Design of Bistable Permanent Magnet Mechanism for 12KV Vacuum Circuit Breaker

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Abstract. In order to solve the problem of design of bistable permanent magnet mechanism with vacuum interrupter, this paper firstly chooses the dimensions of the permanent magnet mechanism and the selection of material properties according to the mechanical parameters of the vacuum interrupter. Using the electromagnetic analysis software ANSYS Maxwell to analyze the two-dimensional model of the permanent magnet actuator. In the dynamic analysis, the optimization of the separation and closing result can be realized by changing the voltage and capacitance capacity of the coil power supply capacitor. The experiment verifies the correctness of the method.

Introduction

The high voltage circuit breaker is one of the most important switching devices in the power system, and it is also an important method used in relay protection in the middle high voltage field. The function of the circuit breaker is mainly reflected by the action of the divider gate, and the action of the divider gate is mainly reflected in the operating mechanism of the circuit breaker. The operating mechanism of traditional circuit breakers is complex, the number of parts is large, and the mechanical reliability is not high. Not a good choice for synchronous closing and breaking techniques. Vacuum circuit breaker based on permanent magnet mechanism, with few parts, simple structure and high life span. In this paper, a vacuum interrupter is first chosen, and the mechanical parameters of the permanent magnet actuation mechanism are designed. Then using the electromagnetic analysis software ANSYS Maxwell to analyze the two-dimensional model of the permanent magnet actuator statically and dynamically, and the optimization of the closing result can be realized. According to the design, the prototype is made and the no-load test is carried out, which verifies the rationality of the design.

Design of Permanent Magnet Mechanism for 12KV Vacuum Circuit Breaker

The design of the permanent magnet mechanism is mainly based on the performance parameters of the vacuum interrupter used. Performance parameters mainly include static and dynamic characteristic parameters[1].Static characteristic parameters including separation and closing retention capacity. Dynamic characteristic parameters include: closing speed and so on. In the structure of the vacuum circuit breaker of the direct-actuated bistable permanent magnet mechanism, above is the vacuum interrupter, below is the permanent magnetic mechanism.

Pretreatment of Permanent Magnetic Mechanism Design

Using a company designed the type EP121231E-L vacuum interrupter sealed terminal post,The contact opening distance is 9mm and the contact opening distance stroke is 4mm, the contact pre-pressure is 2100N and the rated contact pressure is 3100N.From the above parameters, the separation and closing retention capacity F_m and movable iron core stroke L_m of the permanent magnet mechanism can be calculated. The formula for F_m and L_m is as follows:

$$F_m = niP_1(1 + k) + m_1g + m_2g + m_3g - Q \quad (1)$$

$$L_m = \eta\left(L_D + L_0\right) \tag{2}$$

In formulas(1) and(2), i is the system transmission ratio, and the straight up and down structure transmission ratio i is 1. n is the number of circuit breakers, single phase is 1,three phase is 3.k is the safety factor. In this article, k = 0.3.$m_1g+m_2g+m_3g$ is the total mass, the technical parameters of the sealed terminal post in the vacuum interrupter can obtain m=9.7 Kg.Q is the contact closing force, from the technical parameters can obtain Q=100N.L_D is contact opening distance, and take L_D here for 9mm;L_0 is contact stroke,and take L_0 here for 4mm.Substitute the above parameters into formulas to find the following values: F_m=4000N,L_m=13mm.

Movable Iron Core Size Design

Generally, silicon steel is selected to make dynamic iron cores. silicon steel can not only effectively reduce eddy current loss, but also has good magnetic conductivity. D21_50 is chosen here. The calculation formula of the surface cross-sectional area S of the dynamic iron core is:

$$S = \frac{2F_m u_0}{B_1^2} \tag{3}$$

In equation(3) B_1 is the flux density of the working air gap; U_0 is the vacuum permeability: $4\pi \times 10^{-7}$H / M. The magnetic induction strength of the movable iron core is always taken from the value near the knee point of the magnetization curve of the magnetic material used by it[2], where B_1 is taken as 1.6 T. The surface cross-sectional area of movable iron core S_0 is 3927mm^2 by bringing the data into the formula(3).The diameter of the driver rod in this article is taken as 18mm.The total area of the movable iron core is:

