

# A study on Performance Improvement of Axial Flux Motor Through Halbach Array and Same Direction Skew

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In this paper, methods to reduce iron loss through same direction skew and halbach array by utilizing the shape freedom of 3D printing are proposed. Axial flux motors have a higher power density than radial flux motors and are advantageous in a multi-pole structure. However, in the case of an axial flux motor, it is difficult to manufacture through electrical steel sheet lamination for iron loss reduction. As a method for reducing iron loss in existing axial flux motors, manufacturing through core-loss type, armor force steel plate, and powder material rolling is mainly used. However, in the case of the armor force steel plate, there is a disadvantage in that it is difficult to manufacture, and in the case of manufacturing through rolling, high-cost mold manufacturing is essential. It is possible to overcome the disadvantages of the existing manufacturing method when manufacturing a motor by utilizing the shape freedom, which is an advantage of 3D printing technology. However, cores manufactured using 3D printing currently have high iron loss characteristics, which is a fatal disadvantage to motor output. To reduce iron loss, a combination of pole numbers and slots with a small number of poles can be selected, but a combination with a small number of poles opposes the characteristics of an axial flux motor. Through the same direction skew and Halbach array, the performance of an axial flux motor can be increased even in a combination with a small number of poles. The validity of the proposed model was reviewed through finite element analysis.

**Index Terms**—Halbach Array, Skew, Axial Flux Motor, AFPM

## I. INTRODUCTION

Recently, as system electrification progresses in various industrial fields, the demand for high power density motors is increasing. In Equation 1, the torque generating cross-sectional area of the axial flux motor becomes the diameter of the circle facing the rotor, and the torque generating cross-sectional area of the radial flux motor becomes the outer surface of the rotor cylinder facing the stator. While the torque of a radial flux motor is proportional to the square of the diameter, as shown in Equation 2, the torque of an axial flux motor is proportional to the cube of the diameter. In other words, in a thin structure, the axial flux motor has the advantage of higher power density than the radial flux motor. [1-2]

$$T_m = \frac{\pi}{4} (k \hat{B}_{g1} a c \cos \beta) D_g^2 L_{stk} \quad (1)$$

$$T_d = \left\{ \frac{1}{8} (a c \pi k_{\omega1} B_{avg}) (1 - K_d^2) \right\} D_{out}^3 \quad (2)$$

However, while the radial flux motor has a structure in which two-dimensional core shapes are laminated, the axial flux motor has a three-dimensional shape and is difficult to manufacture through electrical steel sheet lamination. Core fabrication through electrical steel sheet lamination is to reduce iron loss. Iron loss is divided into hysteresis loss and eddy current loss. Depending on the stacking, the path of the eddy current becomes longer, so the resistance of the eddy current increases and consequently, the eddy current loss is reduced.

In the case of the existing core type axial flux motor, it is manufactured by rolling armor force steel plate or powder material for eddy current reduction design. In the case of the existing armor force steel plate, it is produced by rolling a thin steel plate. The same effect as lamination is produced, and eddy

current loss can be reduced. However, in the case of armor force production, the technical difficulty of production is very high and mass production is difficult. In the case of rolling production through SMC powder material, it is a method of forming an insulated core for each crystal with a press. In this case, manufacturing is easy, but high manufacturing costs are required because manufacturing is required through a mold. [1-2]



Fig. 1. Teeth shape produced using 3D printing.

Currently, with the development of fe-4.5si metal printing technology, it is possible to manufacture motor cores using 3D printing. Fig. 1 shows the tooth shape of the axial flux motor manufactured using metal 3D-printing technology. When manufacturing the core of a motor by utilizing the shape freedom, which is an advantage of 3D printing technology, it is possible to improve the technical difficulty and productivity, which are disadvantages of Armor Force production. In addition, since mold manufacturing is not required, mold manufacturing cost, which is a disadvantage of powder cores, can be improved. Even if 3D printing is applied, it can play the role of the existing electrical steel sheet or Somalloy material, but it has a greater core loss than the existing Somalloy material.

