

Asymmetric Permanent Magnet Design for Reducing Axial Leakage Flux in Double-Spoke Type Motor

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This paper proposes a design that applies an asymmetric permanent magnet rotor to the Double-Spoke type motor structure. The proposed design demonstrates the potential to effectively reduce axial leakage flux in concentrated flux-type motors, which aim to replace rare-earth permanent magnets. In this study, the performance of the proposed structure was validated through 3D finite element method (FEM) analysis, confirming that the axial leakage flux is reduced compared to conventional symmetric designs. Furthermore, the results showed that the asymmetric structure offers the advantage of increasing back electromotive force (EMF) by adjusting the stacking length of the magnets while maintaining the total amount of magnet material. This finding is significant as it enhances the overall performance of the motor through the efficient utilization of magnetic materials.

Index Terms—Axial Leakage flux, Asymmetric permanent magnet, Double-spoke type, Back electromotive force (EMF), Finite element analysis.

I. INTRODUCTION

Recently, studies on Brushless Direct Current (BLDC) motors have been conducted to address efficiency issues caused by mechanical friction in brushes. Simultaneously, Permanent Magnet Synchronous Motors (PMSM) have garnered significant attention. [1] However, the rare-earth permanent magnets commonly used in PMSMs are highly dependent on imports from China, posing supply instability risks and potential price hikes due to Chinese policies. To mitigate these issues, research on motors utilizing ferrite permanent magnets as an alternative to rare-earth magnets has been actively pursued. Despite their advantages, ferrite permanent magnets have a lower residual flux density compared to rare-earth magnets.[1] Consequently, Concentrated Flux-type Synchronous Motors (CFSM) have also emerged as a promising solution, as they can maintain performance levels and improve air-gap flux density. Especially Double-Spoke type Motor offer the potential to reduce reliance on rare-earth magnets and enhance air-gap flux density. [2] However, due to structural limitations, a significant portion of the flux leaks axially from the rotor instead of linking with the stator through the air gap. This axial leakage flux reduces effective flux and can degrade motor performance. In this study, we propose an asymmetric rotor permanent magnet structure for the Double-Spoke type Motor while maintaining the total amount of magnet material. The proposed structure is compared with a conventional symmetric structure in terms of axial leakage flux for various designs. Furthermore, a magnetic equivalent circuit is constructed to determine the optimal design that minimizes axial leakage flux.

II. AXIAL LEAKAGE FLUX OF DOUBLE- SPOKE TYPE MOTOR

A Double-Spoke type motor, a flux-concentrated machine, features rotor cores separated by permanent magnets and

connected by magnetically saturated bridges. As a result, adjacent rotor cores are magnetized with opposite polarities, and the flux generated in this process does not pass through the air gap to the stator but leaks in the axial direction. This leakage flux can ultimately affect and lead to degradation in motor performance.

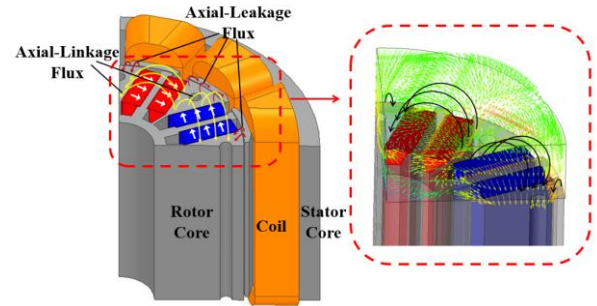


Fig. 1. Axial leakage flux of Double-spoke type Motor

The leakage flux is influenced by the shape ratio, which represents the ratio of the rotor outer diameter to the motor stacking length. It has been observed that when the shape ratio is smaller, meaning the stacking length is short and the rotor outer diameter is large, the leakage flux increases. This shape ratio can be defined by Equation (1)

$$\text{Shape ratio} = \frac{\text{Stack length}}{\text{Rotor Outer Diameter}} \quad (1)$$

From the results show in Figure 2, the back EMF of a Surface Permanent Magnet Motor (SPM) and a Double-Spoke type Motor (DSM) was compared by normalizing the back EMF to 1 based on 2D analysis with respect to the shape ratio. The results revealed that for both models, the back EMF decreases as the shape ratio decreases. However, the back EMF of the CFSM decreases more significantly compared to the SPM. This suggests that the axial leakage flux of the DSM is greater than that of the SPM. To identify the detailed leakage characteristics

and apply them, a 3D Finite-Element Analysis (FEM) was conducted.

