Optimum Design of IPMSM for Electric Motorcycle considering High Speed and High Efficiency Operation

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Abstract — The IPMSM suggested in this paper is a concentrated-winding model which is not suitable for high speed driving because the line voltage partly exceeds the voltage limit because of the harmonic wave. To solve this problem, design for decreasing the harmonic wave was first made, followed by the optimization for reduction of line voltage while other condition and output characteristic were preserved same. Also, design that can increase the efficiency by dropping the Eddy current loss was carried out in order to increase the single-charge mileage because it is an application using battery. Finally, verification of the optimized model's electromagnetic characteristics was made by FEM and experiments.

I. Introduction

The present paper is about the design of interior permanent magnet synchronous motor for motorcycle which was optimized by analyzing trend of the basic models. Since previous models could not endure high speed due to harmonic wave, later design was aimed for reduction of harmonic wave and induced electromotive force in order to gain ability to endure high speed. Also, the motor revolves with high speed because a reduction gear has to be placed due to the limitation in size when designing interior permanent magnet synchronous motor. When the motor rotates with high speed, a massive centrifugal force occurs which can lead to mechanical problem, so the verification through FEM was also made before designing final model.

II. Design of Basic Model

The driving performance requirements of motorcycle is 15km/h at 30% gradient and 80km/h at 0% gradient. Fig.1. shows basic design model satisfied driving performance. Because periodicity is a four, a quarter model is drawn.

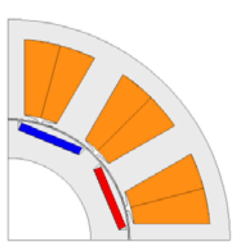


Fig. 1. A quarter model of basic design

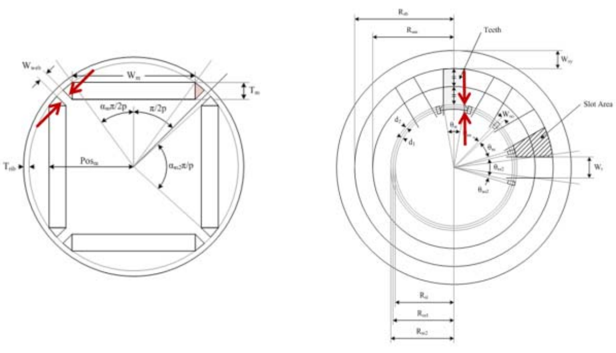
Output characteristics of basic model is obtained by Finite Element Method.

TABLE I
Output characteristics of basic model

	Value	Unit
Torque @ BaseRPM	28.15	Nm
Torque Ripple @ BaseRPM	12.42	%
Shaft Torque @ MaxRPM	9.53	Nm
Core Loss @ MaxRPM	264.1	W
Eddy Current Loss @ MaxRPM	777.3	W
Efficiency @ MaxRPM	79.85	%
MaxRPM	2580	RPM

III. Analysis of Output Characteristics according to Design Variables

It has to be confirmed whether motor satisfies the voltage limit in order to assure the operation characteristics at high speed region. The 8-pole 12-slot model suggested in this paper usually does not satisfy the voltage limit because of the harmonic waves at high speed region. So the design process to decrease the harmonics is required. Also, the concentrated winding model produces large Eddy current loss because of the variation of the magnetic flux at the permanent magnet. Maximum of more than 10% of Eddy current loss occurs which degenerates the total efficiency. Parameters which strongly controls harmonic waves and Eddy current loss are analyzed and optimization is performed.



(a) web width (b) shoe height

Fig. 2. Design variables of rotor

Fig. 2. Shows design variables of rotor. In many variables, web width marked with arrows affects significantly a total efficiency. Fig.3. shows FEM results according to web width.

