

Weight Reduction Design of In-Wheel type Motor For Power density Improvement

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Abstract

This paper deals with the weight reduction design of In-Wheel type motor for high power density. Accordingly, characteristic and weight of the motor caused by modifying reduction gear ratio are examined. Weight of motor is minimized by modulating the ratio of stack length and external diameter of stator. Then, In-Wheel motor geometry based on the prototype is optimized to get the determined parameters using response surface methodology (RSM) and Finite Element Method (FEM). Optimal design of core usage in rotor is conducted for minimizing weight of motor which has identical characteristic to the prototype. Characteristic analysis is conducted by using equivalent circuit analysis of PM type motor. Through the presented weight of In-Wheel type motor, total weight is reduced to 25%, and power density is improved to 57% from the prototype motor.

Keywords: IPMSM, In-Wheel, Weight reduction, Gear ratio, Power density,

1 Introduction

An IPMSM(Interior Permanent Magnet Synchronous Motor) having high output is widely applied to industries at the appropriate range for high speed and mechanical stability[1]. During last decades, In-Wheel type motor has been investigated extensively. Because this In-Wheel type motor is installed in Wheel directly; power train components can be removed, and it has high system efficiency. So, it can provide a system of new concept platform applied in the Eco-friendly car. Also, the moment that car braked, it is possible to improve a mileage collecting braking energy from regenerative braking control.

In this paper, it deals with the weight reduction design of In-Wheel type motor for power density improvement. For weight reduction and high power density, motor size is decreased and

reduction ratio is increased. So, the weight of motor according to change in reduction gear ratio are minimized.

Also, Optimum design proceeded for reducing of the volume of rotor core, and result of power

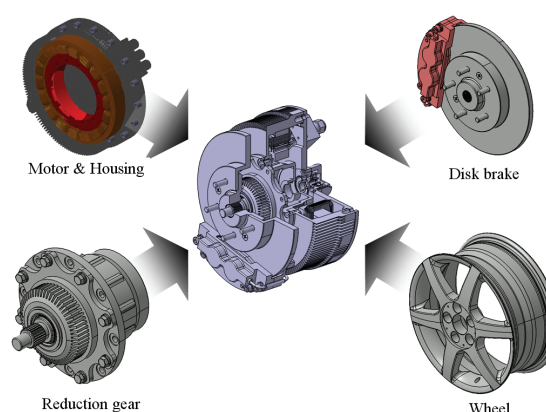


Figure 1. 3D modeling of In-Wheel type motor

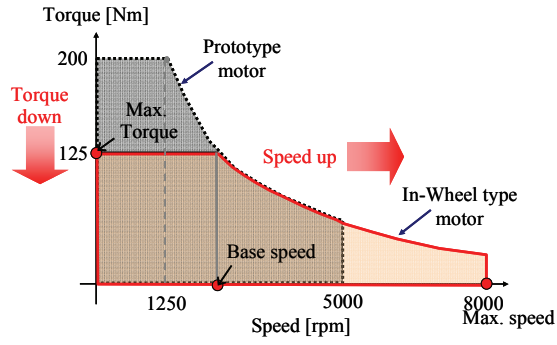


Figure 2. Characteristic of the motor according to change in reduction gear ratio

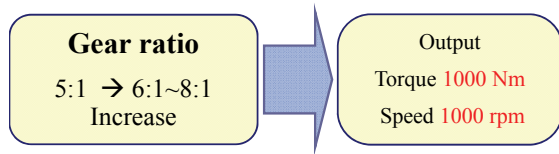


Figure 3. Object of target output

Table 1 : The output in Gear ratio

Gear ratio	6:1	7:1	8:1
Max. torque [Nm]	167	143	125
Base speed [rpm]	1400	1700	1900
Max. speed [rpm]	6000	7000	8000

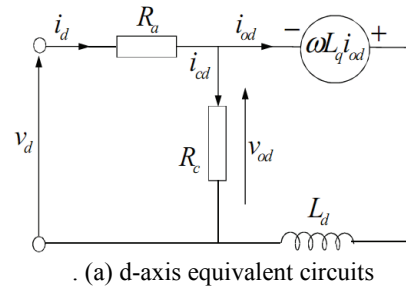
Table 2 : Specifications of Motor

	unit	Prototype motor	Improved motor
Pole / slot number	-	12/18	12/18
DC link Voltage	V _{DC}	320	320
Max./Rated Power	kW	25/10	25/10
Max./Base Speed	rpm	5000/1250	8000/1900
Stator outer dia.	mm	300	270
Rotor outer dia.	mm	221	201
Stack length	mm	50	35
Cooling system	-	Air-cooling	Air-cooling
winding	-	Y	Y
Max. torque	Nm	200	125

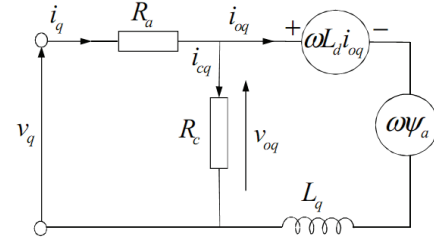
density is compared with one in prototype. Characteristic analysis is conducted by using equivalent circuit analysis of PM type motor.

