Design of High Efficient Motor for Personal Mobility by Pole/Slot Combinations

Dae Yong Um[1], Jae Deuk Joo[1], Jeong Sik Kim[1], Sang Hyeon Im[1] and Gwan Soo Park[1]
[1]School of Electrical and Computer Engineering, Pusan National University, Busan 46241, South Korea gspark@pusan.ac.kr

In recent years, environmental problems have emerged due to the side effect of technological development. Many kinds of fuel-powered vehicle are blamed for this matter. In this sense, the electric-powered personal mobility has received attention. This paper deals with optimum design of high efficiency brushless motor with exterior rotor for the self-balancing vehicle suitable for a long distance drive. While many existing papers suggest solutions by single parameter's changes, this research handles multiple parameter's changes. The eight pole-slot combinations and other parameter are changed using finite element method. Finally, the improvement model is useful high efficiency solution for running long distance.

***Index Terms*— High efficiency, Finite element method, Pole-slot combination, Personal mobility**

I. Introduction

Recently, the interest in the personal mobility has been increasing rapidly due to traffic problems caused by urbanization. It has advantages such as portability and convenience but there are disadvantages such as stability, low torque and low efficiency. Since low efficiency limits the mobility of main purpose, it is necessary to design it to increase efficiency [1]-[2].

Personal mobility, which is currently being developed, uses BLDC motor. The reason is that BLDC can be small, light and fast. However, due to the limitations of battery of personal mobility, there is a limit to operating for a long time. In order to operate for a long time in a constant battery, it is necessary to increase the efficiency of the motor [3]-[4].

In this paper, the design for high efficiency of BLDC was focused for driving long distance. Since the flow of magnetic flux was determined by the GCD of the poles and slots, the optimal combination of poles and slots was mainly analyzed by using FEM simulation. In addition, the optimal design was performed according to the combination, so the efficiency of BLDC was finally improved.

II. Conventional personal mobility

Personal mobility has been produced and used recently. Fig.1 shows a conventional model and BLDC motor used. The BLDC motor consists of 30 poles and 27 slots. The magnetic flux lines when the motor is no-load and rated are shown in Fig. 2. It can be seen that it forms three large loops equal to the GCD of the poles and slots. This indicates that adjusting the combination of poles and slots allows the magnetic flux to flow more smoothly.

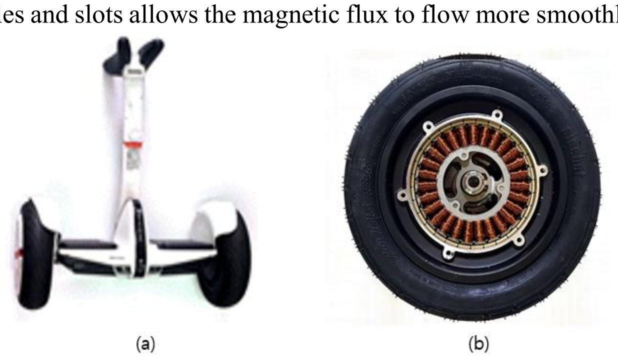

Fig. 1. The conventional model of personal mobility. (a) Conventional model. (b) BLDC motor used in the model.

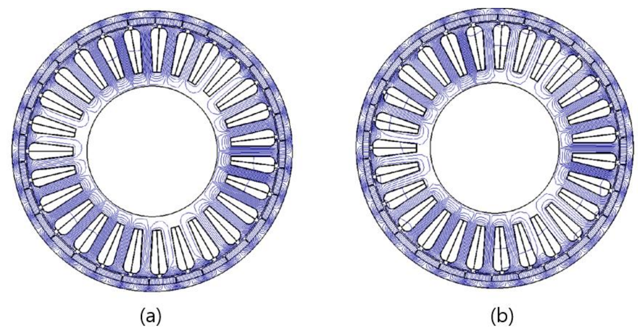

Fig. 2. The Flux lines when no-load and rated. (a) No-load. (b) Rated.

The model has a copper loss of 106.7W and iron loss of 4.6W, with a total loss of 111.3W. As a result, the total efficiency is 78.2% and it is needed to designing for higher efficiency to drive a long distance.

III. Proposed design of BLDC motor

A. Combination of poles and rotors

In order to improve the efficiency, the optimal combination of the poles and slots was analyzed by using FEM simulation. The outer diameter of the rotors is fixed and the number of poles and slots are changed. The efficiency of the combination of poles and slots is compared in Fig. 3. In case of 26 poles and 24 slots, the efficiency was 78.88%, which is 0.6% higher than the conventional model.

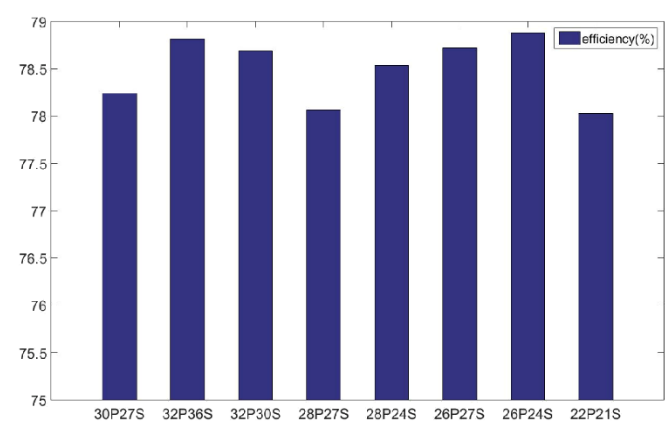

Fig. 3. Comparison of efficiency with respect to pole-slot combination.

