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Field-Control Performance of Direct Current Memory Flux Orthogonal Magnetizing Controllable Reactor

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Abstract

Aiming at the condition that the exciting power is bigger when the orthogonal magnetizing controllable reactor adjusts the flux in wide range and there is coupling between the alternate current(AC) magnetic circuit and the direct current (DC) circuit. This paper proposed a kind of orthogonal magnetizing controllable reactor based on DC memory flux. The aluminum nickel cobalt alloy (AlNiCo) magnet with low coercive force and high residual flux density was used so that the DC flux could be online tuned without additional copper loss. This paper designed the new type of orthogonality magnetic structure without coupling between the AC-DC circuit and magnetic circuit. The simulated analysis result shows that this electric reactor realizes the unidirectional control from the DC magnetic circuit to AC magnetic circuit, which makes the inductor of electric reactor controllable more easily.

Keywords: DC memory flux; orthogonal magnetizing controllable reactor; AlNiCo;

Introduction

With the development of the power industry, controllable reactors are widely used Grid reactive power compensation, limiting over-voltage and improving power quality, etc [1-6]. The quadrature magnetized controllable reactor is a late-start DC magnetron-type reactor, which is developed from a parametric transformer. The structure of the traditional orthogonal magnetizable controllable reactor adopts a special iron core orthogonal structure, which makes the DC magnetic field generated by the exciting winding and the AC magnetic field generated by the working winding orthogonal, which is a kind of DC magnetic control reactor. The magnetic permeability in the direction of the AC magnetic flux of the iron core material is changed by adjusting the current in the DC field winding, thereby achieving the purpose of smoothly adjusting the inductance value [7-12].Conventional quadrature magnetized controllable reactors have large excitation power during wide-range tuning, and there is coupling between the AC magnetic circuit and the DC circuit. This will affect the operating efficiency and reliability of the reactor. Based on this, this paper proposes a DC memory flux-based orthogonal magnetizable controllable reactor (DMFOMCR), which introduces the structure characteristics and magnetic regulation mechanism of the reactor in detail, and establishes its magnetic circuit model and mathematical model. The finite element analysis of the magnetic field distribution and tuning characteristics of the DC magnetic circuit.

Controllable reactor structure and magnetization mechanism

1. Controllable Reactor Structure

Figure 1 shows the structure of a single-phase DMFOMCR. Its main structure consists of a single-phase AC working winding, an AC core, a DC core, a DC excitation coil, and an AlNiCo permanent magnet. The DC excitation coil is wound on the AlNiCo permanent magnet, which adjusts the AlNiCo on-line magnetization and demagnetization, so that the magnetic field in the DC magnetic circuit has a memory function. Figure 2 shows the orthogonal area of AC and DC magnetic fields in the reactor. The AC iron core post passing through the opening area of the DC iron core contains both AC working main magnetic flux and DC memory magnetic flux, and is 90 ° orthogonal. The principle of magnetic regulation based on DC memory flux is also applicable to other forms of orthogonal magnetizing reactors (such as three-phase three-column structure).