2 Examination of Motor size as Changing Gear ratio

Figure 2. is characteristic of the motor according to change in reduction gear ratio. According to the figure, it is necessary to control high speed range, but maximum torque decreases. The maximum torque is related to rotor volume, as shown in (1);



(a) d-axis equivalent circuits



(b) q-axis equivalent circuits.

Figure 4. Equivalent circuits of IPMSM.

$$TRV = \frac{T}{\frac{\pi}{4} D^2 L_{stk}} [kNm / m^3] \quad (1)$$

where T is torque, D is a diameter of rotor, and L_{stk} is stack length of rotor.

Thus, as gear ratio is increased, rotor volume of the motor is reduced. Simultaneously, it means motor weight is reduced.

2.1 Change of the Gear ratio

Increasing gear ratio is necessary to reduce the size. Figure 3. presents the object of target output. Maximum torque is 1000Nm and 1000rpm is object of maximum output speed. The feasible gear ratio is 6:1~8:1, as shown in Table 1. While gear ratio of former model is 5:1, satisfactory output power is examined by changing from 6:1 to 8:1. Also Maximum torque of former model is 195Nm, those of improved model is examined by changing from 167Nm to 125Nm.

2.2 Selection of the Gear ratio

Equation (2) decide maximum torque, maximum speed and output power depending on gear ratio.

$$P = \omega T [W] \quad (2)$$

Where, P is output power [kW], ω is speed of rotor [rad/s], and T is torque [Nm].

Gear ratio is determined 8:1 by the equation (1) and Table1. In this case, it provides fulfilling output power and reduce size of the rotor

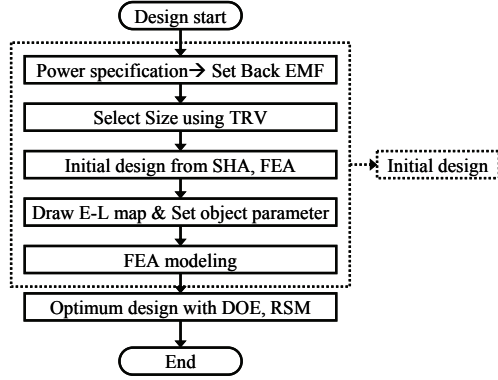


Figure 5. Process of motor design

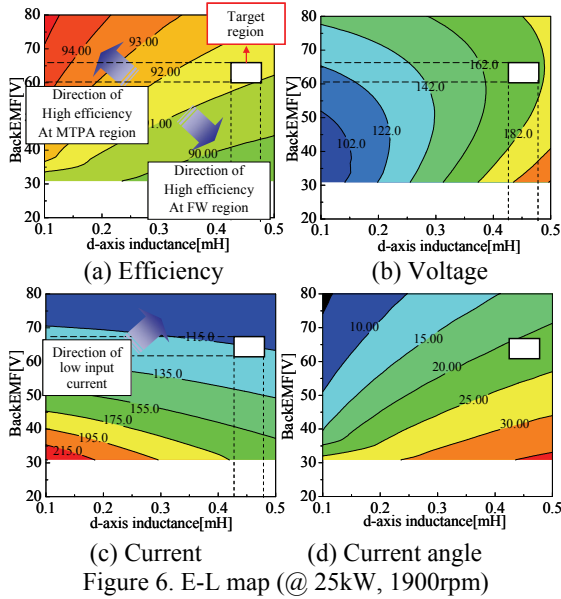


Figure 6. E-L map (@ 25kW, 1900rpm)

considerably according to equation (1). Table 2 shows reduced size of the rotor adequately.

3 Motor Design and Characteristic analysis

Table 2 shows specifications of prototype motor and improved In-Wheel type motor. Rotor, stator diameter and stack length are reduced. The number of poles and slots, and voltage specification are equal to prototype motor's.

3.1 Initial Design of In-Wheel Motor

Figure 5. shows design process of the In-Wheel motor used in this paper[2]. E-L map at maximum rating and base rpm is shown in Figure 6. Using E-L map, goal parameters of motor can be determined goal parameters of motor can be determined in less time with changing the back-

EMF and inductance value as major parameters of motor. Equation(3)-(5) are voltage equation using d-q axis equivalent circuit shown in Figure 6. By these equations, E-L map is fixed and characteristic of motor is evaluated.

