depth of 1 mm, and the eddy current intensity distribution on the object to be measured is simulated without changing other conditions. As shown in Fig. 16 and Fig. 17,
when the defects on the object are at different positions, the eddy current intensity distribution on the object is changed. When the defect is located below the coil, the eddy current distribution on the measured object changes more obviously, and the eddy current intensity also changes. As shown in Fig. 18, the influence of the defect position on the coil resistance on the object to be measured has no regularity, and it can be distinguished from the coil resistance when the measured object has no defects.

4. Conclusion
Using ANSYS finite element analysis software, modeling and analyzing the application effect of eddy current testing in ferromagnetic workpieces such as bearing parts. By analyzing the influence of the eddy current probe coil size, lift distance and excitation frequency on the detection effect, the higher the excitation signal frequency, the stronger the detection signal but the shallower the detection depth. The change in the lift distance has a significant effect on the detection signal. The larger the distance, the weaker the signal. In the size of the coil, the increase in the thickness of the coil and the radius inside the coil enhances the detection signal, and the increase in the inner radius causes the optimum detection area to shift outward. The width and depth of the defect size will cause a certain regular change of the detection signal, while the detection signal is irregular when the position of the defect changes, but there is a detection signal that is different from the defect-free.

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