Optimal Rotor Design of an 150kW-Class IPMSM by the 3D Voltage-Inductance-Map Analysis Method

Sol Kim[1], Tae-chul Jeong[2], Seung-Joo Kim[3], Hyun-soo Seol[2] and Ju Lee[2], *Senior Member IEEE*

[1]Yuhan University, Bucheon-si, Gyeonggi-do, Korea, Republic of, slamsol@naver.com

[2]Department of Electrical Engineering, Hanyang University, Seoul, 133-791, Korea, Republic of , julee@hanyang.ac.kr

[3]Korea Testing Certification, Gunpo-si, Gyeonggi-do, 435-862, Korea, Republic of , w3ksj@hanmail.net

A method is presented to determine the detailed design of a 150-kW-class interior permanent-magnet synchronous motor. The basic designs of the stator and rotor were determined. After dividing the designed models into the best and worst cases on the basis of the rotor shape parameters, a sensitivity analysis was conducted, and the three-dimensional voltage–inductance map parameters were analyzed. Then, the design of the final model was predicted. On the basis of this prediction, the final model was extracted with a trend analysis. Finally, the final model was validated with experiments.

***Index Terms*— Permanent magnet motors, Optimal design**

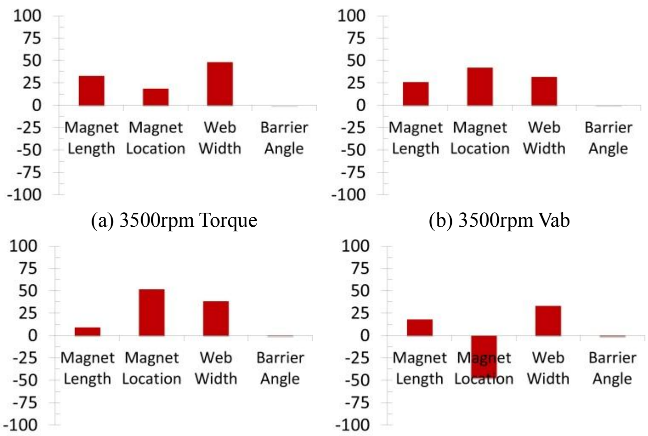
I. INTRODUCTION

Due to green energy policies, shuttle buses have preferentially been transformed into electric vehicles in Korea. However, a vehicle space limitation should be considered when designing an electric shuttle bus compared to a conventional fossil-based bus. Therefore, for such shuttle bus applications this study considers an IPMSM with higher power density, higher efficiency and wider operating range than an induction machine as a motor. The required specifi cations and the basic model design are shown in Table I.[1]

TABLE I
PERMANENT MAGNET MOTOR PERFORMANCE REQUIREMENTS

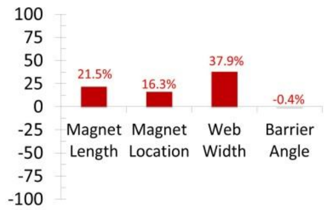
	Value	Unit
Continuous Power / Torque	75 / 204	kW / Nm
Maximum Power / Torque	150 / 409	kW/ Nm
Outer Diameter/ Stack Leg.	350/140	mm
Base / Maximum Speed	3500 / 10,000	rpm / rpm
Current Density	10.6	Arms/mm2
Magnet(NdFeB)	1.17(@20℃)	T
Operating Temp./Cooling	150/ Water	℃
Current/Voltage Limits(Fund.)	275↓/530↓ (Vab)	A/Vpeak

II. PARAMETER ANALYSIS



(a) 3500rpm Torque (b) 3500rpm Vab

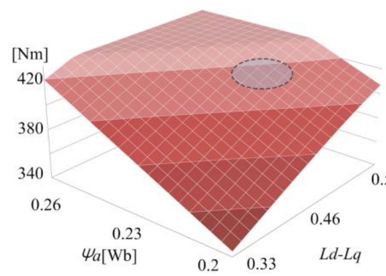
(c) 10000rpm Torque (d) 10000rpm Vab



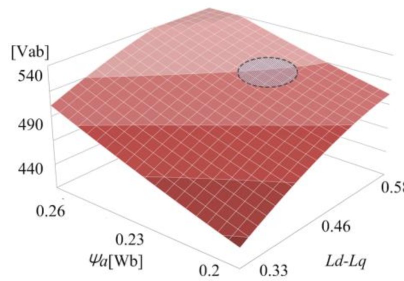
(e) average sensitivity

Fig. 1 Sensitivity Analysis

Due to rotor stress problems, a permanent magnet bridge was inserted into the designed basic model. As illustrated in Figure 1, its sensitivity analysis was also conducted in order to select the rotor shape parameters that were highly affected by a motor performance. After dividing the selected rotor shape parameters into the best cases and the worst cases, motor parameters were obtained through a finite element method. L_d, L_q and 3d Map were organized as shown in Figure 2. According to these parameter analyses, it can be concluded that that the design to improve saliency was appropriate.[2][3]



