Optimum Design of Coil Disc Magnetic Field of Rapid Repulsion Mechanism

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Abstract. The electromagnetic repulsion mechanism (ERM) based on the principle of eddy current repulsion has been widely applied in DC circuit breakers, but its energy conversion efficiency is low. In order to design a high-efficiency ERM, this paper establishes a simulation model of the ERM with double coil structure by the finite element analysis method. The coil disc skeleton is analyzed and optimized from the aspects of magnetic conductive material and structure. The problems of magnetic saturation and power loss are avoided, and the optimum design parameters of magnetic conductive components of coil disc are obtained. The simulation results show that the magnetic conductive material should be made of silicon steel sheet and designed into an E-2 type. Compared with the hollow double-coil repulsion mechanism, the electromagnetic repulsion peak value increases by 10.6%, the maximum opening speed increases by 25.3%, and the driving efficiency increases by 41.6%. The travel distance of 12mm can move within 1.8ms, providing a reference for the design of high-speed and high-efficiency ERM.

1. Introduction

With the development of flexible DC transmission and distribution technology, multi-terminal DC grid is the trend and direction of smart grid development in the future. As the key equipment for DC grid control and protection, DC breaker is a hot topic at home and abroad [1-2]. The fast repulsive mechanism has the advantages of short response time and high precision, and has wide application space in the fields of medium voltage mechanical DC circuit breakers and hybrid DC circuit breakers [3-4].

In recent years, the rapid repulsive mechanism has become a hotspot of research at home and abroad. The reel repulsion mechanism based on the principle of eddy current repulsive force has the advantages of simple structure and high speed, but it also has the problem of low electromagnetic conversion efficiency. In reference [5], the finite element method is used to establish the coil-type simulation model. Firstly, the structural parameters of the metal disk and the coil disk, as well as the capacitance and voltage of the coil are simulated and analyzed. Then, the magnetic material is added to improve the opening speed, but the simulation material is used. The property is ideal for pure iron, and does not consider magnetic saturation and power loss. Based on the finite element simulation model, the literature calculates and analyzes the influence of the drive loop parameters and the shell parameters on the motion characteristics. The results show that the steel shell is more conducive to high-speed opening and is not sensitive to the distance of the shell. In reference [6], the coil-coil
repulsion mechanism is taken as the research object, and the two sub-processes of loop discharge and electromagnetic induction coupling are decoupled to obtain the shape scale factor and circuit coefficient, and the optimal design method of the repulsion mechanism is formed. At present, mainly through the analytical analysis of the circuit model and the numerical analysis of the finite element analysis software, the influence of the coil parameters, the metal disk parameters, the repulsion mechanism shape structure and the external circuit parameter analysis on the driving efficiency of the repulsion mechanism, and the external circuit control mode, plus the magnetic conductive material is optimized [7-9]. However, there is little research on the influence of the type and structure of the magnetically permeable material on the output efficiency of the double-coil electromagnetic repulsive mechanism.

In this paper, based on the finite element analysis method, the simulation model of the double coil repulsive mechanism is established. In order to reduce the influence of the spatial magnetic field loss on the driving efficiency, the magnetic circuit is changed by adding the magnetic conductive material, the effective magnetic induction intensity around the coil is increased, and the magnetic conductive material is quantitatively analyzed. The influence of parameters such as type and structure. Finally, based on the simulation results, the specific parameters and general guiding principles of the prototype of the double-coil repulsion mechanism are obtained.

2. Rapid repulsive mechanism scheme design and simulation model

2.1. Repulsive mechanism design

The principle of the wire-disc electromagnetic repulsive mechanism is mainly to use the principle of eddy current electromagnetic induction, the pre-charging capacitor discharges to the driving coil, generates a high-frequency alternating magnetic field, and induces a reverse eddy current in the metal disk. Figure 1 shows the structure of a fast vacuum switch based on a double-coil structure. The working process is as follows: the pre-charging capacitor is connected to the repulsive structure static and dynamic coils with opposite currents, and the magnetic interaction between the two coils generates electromagnetic repulsion to drive the vacuum. The switch opens quickly.

2.2. Simulation model

The motion process of the double-coil electromagnetic repulsive mechanism actually involves multi-field coupling. It must be combined with the circuit equation, electromagnetic field and eddy current loss, and the equation of motion to solve the calculation, and the transient changes of each physical quantity during the motion process are relatively complicated. In order to study the dynamic characteristics of the double-coil electromagnetic repulsive mechanism, this paper uses the electromagnetic field finite element simulation software Ansoft Maxwell to establish a 2D plane symmetry model as shown in Figure 2. Calculate the discharge current, electromagnetic repulsion, opening speed and motion stroke in the repulsive coil disk. The curve of variation, as well as the parameters such as the distribution of magnetic lines of force. The simulation initialization parameters of the double-coil electromagnetic repulsive mechanism are shown in Table 1. This paper mainly
focuses on the optimization design of the coil disc structure, regardless of the external circuit parameter changes. All simulations are based on the external circuit capacitor voltage of 800V and the capacity of 4700μF.

