

A Study on Design to Improve Output of Axial Flux Motor for Collaborative Robots

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Recently, the need for collaborative robots is increasing as they can replace workers' repetitive manual work to improve work efficiency and solve labor shortage problems. The motor used for the joint of the collaborative robot must satisfy the limited axial length to ensure safety while having a large driving range in a limited space. Therefore, in the size of a thin structure with a short axial length, a design was performed to improve the output by replacing the existing radial permanent magnet motor (RFPM) with an axial flux permanent magnet motor (AFPM). In RFPM, the torque is proportional to the square of the diameter of the motor and the stacking length, so if the axial length is short, the performance is reduced in proportion to it. On the other hand, since the torque density of AFPM is proportional to the cube of the diameter of the motor and the permanent magnet can be used as much as possible as long as the core is not saturated, the output can be higher than that of RFPM in the same volume. In this paper, the design process for selecting the shape of AFPM that can increase the power density of the axial flux motor was proposed and the final model was selected. The combination of the number of pole slots was selected, detailed design for shape variables for various types was carried out, and the feasibility of the study was verified by performing finite element analysis (FEA).

Index Terms—Permanent magnet motors, Axial flux motors, Collaborative robots, Output improvement.

I. INTRODUCTION

RECENTLY, collaborative robots are expanding a new market in the manufacturing industry [1]. Collaborative robots are industrial robots that can work together with humans in the same space without installing safety fences. It not only replaces repetitive manual work that relied on workers such as assembling screws and parts and inspecting electrical components, but also improves work efficiency to the extent that a task performed by several workers for an hour can be completed in about 3 minutes. Therefore, it is possible to reduce the frequency of accidents that may occur in the workplace, lower costs, and contribute to solving the problem of labor shortage, so the need for it is increasing. Fig. 1 shows a collaborative robot with a high payload that is being manufactured.

Due to the nature of collaborative robots that perform tasks in the same space as humans, the robot itself must be lightweight for safety reasons. To increase the payload of the collaborative robot, high torque must be produced. The increase in the output of the joint motor responsible for driving the collaborative robot leads to high torque, which is a key part to design when aiming to increase the payload of the cooperative robot.



Fig. 1. 15kg Payload Collaborative Robot.

This paper proposes a shape design process for a permanent magnet type motor for robot joints with a structure in which the

rotor shaft diameter is large and the axial length is very short. The power density can be improved the most by changing the same shape and dimensions as the target radial flux motor to an axial flux type motor, examining the performance of various shapes of the axial flux motor, and selecting variables that satisfy the target specifications. A proposed model was selected.

II. TORQUE GENERATED BY AXIAL FLUX MOTOR AND RADIAL FLUX MOTOR

Fig. 2 shows a radial flux motor as a target and an axial flux motor for power improvement in an ultra-thin structure. Equation (1) is a torque generated in the radial flux motor and occurs in proportion to the square of the motor diameter. Equation (2) is a torque generated by the axial flux motor, which is proportional to the motor diameter cube, so it has an advantage in an ultra-thin structure because it has a high torque density in the same volume, reduces the axial length, and increases the permanent magnet usage [2].

$$T_m = \left(\frac{\pi}{4} k_w \hat{B}_{g1} ac \cos \beta \right) D_g^2 L_{stk} \quad (1)$$

$$T_d = \left\{ \left(\frac{1}{8} ac \pi k_{w1} B_{avg} \right) (1 - K_d^2) \right\} D_{out}^3 \quad (2)$$

Where ac is the total electric charge divided by the circumference in the air gap, and k_w is the winding factor.

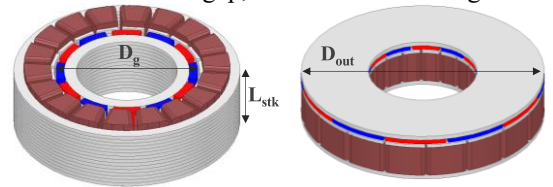


Fig. 2. Shapes of Radial Flux Motor and Axial Flux Motor.

III. DESIGN FOR IMPROVING OUTPUT OF AXIAL FLUX MOTOR

A. Target model specification and design process

Table 1 shows the specifications and target performance of the target radial flux motor. For performance comparison, the design was carried out with the same volume, fill factor, and winding specifications as the target model. In addition, the conventional motor was manufactured with electrical steel laminated structure, but in the case of axial flux motor, it was designed as a shoeless model with soft magnetic powder composite (SMC) in consideration of manufacturability.

