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Session EL

PERMANENT MAGNET MACHINES III (POSTER SESSION)

Jiabin Wang, Chair

EL-01. Determining parameters of a line-start interior permanent magnet synchronous motor model by the differential evolution. *T. Marčič*[1], G. Štumberger[2,1], B. Štumberger[2,1], M. Hadziselimović[2,1] and P. Virtič[1] *1. TECES, Research and Development Centre for Electrical Machines, Maribor, Slovenia; 2. University of Maribor, Faculty of Electrical Engineering and Computer Science, Maribor, Slovenia*

EL-02. Design and performance measurement of high speed permanent magnet synchronous motor with full-ring magnet for axial-flow turbo fan. S. Jang[1], *J. Park*[1], K. Ko[1] and J. Hwang[2] *1. Electrical Engineering, Chungnam National University, Daejeon, South Korea; 2. MAGPLUS, Daejeon, South Korea*

EL-03. Finite element analysis of stator winding faults in permanent magnet brushless AC motors. *J.A. Farooq*[1], T. Raminosoa[1], A. Djerdir[1] and A. Miraoui[1] *1. Electrical Engineering and Control Systems, University of Technology Belfort Montbeliard, Belfort, France*

EL-04. Analysis method for considering the effect of magnetic cross saturation of IPMSM. *Y. Kim*[1], I. Jung[1], J. Hur[1] and J. Hong[2] *1. KETI, Bucheon, South Korea; 2. Hanyang University, Seoul, South Korea*

EL-05. Design and finite-element analysis of interior permanent magnet synchronous motor with flux barriers. *B. Stumberger*[1], G. Stumberger[1], M. Hadziselimovic[1], T. Marcic[2], P. Virtic[2], V. Gorican[1] and M. Trlep[1] *1. University of Maribor, Faculty of EE&CS, Maribor, Slovenia; 2. TECES, Development centre for Electrical Machines, Maribor, Slovenia*

EL-06. Performance of IPMSM for Electro-Hydraulic Power Steering with Electric Driven Pump Unit. *Y. Kim*[1], S. Rhyu[1], J. Hur[1] and J. Hong[2] *1. KETI, Bucheon, South Korea; 2. Hanyang University, Seoul, South Korea*

Performance of IPMSM for Electro-Hydraulic Power Steering with Electric Driven Pump Unit

Young-Kyoun Kim[1], Se-Hyun Rhyu [1], Jin Hur[2], Senior Member, IEEE and Jung-Pyo Hong[3], Senior Member, IEEE

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Interior PM synchronous motor (IPMSM) is used in many industrial due to its advantages. However, the torque ripple and cogging torque of IPMSM are generally greater than those of surface permanent magnet synchronous motor. Especially, in point of automobile application such as the electro-hydraulic power steering (EHPS) system, the lower cogging torque is one of the most important performances in the electric motor. Therefore, this paper presents a shape optimization to reduce the cogging torque. The shape optimization is accomplished by using response surface method (RSM), the optimization results is verified by the measurement of the fabricated IPMSM.

***Index Terms*—IPMSM, Cogging torque, EHPS system, Response surface method**

I. INTRODUCTION

RECENTLY, as the needs of motorizations in automobile system increase, the electro-hydraulic power steering (EHPS) system is in the spotlight. Because the EHPS system does not need a drive belt, take up very little space and easy to position in the car. Additionally, energy consumption is lowered, which leads to reduced fuel consumption [1]. The electric driven pump unit for the EHPS system is consisted of a hydraulic pump, a pump motor and an electric control unit (ECU), as shown in Fig. 1, and the hydraulic pump is run by the electric motor.

In this application, the main concerns of the electric motor are both the higher power density and the lower torque ripple, as these reasons, the interior permanent magnet synchronous motor (IPMSM) is very attractive for the EHPS system required high power density, because that IPMSM is possible to employ both relructance and magnetic torque and to drive a motor over a wider speed range through the use of field weakening control [2]-[3]. As the EHPS system become more compact, the IPMSM are getting highly saturated. Therefore, it is necessary to consider the non-linearity of the magnetic saturation when the IPMSM is designed or analyzed [4]-[5].