3. Influence of magnetically permeable materials on the operating characteristics of repulsion mechanism

3.1. Influence of the structure of magnetic materials

In order to improve the utilization rate of the induced magnetic field between the two coil plate, reduce the loss of magnetic induction line in the air, this paper puts forward four kinds of different shape of magnetic material, in view of the repulsive force coils of different location to add, add permeability material structure diagram as shown in Figure.3, respectively, E-type structure 1 (hereinafter referred to as E-1 structure), the structure of the E-2 (hereinafter referred to as E - 2) structure, loop structure, the structure of the model T.
In addition, the eddy current loss and iron loss of the silicon steel were calculated. The influence of the magnetic conductivity materials of four different structures on the output of the mechanism was simulated and analyzed. The motion characteristic curve was shown in Figure 4, and the distribution of magnetic force lines was shown in Figure 5. As can be seen from Figure 5 (a), when no magnetic conductive material is added, the magnetic field strength around the coil is weak, and most of the magnetic field energy is lost in the air. As can be seen from Figure 4 (a) and 4 (b), the inductance of the coil increases and the peak current decreases after the addition of magnetic conducting materials, but the magnetic field intensity around the coil and the peak electromagnetic repulsion force both increase and the operating time is prolonged. The E-2 structure has the optimal characteristics. Compared with the hollow double-wire coil, the peak current of the coil decreases by 6%, the peak electromagnetic repulsion force increases by 12.1%, and the full travel time of 12mm decreases by 15%.

![Figure 4](image)

(a) discharge current  (b) electromagnetic repulsion

(c) velocity  (d) displacement

Figure 4 Effect of Different Magnetic Conduction Structures on Repulsion Mechanism

![Figure 5](image)

(a) distribution map of magnetic force lines of hollow double-coil  (b) distribution map of magnetic force lines of e-2 structure

Figure 5 Distribution Map of Magnetic Force Line

3.2. Influence of material properties

According to the analysis results of 3.1, E-2 structure is adopted for model simulation. When the materials are epoxy resin, stainless steel, electrician pure iron, silicon steel sheet and cold heading steel, simulation analysis is carried out respectively. The thickness of bottom plate and side is 5mm.

Figure 6 shows the influence curve of different magnetic conductive materials on the motion characteristics of double-coil electromagnetic repulsion mechanism. It can be seen from Figure 6 (b) that the electromagnetic repulsion of materials with higher relative permeability has been significantly improved. When the material is silicon steel sheet, its performance is relatively superior, followed by pure electrical iron, cold heading steel, epoxy resin and stainless steel. According to the B-H curve, the
The electrical conductivity of silicon steel sheet and cold heading steel sheet is the same, but the relative magnetic conductivity of silicon steel sheet is larger, so the output effect of silicon steel sheet is better than that of cold heading steel sheet. The main difference between stainless steel material and epoxy resin material is the difference in conductivity, because the rapidly changing magnetic field in the conductive medium also produces eddy current loss, the more the conductivity increases, the greater the eddy current loss, the electromagnetic repulsion of stainless steel material compared with epoxy resin material is reduced; Electrical pure iron and silicon steel relative permeability were similar, but the electrical conductivity of pure iron a lot larger than the conductivity of silicon steel sheet, due to the increase in permeability permeable materials performance as well as the additional power loss problem, eddy current loss is greater than the amount of the increase of magnetic field intensity, therefore, silicon steel materials output effect is better than electrical pure iron.

Figure 6 The influence of different magnetic conductive materials on repulsion mechanism

According to the above analysis, the higher the relative magnetic permeability, the better the magnetization effect, but when the magnetic field strength is saturated, the material with little difference in magnetic permeability has less influence on the mechanical performance, and the eddy current loss caused by the material resistivity. It will play a leading role; therefore, reducing the electrical conductivity of the material can reduce the eddy current loss and improve the driving efficiency. The prototype should be made of a magnetically permeable material with high relative magnetic permeability and low electrical conductivity.

While the magnetic field enhances the magnetic field, it is also accompanied by the problems of magnetic saturation and power loss. In practical applications, materials with higher relative permeability and low conductivity should be selected as the magnetic conductive medium; E-2 type structure can be selected. The magnetic circuit of the repulsion mechanism is optimized and magnetic saturation is avoided to optimize the driving efficiency. According to the above simulation analysis, the magnetic conductive material should be selected from silicon steel sheets, and the structure should be designed as E-2 structure.

4. Conclusion
(1) While the magnetic field enhances the magnetic field, it is also accompanied by the problems of magnetic saturation and power loss. In actual production, a silicon steel sheet material with high relative magnetic permeability and low electrical conductivity should be selected as the magnetic conductive medium to reduce the space. Magnetic leakage. The structure of the magnetically
permeable material should be designed as an E-2 structure to optimize the magnetic circuit of the repulsion mechanism and avoid magnetic saturation, so as to optimize the driving efficiency.

(2) The double coil repulsive mechanism designed in this paper has a capacitor voltage of 800V and a capacity of 4700 µF. Compared with the air core double coil repulsive mechanism, the peak value of the electromagnetic repulsion increases by 10.6%, and the maximum opening speed increases by 25.3%. The movement time is shortened by 14.2%, the driving efficiency is increased by 41.6%, and the stroke distance of 12 mm is able to be moved within 1.8 ms.

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