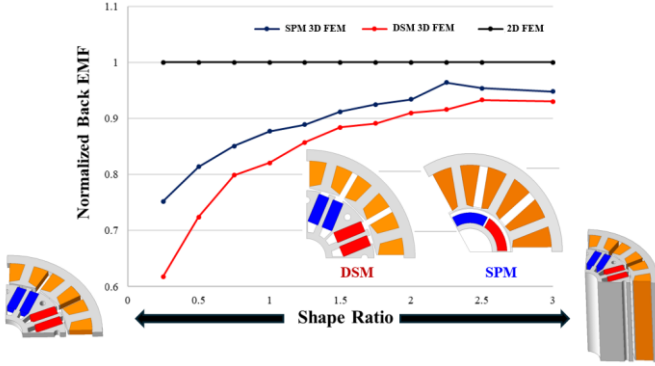
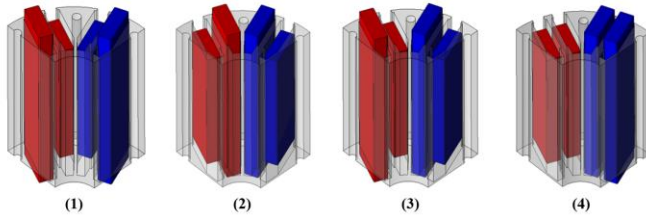
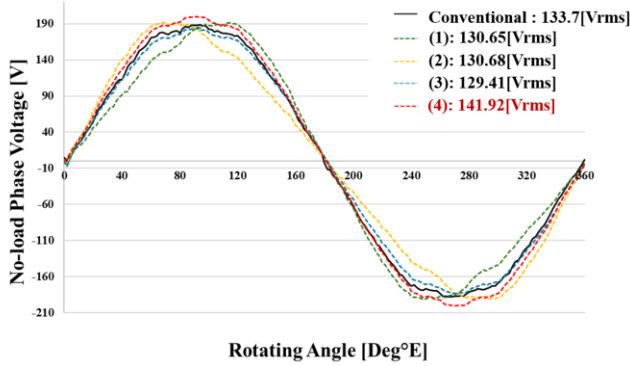


Fig. 2. Comparison of Normalized Back EMF Between SPM and DSM Based on Shape ratio

III. SELECTION AND ANALYSIS OF ASYMMETRIC PERMANENT MAGNET ROTOR STRUCTURES



(a) Design Examples



(b) No-load Phase Voltage

Fig. 3. Analysis of Various Asymmetric Permanent Magnet Rotor Designs and each No-Load Phase Voltage

To reduce the axial leakage flux caused by the rotor structure in the Double-Spoke type Motor, asymmetric permanent magnet models (1), (2), (3), and (4) were designed by varying magnet stacking lengths while maintaining the total amount of magnet material from the conventional model. Measurements of the no-load phase voltage, i.e., the back EMF, showed results of 133.7[V] for conventional model, 130.65[V] for (1), 130.68 [V] for (2), 129.41 [V] for (3), and 141.92[V] for (4). It was observed that the back EMF in the (4) structure increased by 6.13% compared to the original structure.

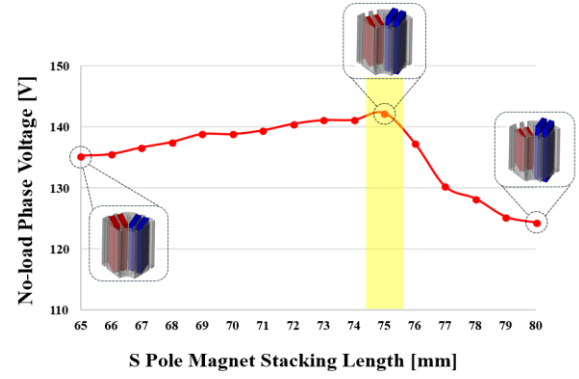


Fig. 4. No-load Phase Voltage for the (4) Model at Different Staking Lengths

Subsequently, No-load back EMF measurements were conducted for the modified structure with different magnet stacking lengths, and the most significant result was obtained with a 75mm structure, applying a 15% change from the original 65mm stacking length of the S-pole magnet, resulting in 141.92[V].

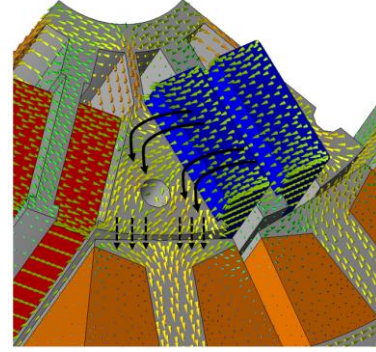


Fig. 5. Magnetic Flux Density of the Overhang structure

In the Overhang Rotor, it was observed that the magnetic flux concentrates at the core ends, and due to the fringing effect, the flux linking with the stator also becomes concentrated.

IV. CONCLUSION

To reduce axial leakage flux in a Double-Spoke type Motor, an asymmetric rotor structure was applied by modifying the magnet stacking length. A model was identified where the back EMF increased by 6.13% and it was confirmed that the maximum performance was achieved when the stacking length was increased by 10mm.

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