Simulation Analysis of Static Characteristics of Electromagnetic Mechanism of Magnetic Holding Relay Based on ANSYS

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Abstract. As an important part of the magnetic latching relay, the design of its parameters will directly affect the static characteristics of the entire system. This article first explains the working principle of the magnetic latching relay and the electromagnetic field analysis theory. Based on this, a simplified model of the electromagnetic mechanism is established. The ANSYS finite element analysis software is used to simulate and analyze the electromagnetic mechanism. The electromagnetic generated by the electromagnetic mechanism under different parameters is obtained. The magnitude of the force and its magnetic induction intensity distribution cloud map provide a useful reference for the performance optimization of the magnetic holding relay and subsequent related research.

1. Introduction

The relay is a type of automatic electrical control switching device that causes the controlled electrical output circuit to be turned on or off when the input amount (excitation amount) reaches a certain condition limit. In recent years, with the rapid development of electronic technology, relays used in conjunction with electronic devices have shown a trend of small size, compact structure, and low power consumption. Magnetic latching relays have emerged as the times require, and they have become the representative of low-power consumption electrical appliances, and they are widely used in many fields of smart grid, aviation, military, and daily life. The electromagnetic mechanism is the driving force source of the entire relay, and plays a vital role in the operation of the relay. Electromagnetic force is an important indicator of its static characteristics. How to accurately obtain the magnitude of the electromagnetic force under the condition that the relay works normally is of great significance for optimizing the design index of the relay and improving the reliability of the product.

ANSYS software is general-purpose software for large-scale finite element analysis, and has high accuracy in electromagnetic analysis. In this paper, ANSYS software is used as the simulation analysis platform and the parameterized language APDL is used to compile the command stream file. The static characteristics of the electromagnetic mechanism are simulated and calculated. The magnetic field cloud diagrams and the magnitude of the generated electromagnetic force under different structural parameters are provided, which can provide reference for the improvement of the magnetic holding relay model and the optimization of performance.
2. Principle and analysis theory of electromagnetic mechanism of magnetic latching relay

2.1. Structural parameters and working principle of electromagnetic mechanism
This article studies and analyzes a certain type of magnetic latching relay. The rated voltage of the coil is 9V DC, with 2500 turns in the coil and 0.13mm in wire diameter. The physical map of the magnetic holding relay is shown in Figure 1. As a very important part of the magnetic holding relay, the electromagnetic mechanism determines whether the entire magnetic holding relay can work normally. Its structure mainly includes an armature component (permanent magnet and magnetic pole piece), two yokes, an iron core, and a coil part. Figure 2 is a schematic diagram showing the structure of an electromagnetic mechanism of a magnetic latching relay. A certain direction of pulse current is passed in the coil, and the coil with the iron core generates a magnetic field under the action of electromagnetic induction, and interacts with the magnetic field of the permanent magnet to generate electromagnetic force, which realizes the energy conversion process from electric energy to electromagnetic energy and then to mechanical energy. Under the effect of the generated electromagnetic force, the armature component is twisted, which drives the contact mechanism to complete the breaking action. When the current pulse disappears, because of the presence of the permanent magnet, the armature assembly will continue to maintain its attracted state. Similarly, when a reverse current pulse is applied, the direction of the magnetic field is reversed, and a reverse electromagnetic torque will be generated, and then the current position is still maintained by the permanent magnet itself. This is the bistable principle of the magnetic holding relay.

![figure1.png](image1)

Figure 1. Physical map of magnetic latching relay.

![figure2.png](image2)

Figure 2. Schematic diagram of electromagnetic mechanism of magnetic latching relay.

2.2. The electromagnetic field simulation analysis theory
The analysis of electromagnetic mechanism is mainly based on the theory of electromagnetics, and its main body is the Maxwell equations, including the four major equations of Faraday's electromagnetic induction law, Maxwell-Ampere's law, Gauss magnetic law, and Gauss law. The above equations are a comprehensive summary of the macroscopic laws of electromagnetic fields. They interact with each other in integral and differential form, and complement each other. When analysing actual problems, different forms of equations and physical characteristics must be selected for specific problems. In the following, the four laws included in Maxwell's equations will be explained.

The principle of Faraday's law of electromagnetic induction is that the integral of the induced electromotive force along the closed loop has a positive correlation with the change rate of the magnetic flux in this loop. The larger the change rate, the stronger the induced current. Its calculus form can be expressed as:

\[
\phi_t = \int J \cdot dS
\]

\[
\nabla \times E = \frac{\partial B}{\partial t}
\]
Where $E$ is the electric field strength vector ($V/m$); $B$ is the magnetic induction strength ($T$).