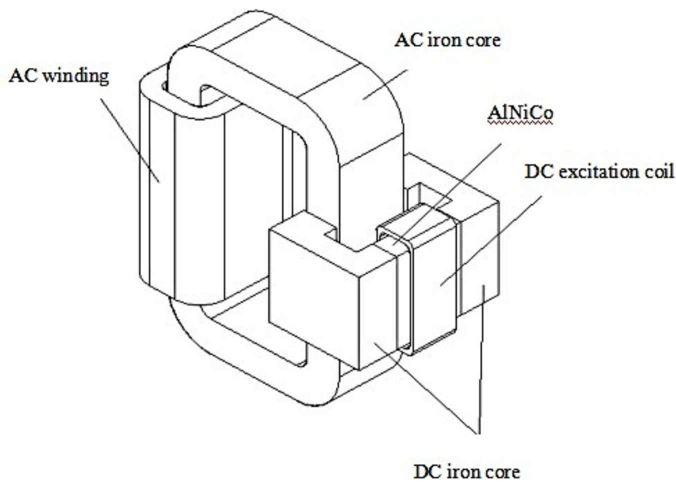


Figure 1: Schematic diagram of single-phase DMFOMCR

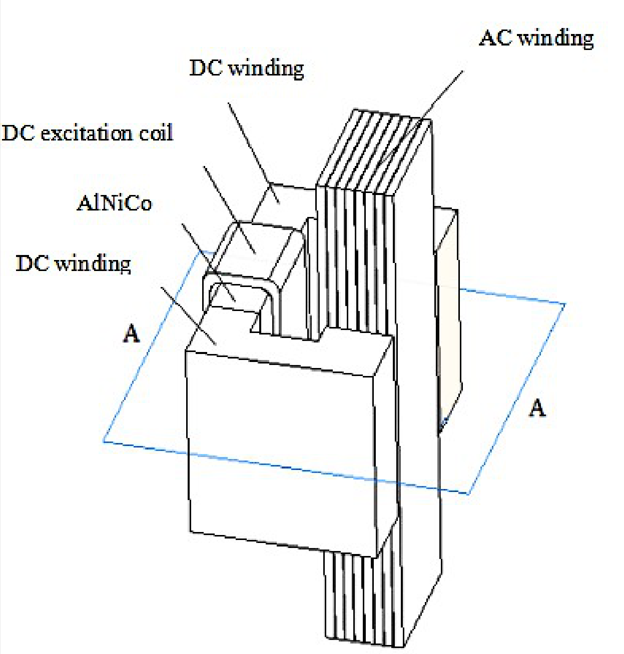


Figure 2: AC and DC magnetic field superimposed area

The magnetic circuit structure of the quadrature magnetization reactor proposed in this paper does not expose the DC excitation winding to the AC working magnetic field, so there is almost no eddy current loss in the DC winding; On the other hand, although AC magnetic flux will induce electromotive force in the DC core when it passes through the DC magnetic circuit, due to the non-conductive gap in the DC magnetic circuit, no inductive circulation will form in the DC core. Furthermore, the change in the working point of the AC magnetic flux also affects the magnetic permeability in the direction of the DC magnetic flux in the orthogonal region of the core, but the magnetic permeability is larger in magnitude than the magnetic permeability of the permanent magnets and non-conductive gaps in the DC magnetic circuit. So the working point of the DC magnetic circuit is mainly determined by the coercive force of the permanent magnet, the thickness of the permanent magnet, and the non-conductive gap. Therefore, the working point of the magnetic flux density of the DC magnetic circuit is not affected by the AC magnetic density, making the DC magnetic circuit Control adjustment is simpler.

2. DC Memory Flux Tuning Mechanism

Since the orthogonal DC magnetic field mainly affects the magnetic permeability of the core in the area where the AC and DC magnetic fields overlap, a section perpendicular to the AC magnetic field in this area is selected for analysis, as shown in Figure 3. According to the requirements of the inductor inductance adjustment, perform online repeated irreversible magnetizing and demagnetizing of AlNiCo permanent magnets. It can be called at any time according to the recorded charging and demagnetizing parameters to meet the operation target, and realize the gradation magnetic regulation of the DC magnetic field. Further, according to the accuracy requirement of the inductor inductance adjustment, by applying a small DC current to the DC excitation winding, the DC magnetic field can be provided and adjusted by mixing with the AlNiCo permanent magnet, so that the stepless smooth adjustment of the inductor inductance can be achieved and fast response. In the figure, Φ_m represents the DC magnetic field generated by the AlNiCo permanent magnet; Φ_i represents the DC magnetic field generated by the current in the DC excitation winding.