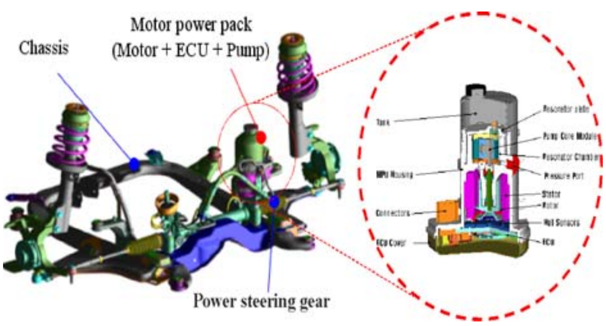

Fig. 1 Structure of EHPS system

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In addition, the motor for EHPS system is needed to have low cogging torque as well as high efficiency of the motor beacuse of requiring low torque ripple characteristics for providing with comfortable steering performance of a vehicle. The cogging torque in the IPMSM is produced by stator teeth interacting with the buried permanent magnet in the rotor of that. Therefore, this paper illustrates the optimal shape design to reduce the cogging torque by using the RSM, and experimental performances of the IPMSM for EHPS system.

II. DESIGN PARAMETER

Fig. 2 shows the configuration of the proto type IPMSM, which is in the employment of the Electro-hydraulic power steering (EHPS) system of 42V automobile. The motor is designed by using parameter verification and characteristic analysis from the nonlinear equivalent magnetic circuit model [1-3]. The main dimension and specifications are listed in Table I.

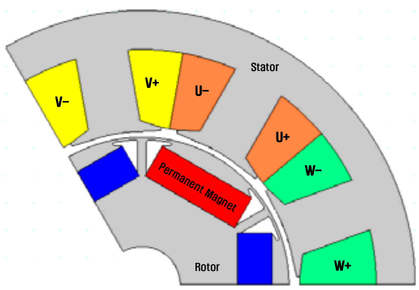
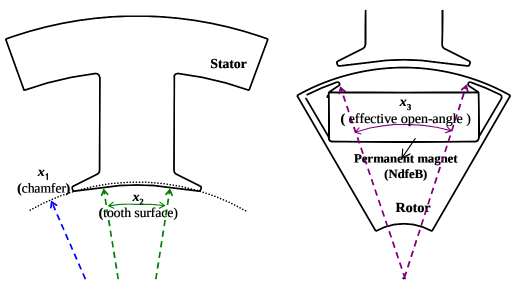


Fig. 2 Cross section of initial designed IPMSM for EHPS system



(a) Stator (b) Rotor

Fig. 3 Configuration of the variables of shape optimal design

TABLE I. SPECIFICATION OF IPMSM

Item	Value	Unit
Number of phase	3	phase
Number of slots	9	slot
Number of poles	6	pole
DC linkage Voltage	42	V
Rated Speed	4000	rpm
Rated Torque	2.4	N-m
Resistance per a phase	12.5	mΩ
Air-gap	1.0mm	mm
Stack length	40mm	mm
Br	1.2	T

From the initial shape of the motor, three design variables are considered for the reduction of the cogging torque such as chamfer, tooth surface, and effective open-angle of permanent magnet in rotor. Three design variables are shown in Fig. 3.

III. OPTIMIZATION FOR REDUCING COGGING TORQUE

In the paper, optimal shape design for reducing the cogging torque is acomplished by using the response surface method (RSM), the RSM is well adapted to make an analytical model for a complex problem. Moreover, the RSM provides the designer with an overall perspective of the system response to the behavior of design variables within a design space [6]-[7]. Another group of these authors has given the detail explanation about the optimization procedure by using the response surface method [8].

The centeral composit dedign (CCD), which is one of the defign of exprement (DOE), is used. The reasen is frequently used for fitting second-order response model and CCD involving three factors is required to conduct 15 experiments. Axial points on the axis of three design variables at a distance from the design center choose 1.68 for a rotatable experiment design. The levels of three design variables are shown in tables II.