$$S = S_0 + S_1 \tag{4}$$

In equation(4), S_1 is the area of the drive rod, S is the total surface cross-sectional area of the movable iron core, R is the radius of the movable iron core. Into the data to obtain movable iron core radius equal to 36mm.The movable iron core gap flux is:

$$\phi_p = B_1 S = 62.83 \times 10^{-4} W_b \tag{5}$$

Design of Permanent Magnet Parameters

Calculation of Permanent Magnet Height. The permanent magnet uses N48 type NdFeB permanent magnetic material. Its residual magnetic induction strength Br is 1.37 T, and its coercive force HC is 838KA/m. The key to designing a permanent magnet is to determine its working point. This design chooses the working magnetic density B_2 of the permanent magnet as 75 % of the residual magnetic Br, and the working point is(250KA/m,1.05T)[3].The upper section has already sought to activate the iron core gap flux Φ_P. The formula for the permanent magnet cross-sectional area S_0 is:

$$S_0 = \frac{\phi_P}{B_2} \tag{6}$$

Bring in data to obtain permanent magnet cross-sectional area S_0 is 6551 mm^2 ,and is taken as 6600mm^2.According to the shape of the permanent magnet as a cylinder, the gap between the permanent magnet and the movable iron core is taken as 1mm.The formula for the height calculation of the permanent magnet is:

$$h_0 = \frac{S}{2\pi R_2} \tag{7}$$

In formula(7), R_2 is the radius of the permanent magnet, which is 49.5 mm. The height of the permanent magnet can be found at 21mm.

Calculation of Permanent Magnetic Thickness. To calculate the thickness of the permanent magnet, the magnetic potential consumed by the magnetic circuit should be calculated first. The magnetic potential consumed by the magnetic circuit mainly includes two aspects[4].The first aspect is the magnetic potential consumed by the air gap, and the second aspect is the magnetic potential consumed by components such as the movable iron core and magnetic yoke. The operating air gap between the movable iron core and the static iron core δ_1=0.1mm.There are 3 non-operating gas gap:δ_2=1mm,δ_3=0.1mm,δ_4=0.1mm.In the above article, the working flux density of the working air gap is B_1 of 1.6T, and Assume that the non-working gap flux density B_2 is 1.2T.The magnetic potential IN_1 consumed by the air gap is:

$$IN_1 = \frac{1}{\mu_0}(B_1\delta_1 + B_2(\delta_2 + \delta_3 + \delta_4)) \quad (8)$$

The magnetic potential IN_1 that is brought into the data to obtain gas gap consumption is 1159A.Due to the unknown size of movable iron core and magnetic yoke, the magnetic potential consumed by components such as dynamic core and magnetic yoke can't be determined[5],Some literature has pointed out that the magnetic potential consumed by air gaps is much larger than that consumed by components such as moving iron cores and magnetic yoke. Assume that the total magnetic potential IN consumed to be 1800A.The working point is 250KA/m, and the formula for calculating the thickness L of the permanent magnet is:

$$L = \frac{IN}{H} \quad (9)$$

Substituting data to obtain permanent magnet thickness L is 6mm. The final inner diameter of the permanent magnet is 49.5 mm. The outer diameter is 55.5 mm and the height is 21mm.

Design of Coil Size

Closely related to the separation and closing is the closing coil. The reason why the movable iron core can drive the contact motion is because the current in the coil changes the original permanent magnetic field. Whether the parameter design of the closing coil is reasonable has a direct influence on the dynamic characteristics of the permanent magnet mechanism[6].Parallel winding generally uses a small wire diameter and good insulation of the paint package, series winding generally uses a large wire diameter copper wire[7,8].The bistable permanent magnet mechanism is capacitor discharge when separation and closing. During the closing process, the coil is required to provide a combined force that can overcome other forces in order to successfully close the gate, and the magnetic force is the closing force. The formula is:

$$F = F_1 - (F_3 + F_4 - m_1 g) \cdot i - m_2 g + F_2 \quad (10)$$

In type(10), the retaining force F_1=2000N, and the pretension F_2 is taken to 380N.Substituting data to obtain a combined force F is 2080N.According to Maxwell's equations:

$$F = \frac{B^2 S}{2\mu_0} \quad (11)$$

In equation(11), B is the magnetic density of the coil, and substitution data to obtain B=1.23 T. Substituting data to obtain IN_1 is 19586A.The magnetic pressure provided by each non-main air gap and conductor of the coil is reduced to 0.3 IN_1, and the total magnetic pressure drop IN_0 is 1.3 IN_1 is 25461A.