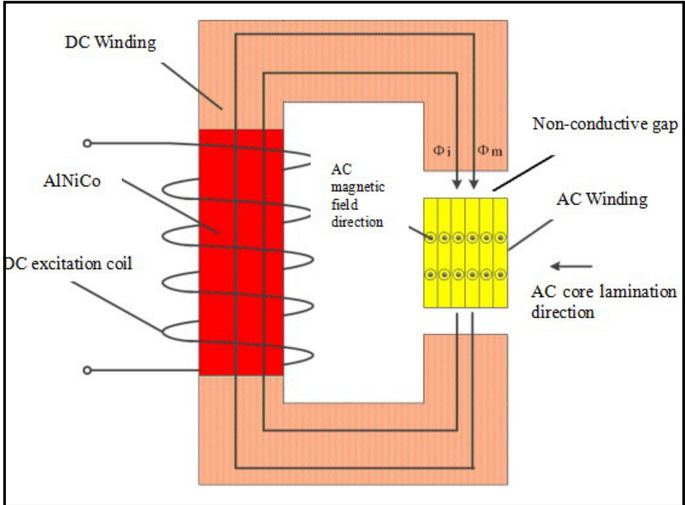


Figure 3: Cross-sectional view of the superimposed area of AC and DC magnetic fields

Equivalent magnetic circuit and mathematical model

1. Equivalent Magnetic Circuit

From the structural characteristics of the orthogonally magnetized controllable reactors shown in Figures 1 and 2 and the magnetic flux distribution characteristics of the orthogonal iron core shown in Figure 3, according to the electromagnetic field theory, the orthogonally magnetized controllable reactors can be equivalent to those shown in Figure 4.

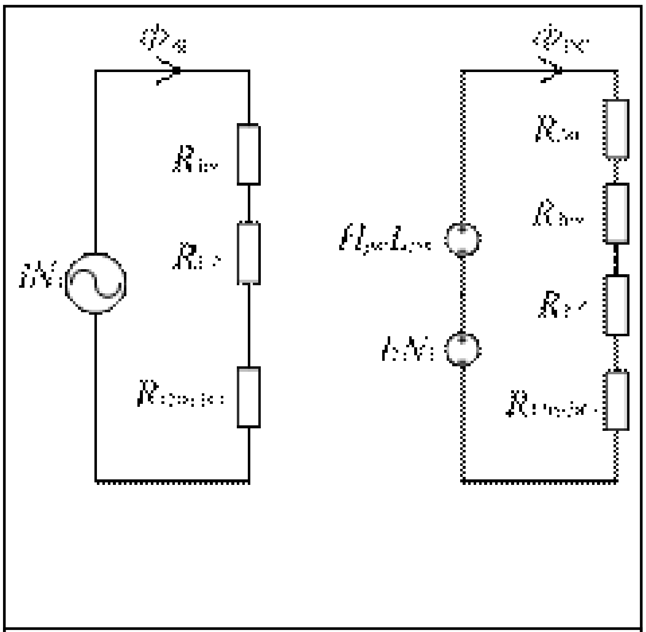


Figure 4: Equivalent magnetic circuit of reactor

The AC working side magneto resistance can be divided into three parts, non-common part iron core magneto resistance R_{1m}, air gap magneto resistance $R_{1\delta}$ and common part iron core magneto resistance $R_{12m\,(AC)}$; Adjusting the AC inductance of the reactor by changing $R_{12m\,(AC)}$.The magnetic flux of the AC magnetic circuit is generated by the magnetic potential iN_1 of the AC winding. The DC reluctance magnetization side magneto resistance can be divided into four parts, non-common part iron core reluctance R_{2m}, AlNiCo permanent magnet R_{2pm} resistance, air gap reluctance $R_{2\delta}$ and common part core resistance $R_{12m\,(DC)}$.The magnetic flux of the DC magnetic circuit is generated by the permanent magnet magnetic potential $H_{pm}L_{pm}$ and the magnetic potential I_2N_2 of the exciting coil.

2. Mathematical Model

According to the magnetic field law, the relationship between the inductance of the AC core and the magnetic circuit parameters can be expressed as:

$$L = f_1(N_1; R_{1m}; R_{1\delta}; R_{12m(AC)}) \qquad (1)$$

In the case of certain structural parameters, N_1 and $R_{1\delta}$ are fixed values, and R_{1m} is affected by Φ_{AC} .$R_{12m(AC)}$is affected by both Φ_{AC} and Φ_{DC}.

Therefore, the relationship between the inductance and the AC and DC magnetic fields is established as:

$$L = f_2(R_{1m}(\phi_{AC}); R_{12m(AC)}(\phi_{AC}; \phi_{DC})) \qquad (2)$$

From equation (2), it can be seen that when the AC magnetic circuit magnetic flux is constant, the size of the inductor of the reactor can be changed by adjusting the magnetic flux of the DC magnetic circuit.