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R_a \begin{bmatrix} i_{od} \\ i_{oq} \end{bmatrix} + \left(1 + \frac{R_a}{R_c}\right) \begin{bmatrix} v_{od} \\ v_{oq} \end{bmatrix} + p \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} \begin{bmatrix} i_{od} \\ i_{oq} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} v_{od} \\ v_{oq} \end{bmatrix} = \begin{bmatrix} 0 & -\omega L_q \\ \omega L_d & 0 \end{bmatrix} \begin{bmatrix} i_{od} \\ i_{oq} \end{bmatrix} + \begin{bmatrix} 0 \\ \omega \Psi_a \end{bmatrix} \quad (4)$$

$$T = P_n \left\{ \Psi_a i_{oq} + (L_d - L_q) i_{od} i_{oq} \right\} \quad (5)$$

Where i_d and i_q are d- and q-axis component of armature current, i_{cd} and i_{cq} are d-and q-axis component of terminal voltage, R_a is armature winding resistance per phase, R_c is iron loss resistance, Ψ_a is flux linkage of permanent magnet per phase (rms value), L_d and L_q are d-and q-axis armature self-inductance, and P_n is pole pair [5].

3.2 Optimum Design & Characteristic Analysis

Finally, optimization step with DOE and RSM is progressed to improve motor characteristics [3]. Final optimization model parameters calculated using the finite element method and then analyzed characteristics using equivalent circuit [4], [5]. It is accomplished the reduction of the motor's weight by minimizing the usage of core inside a rotor. The areas, which are not related to magnetic paths, are cut through optimal design technique. Figure 7. indicates the regions for optimization and the lower amount of irons used while the properties that the motor has are being preserved. Consequently, 20% of the total quantity of the materials consumed is declined. At the same time, we manufacture the model considering the safety coefficient 2 based on structural and stiffness analysis about the rotor. Figure 8 indicates the results through structural analysis at the maximum speed 8000rpm. And two motors compared to the weight and power density.

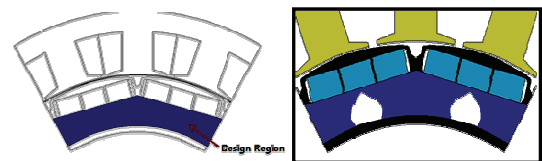


Figure 7. Optimum design of rotor

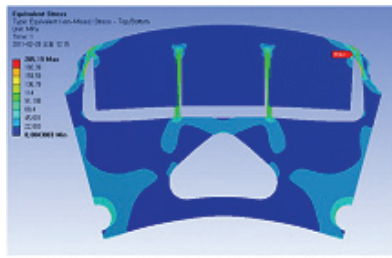


Figure 8. Structure analysis of rotor

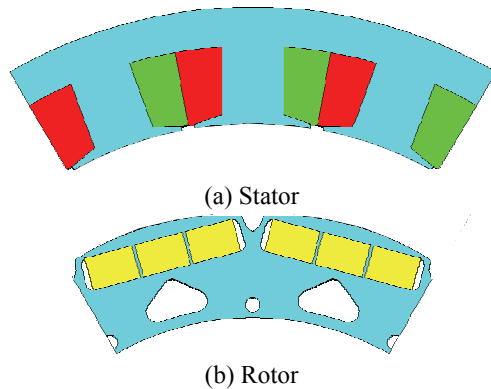


Figure 9. Structures of In-Wheel type motor

Table 3 : Weight and power density

Contents	unit	Prototype motor	Improved motor
Weight1 (Rotor & Stator)	kg	16.6	7.9
Weight2 (Housing & Gear)	kg	16.4	13.0
Power density (Weight 1)	kW/kg	1.51	3.16
Power density (Weight 1+2)	kW/kg	0.76	1.20

4 Results & Experiments

The feature of improved In-Wheel type motor is shown in figure 9. Results comparing the power of the prototype and the improved model are shown in Figure 10. And results comparing the weight of the prototype and the improved model are shown in Table. 3.

4.1 Reduction of the size & the weight

It shows that the novel model weight 52% less than prototype as motor single item. This weight is calculated though considering the density of coil and permanent magnet. Although the weight of motor was reduced, but it increases the gear ratio, so the gear changed from one planetary gear to two planetary gears. The weight of gear

also changed from 5.6kg to 8.7kg. Thus, in the end, the weight of improved motor reduced 25% than prototype. Similarly, the output power has same level in each operating region at 25kW.