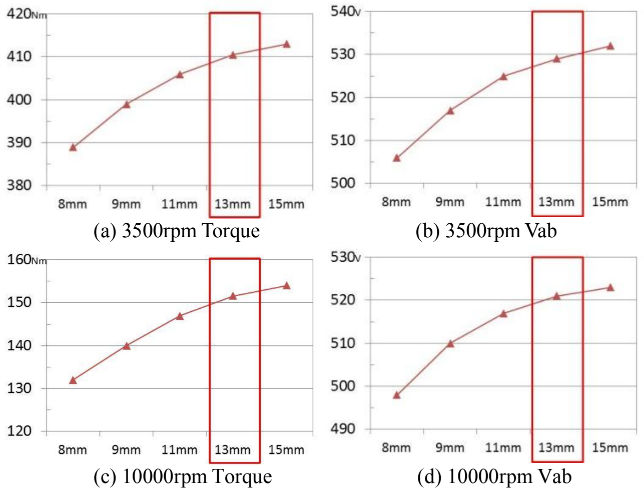
(a) 3500rpm Torque



(b) 3500rpm Vab

Fig. 2 3D-EL Map

III. Detail Design of the Final Model



(a) 3500rpm Torque (b) 3500rpm Vab

(c) 10000rpm Torque (d) 10000rpm Vab

Fig 3 Results of Trend Analysis

TABLE II
Parameter of Three Bridge VS Final Model

	3 Bridge Model	Final Model	Unit
No Load Flux Linkage	0.216	0.216	Wb
Ld/Lq(@3500rpm)	0.276/0.656	0.274/0.795	mH
Ld/Lq(@10000rpm)	0.367/0.996	0.355/1.082	mH
Ld-Lq(@3500rpm)	-0.38	-0.521	
Ld-Lq(@10000rpm)	-0.629	-0.727	

TABLE III
FEM Results of Final Model

	Target Spec.	Final Model	Unit
3500rpm, Input Current	275	275	Arms
10000rpm Input Currnet	275	275	Arms
3500rpm Torque	409	411.6	Nm
3500rpm Vab	530↓	529.1	Vpeak
10000rpm Torque	143	151.6	Nm
10000rpm Line Vab	530↓	521.1	Vpeak
Efficiency(3500/10000rpm) (Only Electrical Loss)		97.6/94.7	%

A detail design was performed, based on the predictions in Chapter 2 and 3. Finite element analysis was carried out, fixing permanent magnet's length at 77mm and increasing web width. As a result, it approached the goal performance, when increasing web width at both of a low speed and a high speed, as Figure 3 shows. Thus, a web width of 13mm was considered as the optimum point.

Table 2 shows the results of comparison of parameter values between the basic model and the final model. Compared to the basic model, the final model's saliency(*Ld-Lq*) was highly improved, as the 3d EL-Map forecasted. In short, it is likely that web width has a big impact on the improvement of saliency. This implies that rather than permanent magnet's length, increasing web width to improve saliency is advantageous, for improving power density. Figure 4 indicates the shape of the final model. Figure 3 also shows the results of finite element analysis of the final model at 3500rpm and 10000rpm. As shown in the table, it satisfied the required performances all.[4][5]

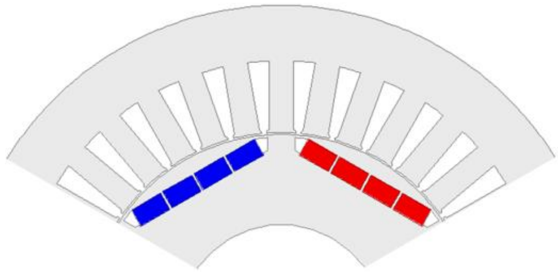


Fig 4 Final model

IV. Experiment

Figure 8(b) shows the experiment configuration using the extracted model. Load tests were conducted during experiments, and their results are shown in Table IV.

TABLE IV
Results of Experiment

	120kW	150kW
q-axis Current	-226.9A	-333.2A
d-axis Current	223A	229A
Average Torque	346.6Nm	408.5Nm
Efficiency	97.3%	96.7%

V. Conclusion

In conclusion, it was proven that the proposed 3D EL-Map analysis was appropriate for designing a detail model. In addition, the saliency ratio highly changed depending on the change of web width. These findings demonstrate what increasing rotor's saliency to improve power density is better than raising the use of permanent magnet.

VI. References

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