According to Ohm's law of magnetic circuits, the DC magnetic circuit satisfies:

$$H_{pm}L_{pm} + I_2N_2 = \phi_{DC} \times (R_{2m} + R_{2pm} + R_{2\delta} + R_{12m(DC)}) \quad (3)$$

The magnitude of the quadrature core magnetic resistance R_{12m} is determined by the magnitude of the AC and DC magnetic fluxes. However, in the DC magnetic circuit, the permanent magnet reluctance R_{2pm} and the air gap reluctance $R_{2\delta}$ are much larger than R_{12m} and R_{2m} in terms of magnitude, so formula (3) can be simplified as:

$$H_{pm}L_{pm} + I_2N_2 \approx \phi_{DC} \times (R_{2pm} + R_{2\delta}) \qquad (4)$$

When the DC magnetic circuit has only permanent magnets ($I_2N_2 = 0$), a constant DC magnetic flux will be generated in the magnetic circuit. The magnetic flux of the DC magnetic circuit is:

$$\phi_m = \phi_{DC} \approx \frac{H_{pm}L_{pm}}{R_{2pm} + R_{2\delta}} \qquad (5)$$

If the permanent magnet is demagnetized online and the magnetization level and magneto motive force $H_{pm}L_{pm}$of the permanent magnet are changed, the magnetic flux ϕ_m of the DC magnetic circuit can be adjusted.

The magneto motive force $H_{pm}L_{pm}$ of the permanent magnet can also be mixed with the magneto motive force ($I_2N_2 \neq 0$) in the exciting coil to adjust the magnetic flux of the DC magnetic circuit. The magnetic flux in the magnetic circuit can be expressed as:

$$\begin{aligned}\phi_{DC} &\approx \frac{H_{pm}L_{pm} + I_2N_2}{R_{2pm} + R_{2\delta}} \\ &= \frac{H_{pm}L_{pm}}{R_{2pm} + R_{2\delta}} + \frac{I_2N_2}{R_{2pm} + R_{2\delta}} \qquad (6) \\ &= \phi_m + \phi_i\end{aligned}$$

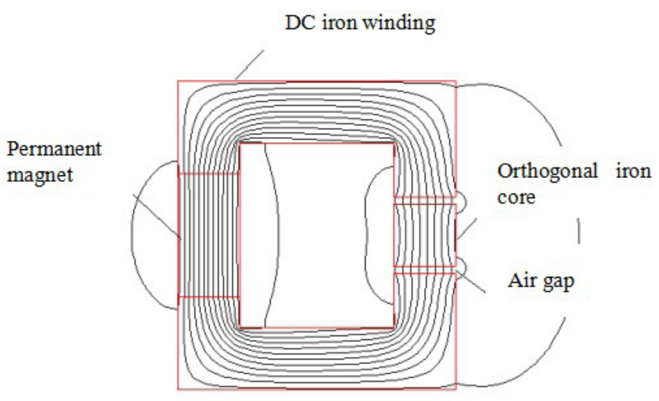
From equations (2) and (6), the governing equation of the DMFOMCR inductance adjustment can be obtained as:

$$L = f_3(H_{pm}; I_2) \qquad (7)$$

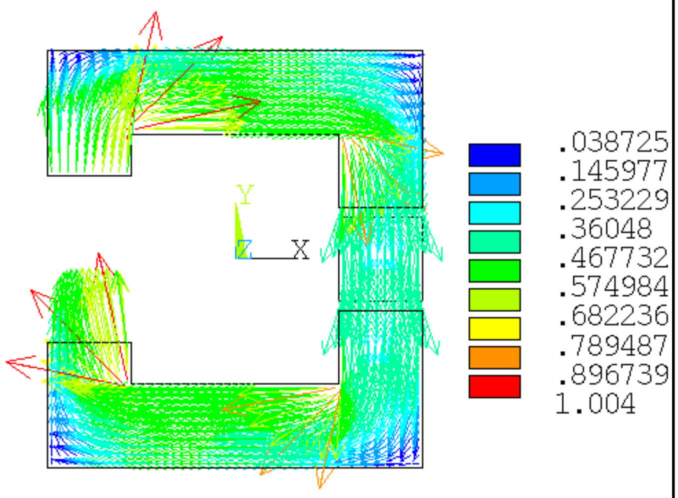
Finite element analysis of orthogonal magnetic fields