There are two ways to generate a magnetic field, which are the movement of electric charges (Ampere's law) and the magnetic field generated by changes in the electric field (Maxwell correction project). Maxwell-Ampere's law can be expressed as the line integral of the magnetic field strength vector along the closed path is equal to the sum of the currents in this surface. Its integral form and differential form can be expressed as follows:

$$\oint_{\Gamma} \mathbf{H} \cdot d\mathbf{l} = \iint_{S} \left( J + \frac{\partial \mathbf{D}}{\partial t} \right) \cdot d\mathbf{S}$$

$$\nabla \times \mathbf{H} = J + \frac{\partial \mathbf{D}}{\partial t}$$

Where $\mathbf{H}$ is the magnetic field strength ($A/m$); $\Gamma$ is the boundary of the surface; $J$ is the volume current density vector ($m/A^2$); $\mathbf{D}$ is the electrical displacement vector ($C/m^2$).

In an electric field, the integral of the electric displacement vector $\mathbf{D}$ to an arbitrary closed curve is equal to the amount of charge in this plane. The calculus form of Gauss's law is as follows:

$$\iiint_{V} \mathbf{D} \cdot d\mathbf{S} = \iiint_{V} \rho d\mathbf{S}$$

$$\nabla \cdot \mathbf{D} = \rho$$

Where $\rho$ is the charge body density ($C/m^3$); $V$ is the area surrounded by the closed surface $S$.

The Gauss magnetic law is that in a magnetic field, the sum of the magnetic fluxes passing from any closed surface is zero, which can be calculated using the following formula:

$$\iiint_{S} \mathbf{B} \cdot d\mathbf{S} = 0$$

$$\nabla \mathbf{B} = 0$$

It is worth mentioning that in the differential form of Maxwell's equations, the three media also need to satisfy the following relationship at the same time:

$$\mathbf{D} = \varepsilon \mathbf{E}$$

$$\mathbf{B} = \mu \mathbf{H}$$

$$\mathbf{J} = \sigma \mathbf{E}$$

In the above formula $\varepsilon$ is the dielectric constant ($F/m$); $\mu$ is the magnetic permeability ($H/m$); $\sigma$ is the electrical conductivity ($S/m$).

3. Modeling and simulation calculation of electromagnetic mechanism

3.1. The establishment of electromagnetic mechanism model

The electromagnetic mechanism of the magnetic latching relay has a symmetrical structure, so only half of the solid analysis model is established. On the contrary, when calculating the final result, the corresponding value should be doubled. Based on the actual size of the relay, this article uses 3D modeling software SolidWorks to first build a model of each component, including yokes, magnetic pole, magnetic steel, iron core, etc., and finally assemble it into a whole, and then import the model into ANSYS software through a professional interface. It is worth mentioning that in order to simplify the model and improve the efficiency of analysis and calculation, the model built in this article will omit the chamfers and rounded corners that exist in the original model. The electromagnetic mechanism analysis model is shown in Figure 3. At the same time, considering the magnetic field leakage phenomenon around the model, the air domain of the three-dimensional structure was established to reduce the calculation error caused by the magnetic field leakage phenomenon. After creating the air domain, the solid model is shown in Figure 4.
3.2. Finite element simulation analysis

When performing a 3D static electromagnetic field analysis, the following analysis steps should be followed. First set up the physical environment, namely the element type, KEYOPT options, material properties, etc. This article sets the analysis parameter to "Magnetic-Nodal", selects SOLID96 and SOURC36 as the type of analysis unit, and selects the magnetic scalar bit method for analysis and calculation[2-3]. In terms of material settings, the relative permeability of the air zone created above is set to 1.0. The permanent magnet is composed of strontium ferrite and has a relative permeability of 1.4265. The inner core and yokes are mainly made of pure electric iron (DT4E), whose magnetic permeability is non-linear. The corresponding BH curve is shown in Figure 5, B is the magnetic flux density (T), and H is the magnetic field strength (A/m), which means the force of the unit magnetic pole in the magnetic field.

Figure 5. B-H curve of electric pure iron.