TABLE I
DESIGN SPECIFICATIONS AND TARGET PERFORMANCE

Parameter	Value	Unit
Phases	3	-
Air Gap Length	0.5	mm
Height	19.6	mm
Outer Diameter	82	mm
Inner Diameter	44.8	mm
Current Density	13.7	A _{rms} /mm ²
Core Material	Somaloy 700 3P	-
Permanent Magnet	N42SH	-
Rated Speed	3500	rpm
Rated Torque	0.673	Nm
Rated Power	246.7	W

Fig. 3 shows the design process of axial flux motor showing the design sequence in this paper. First, a combination of the number of pole slots with a periodic model is selected so that the winding coefficient is higher than 0.9 and the force in the axial direction is generated symmetrically. For the selected combination, the basic design model of the axial flux motor is analyzed for the same area factor and winding specifications, and a top model with a high RMS value and low THD of line-to-line voltage at no load is selected. Saturation and output performance according to the design variables are determined for the selected pole slot number combination candidates. In this paper, the values for the rotor yoke and stator teeth, which most affect the output in the shape of the axial flux motor, were set as variables.

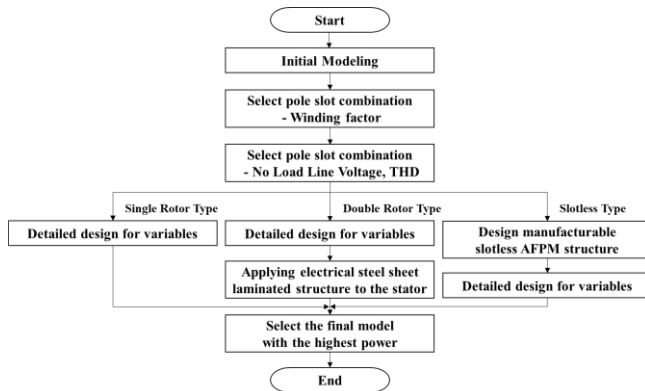


Fig. 3. Design process of axial flux motor.

Among the classifications of axial flux motors, the design was carried out for single rotor and dual rotor structure shape. The dual-rotor structural shape has the advantage of increasing the amount of magnet usage and removing the yoke by

disposing the opposite polarity of the facing magnet, thereby increasing the number of turns in a limited slot volume [3, 4]. The final model that can increase the power density is selected by reviewing the tendency for various shapes.

B. Final model shape and conclusion

Analyzing the tendency of output performance according to the combination of the number of pole slots, the 30P 27S was selected because the output tended to increase at multiple poles in the axial flux motor shape. In addition, in the shape of the dual rotor, the output is reduced compared to the single rotor because the leakage magnetic flux that does not pass through the stator increases even though twice as many magnets are used. Therefore, 30P 27S single rotor type motor was selected as the final model. The magnetic flux density distribution and shape of the final model are shown in Fig. 4. Fig. 5 shows the load line voltage of the motor designed in detail with the existing model and the axial flux type. It was confirmed that the load line voltage increased by about 67% compared to the conventional model, and thus the shaft torque increased by 61%, resulting in an output improvement.

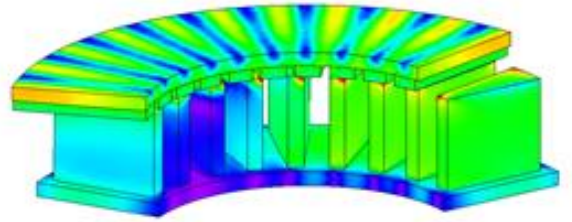


Fig. 4. Magnetic flux density distribution of final model.

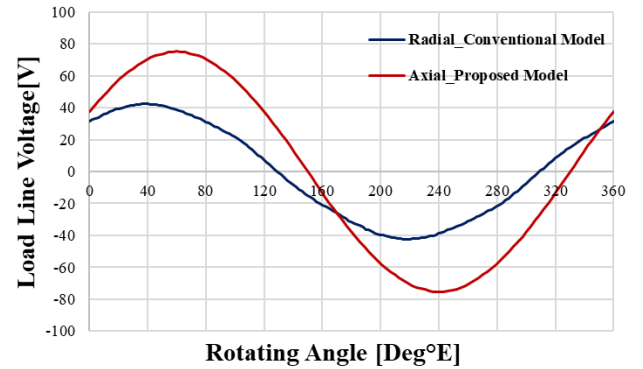


Fig. 5. Comparison of load line voltage between the conventional model and the proposed model.

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