Since the iron loss is proportional to the electric frequency, if the combination of the number of poles and the number of slots with a small number of poles is selected, it is possible to operate with a small iron loss based on the same speed. However, in the case of an axial flux motor, since it has advantageous characteristics in multipoles, if the number of poles in an axial flux motor is reduced, performance may be impaired. The reason why axial flux motors have advantageous characteristics in multi-pole is related to the back yoke. In order to match the same back-yoke saturation, a relatively thick back-yoke thickness can be selected in a multi-pole structure.[1-2]

## II. METHOD TO REDUCE BACK YOKE THICKNESS

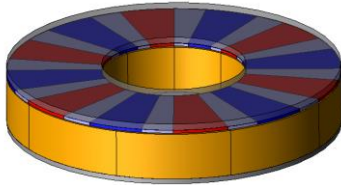


Fig. 2. Axial flux motor shape with Halbach Array.

Fig. 2 shows the shape of an axial flux motor to which a Halbach array is applied. Halbach Array and Same Direction Skew were applied as a back yoke thickness reduction design to select a combination of pole number slots with a small number of poles. Halbach arrangement refers to a structure in which permanent magnets with different magnetization directions are combined. The existing rotor back yoke exists to serve as a magnetic circuit inside the permanent magnet. To make the magnetic circuit of magnetic flux effective, the back yoke must be thick enough not to cause magnetic saturation.

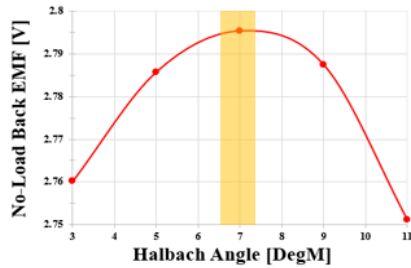


Fig. 3. No-Load Back-EMF according to Halbach Angle.

As the Halbach angle increases, the magnitude of the main flux decreases. Performance deterioration due to back yoke saturation and decrease in running flux were compared with no-load back EMF. Fig. 4 shows that the optimal Halbach angle was selected at 7 degrees.

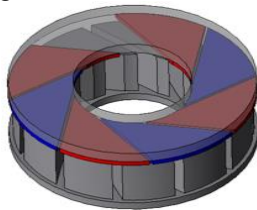


Fig. 4. Axial Flux Motor with Same Direction Skew.

Fig. 4 shows the shape where the skew is applied in the same direction to the tooth and magnet. When Same Direction Skew

is applied, it has the effect of extending the path of the X-Y plane, not the path of magnetic flux in the Z-axis direction. As the same direction skew is applied, the path of magnetic flux can be increased, but the copper loss increases because the length of the winding wire increases.

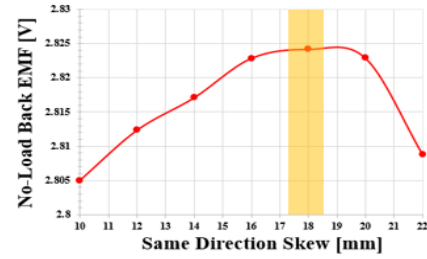


Fig. 5. No-Load Back-EMF according to Same Direction Skew.

Halbach Array and Same Direction Skew can be applied simultaneously to further reduce back yoke saturation. Fig.5 shows the no-load back EMF according to Same Direction Skew at 7 degrees of Halbach angle.

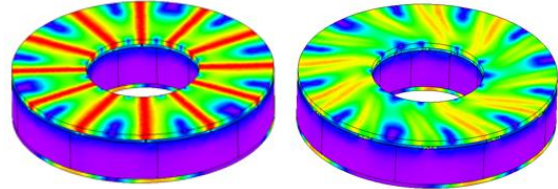


Fig. 6. Comparison of saturation between the original model and the model applied with the two methods.

Fig. 6 shows the saturation when the optimal Halbach Array and the optimal Same Direction Skew variable are applied. It can be confirmed that the saturation of the back yoke is reduced.

## III. CONCLUSION

The saturation of the back yoke was reduced through Halbach Array and Same Direction Skew. If these two methods are applied to the actual design, the thickness of the back yoke can be reduced compared to the existing ones. In this paper, a comparison of no-load counter-EMF according to the Halbach angle was conducted. In addition, the same direction skew was applied to the corresponding Halbach Angle, and the no-load back EMF according to the size of the variable was compared. In the next paper, we will show that the thickness of the back yoke of the actual target motor has been reduced and that the performance of the multi-pole structure can be secured even in the 12-pole structure, which is not commonly used due to the small number of poles in other axial flux motor structures. In addition, we will provide a basic design process using the Halbach array and Same Direction Skew and show the optimal design accordingly.

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