B. Optimal design for 26poles and 24 slots

In order to design the optimum BLDC for 26P24S, the thickness of magnet, stator outer diameter and air gap thickness were redesigned. These parameters are very important to the design because they have a direct effect on the magnetic flux. Also, the torque was determined by (1) according to theses parameters.

$$T \propto (k_w N_s B_g L(D_s + g))I_s \tag{1}$$

where, D_s is the diameter of stator, g is the air gap length.

When the stator diameter is increased first, the efficiency was improved at the same torque. However, when the thickness of the magnet was increased, the efficiency decreased due to magnetic saturation from above 4.15mm. Fig. 4 shows the distribution of efficiency according to magnetic thickness and stator diameter. As a result, the maximum efficiency was about 80% at a magnetic thickness of 4.45mm and stator diameter of 110.64mm.

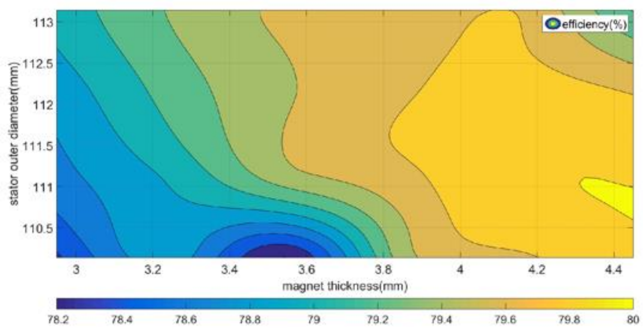

Fig. 4. Distribution of the efficiency according to magnetic thickness and stator diameter

Also, airgap thickenss affects efficiency of BLDC motor significantly. The air gap affects the relectance and therefore affects the current flowing throught the motor. Table I shows the losses and efficiency according to airgap length. When the airgap length was 0.38mm, the efficiency was the largest at 80.54%.

TABLE I
Simulated result according to air gap length

Airgap length	Copper Loss	Core Loss	Efficiency	Ripple ratio
0.33 mm	89.41 W	4.60 W	80.97 %	12.03 %
0.38 mm	92.13 W	4.50 W	80.54 %	9.77 %
0.43 mm	94.64 W	4.40 W	80.15 %	8.35 %
0.48 mm	97.18 W	4.30 W	79.76 %	5.71 %
0.53 mm	99.75 W	4.21 W	79.37 %	4.89 %
0.58 mm	103.10 W	4.14 W	78.88 %	4.36 %
0.63 mm	106.33 W	4.05 W	78.37 %	4.06 %
0.68 mm	109.02 W	3.97 W	77.97 %	3.61 %

C. Simulated results

In order to improve the efficiency, each process would be combined together. The optimal parameters are shown in Table II. Compared to the conventional model, the thickness of the magnet became thicker, and the outer diameter of the stator and the air gap were slightly reduced.

TABLE II
Comparison of parameters

Parameters	Conventional	Proposed
Magnet thickness	2.95 mm	4.45 mm
Stator outer diameter	112.14 mm	110.64 mm
Air gap thickness	0.58 mm	0.38 mm

Also, Fig. 5 shows the cross section of two models. As back york thickness and tooth width increase at modified model, magnetic saturation is relived under 1.8T. Although the manufacturing cost could rise due to the increase of magnet, improving efficiency was considered as a priority. And Table III shows the comparison of results for two models. Finally, the efficiency was improved about 3.7%.

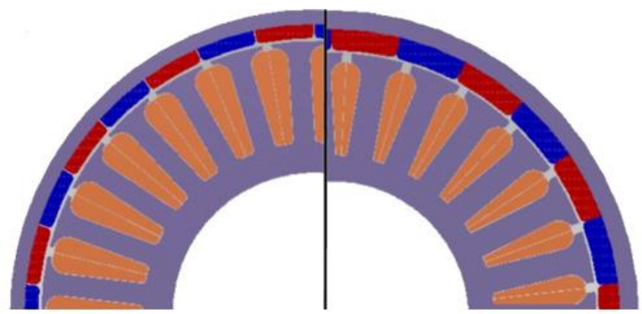

Fig. 5. Cross section of conventional and proposed model

TABLE III
Comparison of the results for two models

Parameters	Conventional	Proposed
Rated speed	360 rpm	277 rpm
Torque @rated speed	10.6 Nm	13.8 Nm
Average torque	10.4 Nm	13.25 Nm
Ripple ratio	11.06 %	8.96%
Output power	400 W	400 W
Efficiency	77.52 %	81.28 %

IV. Conclusion

This paper proposed the design of BLDC motor for high efficiency to drive long distance. First, the optimal combination of the number of pole slots was analyzed and the optimum design was proceeded. Finally, the efficiency of BLDC motor was improved by 3.7%, so it will be able to drive longer on a constant battery.

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