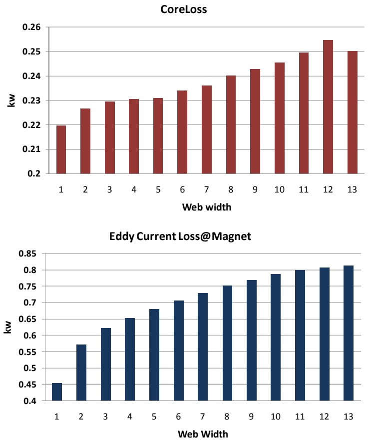
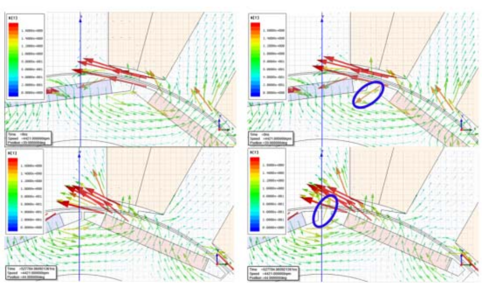


Fig. 3. Loss Comparison according to web width

Ironic loss at the core did not differ certainly but the Eddy current loss of the permanent magnet was doubled from case of 1mm to 13mm. The loss mentioned here decides the efficiency of the motor. The reason Eddy current loss differs with web width can be assumed from the vector diagram in Fig .4. which shows the cases of web width of 1mm and 5mm. The magnitude and direction of propagating magnetic flux make changes to those which goes through the permanent magnet. When the web width is 1mm, there are no paths due to saturation, but when the web width is 13mm, magnitude and direction of magnetic flux alternates in accordance with the position of the rotor. This phenomenon make changes to the flux through the permanent magnet, resulting in increment of Eddy current loss.



(a)Web 1mm (b) web 5mm

Fig. 4. Flux vector distributions in accordance with the position of the rotor.

Maximum speed of basic model is not satisfied with driving performance. The reason is that the line voltage partly exceeds the voltage limit because of the harmonic wave. Fig .5. shows harmonics of line voltage at max RPM.

This can be regarded as a phenomenon of the effective air gap becoming large and small as a result of the sectional saturation becoming on and off as the rotor spins. Harmonic wave occurs at induced electromotive force as the air gap differs by time variation and harmonics appear on magnetic flux interlinkage. The air gap stays constant because sectional saturation continously occurs when the height is 0.5mm, but when height is 2mm, sectional saturation discretely occurs so harmonic wave appears on total magnetic flux interlinkage.

In order to reduce harmonics, new shoe shape is applied in optimum design.

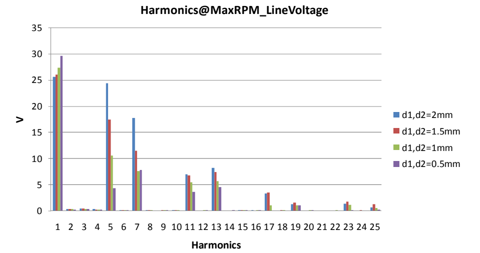


Fig. 5. Loss Comparison according to web width

IV. Design of Optimum Design and Comparison with Basic Design

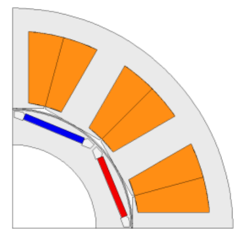


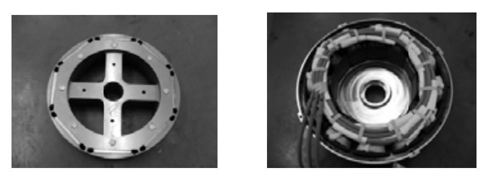
Fig. 6. A quarter model of optimum design

Optimum model designed according to the tendency analysis is shown in Fig .6. with new shoe shape.

Table II shows output characteristics of basic model and optimum model.

TABLE II
Output characteristics of basic model and optimum model

	Basic Model	Optimum Model	Unit
Torque @ BaseRPM	28.15	28	Nm
Torque Ripple @ BaseRPM	12.42	11.23	%
Torque @ MaxRPM	9.53	9.5	Nm
Eddy Current Loss @ MaxRPM	777.3	217.42	W
Efficiency @ Maxrpm	79.85	89	%
MaxRPM	2580	4421	RPM



(a) Rotor (b) stator

Fig. 7. Test Motor

V. Acknowledgment

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VI. References

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