The finite element analysis method is an approximate value analysis method. It is simple to solve and has high accuracy. It is widely used in various types of simulation calculations. Its crucial operation is meshing, that is, the established model is divided into several small ones. Thus, the finer the meshing, the more accurate the results obtain. Based on the characteristics of the model, this paper uses the intelligent size control technology to automatically divide the mesh to an accuracy of 6 levels. In the application of the magnetic holding relay current excitation, the electromagnetic macro RACE is used to establish a ‘current-type runway coil’, and the current is directly loaded on the coil. The ANSYA simulation calculation of electromagnetic force mainly sums Maxwell force and virtual work force acting on the body in the form of a table. Therefore, the macro command FMAGSUM is used to apply force marking to the armature component[4-6]. Figure 6 shows the analysis model after meshing and marking with applied force.
Figure 6. Meshing model after applying force marks and coils.

4. Simulation results of static characteristics of electromagnetic mechanism

By analysing the static characteristics of the magnetic holding relay electromagnetic mechanism, the static electromagnetic force and magnetic flux at different parameter levels can be calculated, and the corresponding magnetic induction intensity vector diagram can be obtained. In addition, according to the model under different loading currents, different air gaps, different magnetization curves, and different magnetic steel structures, the simulation calculation is performed\(^\text{(7)}\). The static electromagnetic force and magnetic flux under different parameters can be recorded, which can provide effective accordance for optimizing the structural parameters of the relay. At the same time, using APDL parameterized language helps save test time and improves calculation efficiency.

As mentioned above, the magnitude of the current level has a direct impact on the action of the electromagnetic mechanism. Specifically, the composition of the electromagnetic mechanism, the number of coil turns and the diameter of the wire are the main factors affecting the current level. This article will calculate the corresponding equivalent load current for the above parameters, and conduct a simulation analysis of the static characteristics of the electromagnetic mechanism of the magnetic holding relay\(^\text{(8-9)}\). Based on the original parameters of the relay and the experimental analysis method, the simulation group is designed to obtain the magnitude of the output electromagnetic force is shown in the following table:

| Coil turns (turns) | 1900 | 2100 | 2300 | 2500 | 2700 | 2900 | 3100 |
|------------------|------|------|------|------|------|------|------|
| Coil wire diameter (mm) | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 |
| Equivalent current (A) | 0.1047 | 0.1099 | 0.1137 | 0.1163 | 0.1176 | 0.1177 | 0.1169 |
| Electromagnetic force (N) | 9.4768 | 9.6116 | 9.7002 | 9.7366 | 10.4688 | 10.5444 | 10.5532 |

When studying the influence of each component of the electromagnetic mechanism on the magnetic field distribution under different coil parameter levels, although the electromagnetic force can intuitively give a numerical value and its changing trend, the magnetic induction intensity distribution of each part is difficult to reflect, so it is impossible to target the magnetic field distribution for further research and optimization. While calculating the electromagnetic force, this paper obtain the magnetic induction intensity and magnetic field intensity cloud diagrams at different parameter levels, which provides an important reference for the influence of each component size on the magnetic field distribution. Figures 7 show the magnetic induction intensity and magnetic induction line distribution of the relay on the original parameter structure.
Based on the above simulation results, the influence of the current level on the electromagnetic force is roughly positively correlated. That is, under the same conditions, the more coil turns, the larger the wire diameter, and the larger the electromagnetic force on the armature component. The wire diameter increases to a certain degree, the magnitude of the change in the magnitude of the electromagnetic force gradually decreases, and the effect is not obvious. Based on the cost control problems in actual production, reasonable parameters should be appropriately selected for manufacturing. At the same time, from the cloud map distribution, it can be concluded that under the superposition of the permanent magnet magnetic field and the magnetic field generated by the energized coil, the magnetic induction strength at both ends of the magnetic pole piece and both sides of the inner core is relatively large, which lays a foundation for the subsequent research on electromagnetic interference and electromagnetic shielding the foundation. 

5. Conclusion and Prospect
The electromagnetic mechanism is a very important part of the magnetic holding relay, which determines whether the entire relay can work normally. This paper uses ANSYS finite element analysis software to perform a static simulation analysis of the electromagnetic mechanism of a magnetic holding relay through the APDL parameterized language. The magnitude of the electromagnetic force and its magnetic induction intensity cloud diagram under different parameter conditions are provided, which provides a certain reference for the subsequent performance optimization analysis of the magnetic holding relay and the corresponding electromagnetic anti-interference technology research. It is worth mentioning that this article only considers some parameters that affect the static characteristics of the electromagnetic mechanism, which cannot be exhaustive. At the same time, accurate values such as the number of coil turns and wire diameters are not calculated. There is room for further research and optimization.

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