1. DC magnetic field distribution

Select the section shown in Figure 3 for magnetic field analysis. Figure 5a) shows the distribution of magnetic field lines in the DC magnetic field when AlNiCo permanent magnets are separately magnetized; Figure 5b) shows the magnetic induction intensity distribution.



a). AC iron core equivalent magnetic circuit



b). DC iron core equivalent magnetic circuit

Figure 5: Magnetic field distribution with permanent magnet alone

2. Effect of Al-Fe-B Magnetization Level on Magnetic Circuit Working Point

Figure 6 shows the DC magnetic flux density of the AlNiCo permanent magnet at different magnetization levels. It can be seen that the DC magnetic flux density is linearly related to the magnetization level of the permanent magnet.

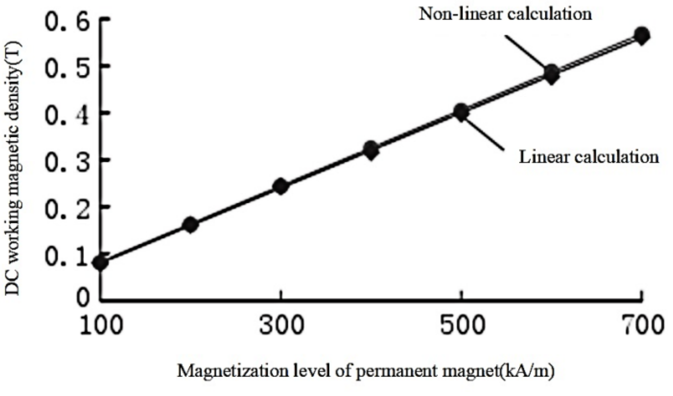


Figure 6: Magnetic flux density at different magnetization levels

Figure 7 shows the DC magnetic flux values corresponding to different relative permeability of the orthogonal core region under a certain magnetization level of the permanent magnet. It can be seen that as long as the relative permeability of the orthogonal iron core is larger in magnitude than the relative permeability of the air gap region, its change in a certain range will not affect the magnetic flux value in the DC magnetic circuit.This also shows that although the different magnetic density working points in the AC magnetic circuit will affect the equivalent magnetic resistance of the orthogonal iron core, the effect on the magnetic flux of the DC magnetic circuit is minimal, thereby realizing the DC magnetic circuit on the AC magnetic circuit. It makes the control and adjustment of the reactor inductance easier.

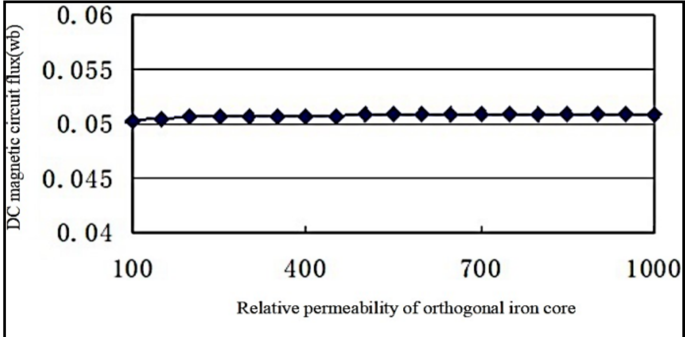


Figure 7: DC magnetic flux corresponding to the relative permeability of different orthogonal iron cores

Conclusion

This paper proposes a DC magnetizable controllable reactor based on DC memory flux, that is, a DC magnetic flux is generated by replacing the DC excitation coil with an AlNiCo permanent magnet that can be repeatedly demagnetized. Based on this, a new orthogonal magnetic circuit structure with no coupling between the AC and DC circuits and the magnetic circuit is designed. Analyze and calculate the orthogonal magnetic field distribution. The influence of AlNiCo permanent magnets on the equivalent operating point of the orthogonal region of the AC magnetic circuit under different magnetization levels was studied.

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