The maximum values of the current at the closing and separation gates are 30A and 80A.The calculation formulas for the number of turns of the closing coil and the separation coil is:

$$N = \frac{IN_0}{I} \quad (12)$$

Bring in the data to obtain N_1=848.7, take an integer of 800 turns, and N_2=318.2, take an integer of 300 turns. This design takes the copper wire with a diameter of 0.8 mm.

Simulation of Static Characteristics of Permanent Magnet Mechanism

Through the second section of the structure parameters design of the permanent magnet mechanism, using ANSYS Maxwell software to build its two-dimensional model, and then the static characteristic simulation is performed. The two-dimensional model of the permanent magnetic mechanism is shown in Figure 1.Without the coil being energized, the static suction of the permanent magnet to which the simulated dynamic core is subjected is shown in Figure 2.

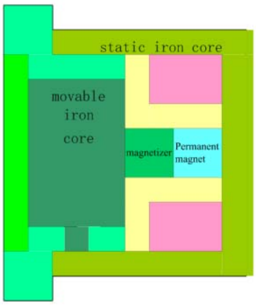

Figure 1. Two-dimensional model design

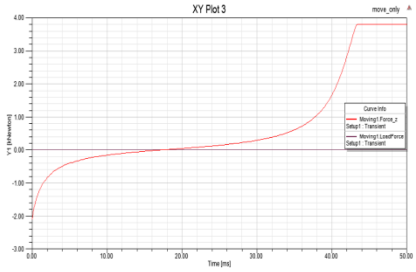

Figure 2. Permanent magnetic retention force-time curve

The distribution of the magnetic field at the separation and closing positions of the movable core is shown in Figures 3 and 4.At the separation gate position, the magnetic force line mainly forms a low reluctance channel through the moveable iron core and the static iron core. The larger space above the moveable iron core indicates that the magnetic impedance is very large, so the magnetic force line is mainly concentrated below the moveable iron core. In the closing position is the opposite of the separation position.

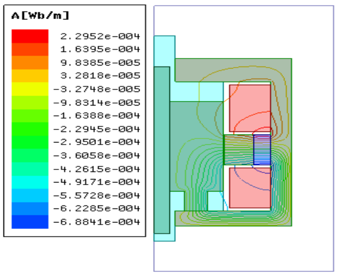

Figure 3. Magnetic lines in the separation gate position

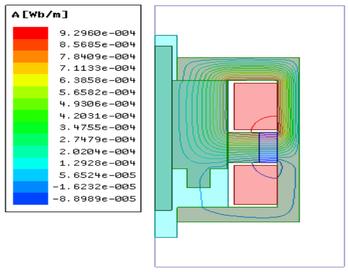

Figure 4. Magnetic lines in the closing gate position

Dynamic Characteristic Simulation of Permanent Magnet Mechanism

Reaction Force Calculation

Before the simulation of the dynamic characteristics, we need to calculate the reaction characteristics of the vacuum arc extinguisher. The curve function of contact spring is obtained by point fitting of disc spring. In the process of closing gate, when the displacement is less than 9mm, there is vacuum self-closure force and gravity of moving parts; when the displacement is 9-14mm, there is vacuum self-closure, gravity of the moving part, and contact spring reaction.

Dynamical Characteristics of the Separation Gate

Before analyzing the dynamic characteristics of the separation gate, this paper analyzes the influence of the change of the capacitance capacity and voltage of the energy storage capacitor on the characteristics of the separation gate.

Change Capacitance Voltage of Energy Storage. The fixed coil number is 250 turns and the storage capacitance capacity is 0.022F.Change the voltage of the energy storage capacitor and obtain the change curve of the current of the separation coil and the displacement of the movable core with time. As shown in Figures 5 and 6, represent the curve of the coil current and the displacement of the moving iron core with time when the voltage of the energy storage capacitance of the separation gate coil is 260V, 220V and 180V, respectively. When the voltage is greater, the coil current is larger, and the speed of the movable iron core will also increase.