4.2 Power density

As shown in Table 3, power density of prototype motor is 0.76 kW/kg while that of improved motor is 1.2 kW/kg. It is increasing about 57%. So, this is obviously acceptable to explain high power density.

4.3 Experiments

Designed in-wheel motor is fabricated. Maximum power is 25kW respectively, as shown in Figure 10. The in-wheel motor obtained by FEA and test a load condition is compared in Fig. 11 which is compared with voltage, input current and efficiency according to speed at max., rated power. And Fig. 12 and Fig. 13 are test setup for load test and fabricated in-wheel motor system.[6]

5 Conclusion

In this paper, the weight of the motor was reduced to increase the gear ratio. In this case, the gear ratio is determined by considering size and weight of the reduction gear as well as weight of the motor. In addition, the Initial shape is determined by design process, and decreased 20% in the areas of design by remove the useless core from the rotor. Consequently, the motor was designed to meet the target attribute. And the weight of the motor was approximately 25% reduction. Also, In order to improve the power density, the output power of the motor at constant power region is preserved. And to conclude, motor's power density is improved to 57% from prototype motor, as shown in this paper. Finally, designing In-Wheel motor, and designed motor is verified by experiments.

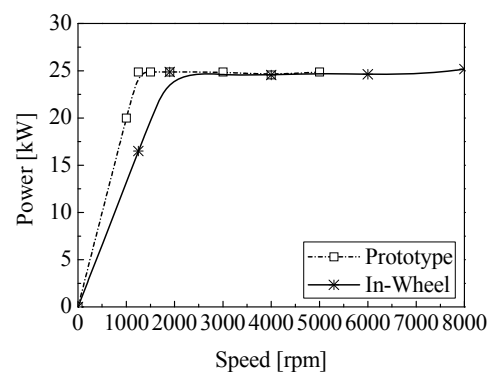
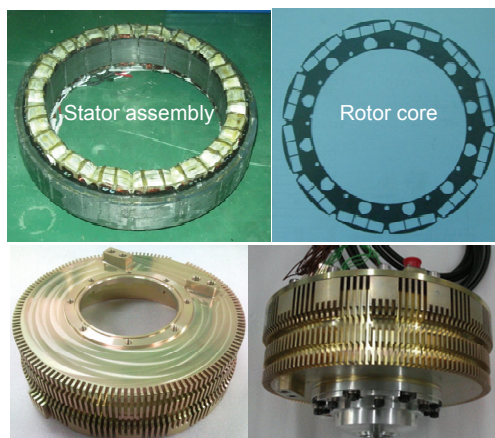
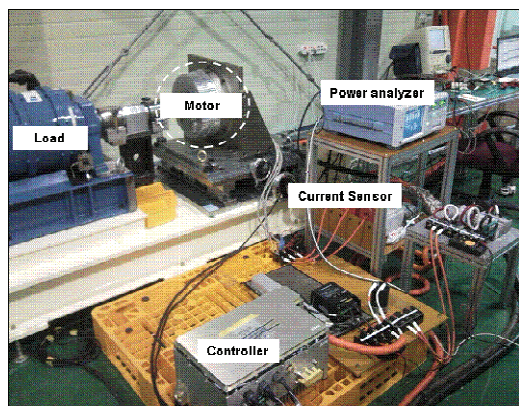
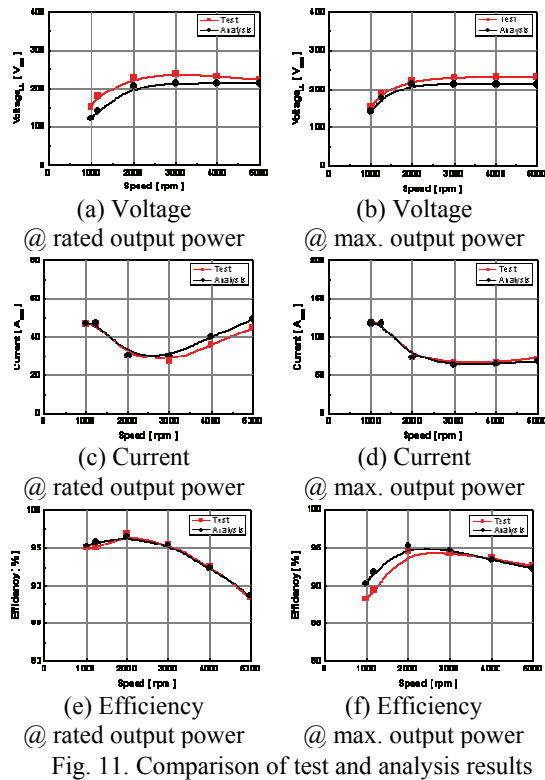


Figure 10. Output of two type of motor



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