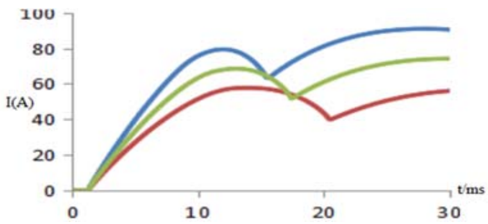

Figure 5. Variation of coil current

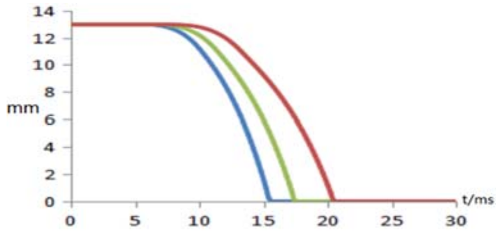

Figure 6. Variation of displacement of movable iron core

Change the Capacitance Capacity of Energy Storage. The fixed energy storage voltage is 260V, and the coil number is 200 turns, changing the size of the energy storage capacitor. It can be seen that the larger the capacitance capacity, the current of the coil will also become larger, and the speed of the movable iron core will also increase.

The above analysis provides a theoretical basis for regulating the separation and closing speed. Meanwhile, provides important information for optimizing the characteristics using ANSYS Mawell electromagnetic simulation software. By using electromagnetic simulation software to optimize the separation coil, it is finally confirmed that the number of turns of the following parameter separation coil is 300 turns, the capacitance voltage is 220V, and the capacitance capacity is 0.022 F. The displacement curves of the separation coil current and the moving core are shown in Figure 7 and Figure 8.

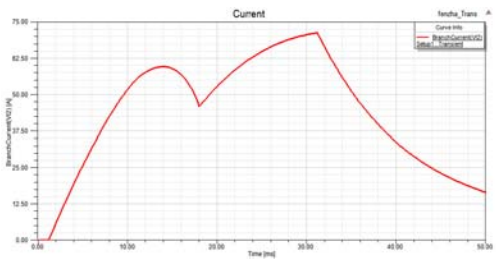

Figure 7. Separation gate current change curve

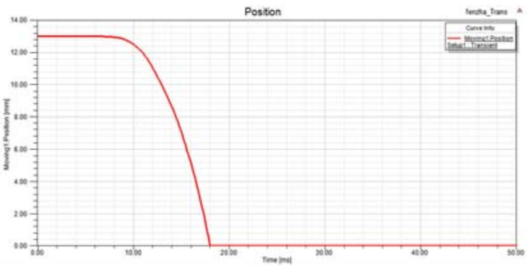

Figure 8. Separation gate displacement change curve

Experimental Analysis

In the previous sections, the permanent magnet mechanism is designed and simulated. The prototype is made by design parameters. The separation and closing of the prototype were tested. The displacement of the movable core is collected by the displacement sensor below the permanent magnet mechanism. The experimental data and the simulation data are compared. The experimental data are shown in Figures 9 and 10, the solid line represents the simulation data and the dotted line represents the experimental data. In the test, the average speed of the separation gate was 1.21 m/s, and the average speed of the closing gate was 0.61 m/s. In the actual situation, it will be affected by the test method and the environment. It will inevitably produce some errors, but the results are basically the same. The rationality and validity of the design are proved.

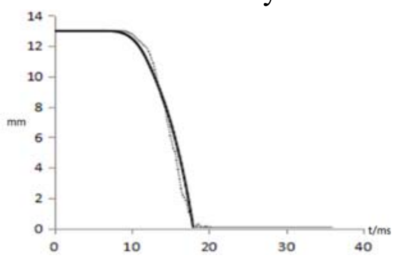

Figure 9. Displacement variation during separation

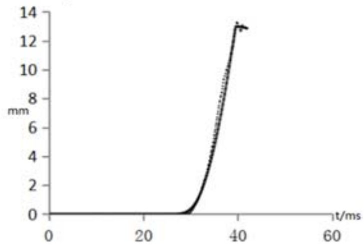

Figure 10. Displacement variation during closing

Conclusion

This paper introduces a design method of a 12KV bistable permanent magnet vacuum circuit breaker, makes a theoretical analysis of the selection of the parameters in the design, and then analyzed the two-dimensional model of the permanent magnetic actuation mechanism statically and dynamically. In the dynamic analysis, the influence of these factors on the dynamic results is explained by simulating the change of capacitance voltage and capacitance capacity, which provides a theoretical basis for the optimization results. The rationality of the design is verified by the no-load test of the prototype. This paper provides a reference for designing permanent magnetic vacuum circuit breakers with different structures and different voltage levels.

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