TABLE II. LEVEL OF DESIGN VARIABLES

Code value	Chamfer (*x*1)	Tooth surface (*x*2)	Effective open-angle (*x*3)
-1.68	28.1	16.5	32.0
-1	28.2	17.5	33.0
0	28.4	19.0	34.5
1	28.5	20.5	36.0
1.68	28.6	21.5	37.0

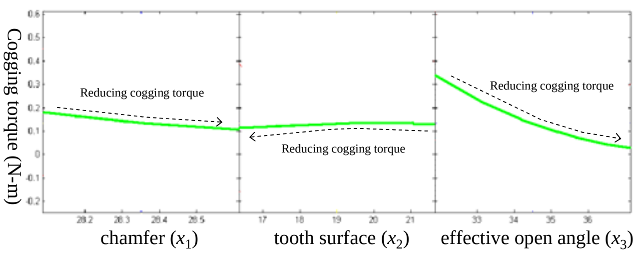


Fig. 4 Main effect of the cogging of each design parameter

TABLE III. OPTIMAL CONDITION OF SHAPE DESIGN VABLES

Chamfer (*x*1)	Tooth surface (*x*2)	Effective open-angle (*x*3)	Cogging torque (Nm)
28.5	20	36	0.015

IV. RESULTS AND DISCUSSION

At each design variable, the effect of the cogging torque is shown in fig. 4. This result is obtained by using the response surface analysis. The cogging torque of the IPMSM can be decreased as increase the chamfer and the effective open-angle of the permanent magnet.

The Table III displays the optimal conditions of minimizing for the cogging torque, and Fig. 5 shows the comparison result of the analyzed and measured results about the optimal condition. Although, the experimental result is a little larger than the analysis result and the measured wave is more distorted than the analysis result, the required level of the cogging torque is obtained by using the response surface method.

Fig 6 shows the experimental configuration for the optimal designed IPMSM, which is in the employment of the EHPS system of 42V automobile.

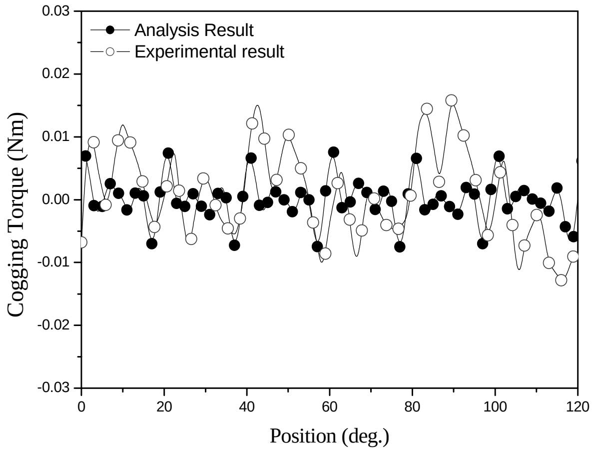


Fig. 5. Cogging torque comparison between the analyzed and measured results.

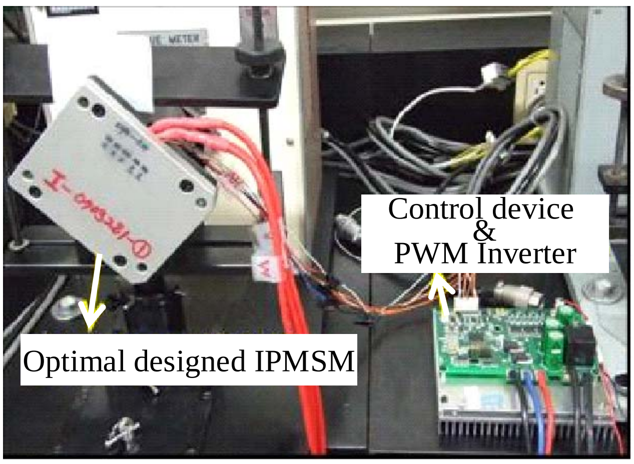


Fig. 6. Configuration of IPMSM with experimental devices.

Fig. 7 shows the experimental results of the dynamo-test, when the speed command is constant as 4000 rpm, and Fig. 8 shows the experimental results of the dynamo-test, when the speed command is constant as 3500 rpm.

Fig. 9 shows the experimental results of the dynamo-test, when the load torque is constant as 3.5 N-m, which is the required maximum torque from the relief condition of the EHPS system. From measured results, the motor efficiency is about 87% at the maximum power point and the efficiency of including the ECU is about 84%. Fig. 10 shows the experimental results of the dynamo-test, when the load torque is constant as 2.4 N-m, the motor efficiency is about 90% at the rated power point and the efficiency of including the ECU is about 85%.

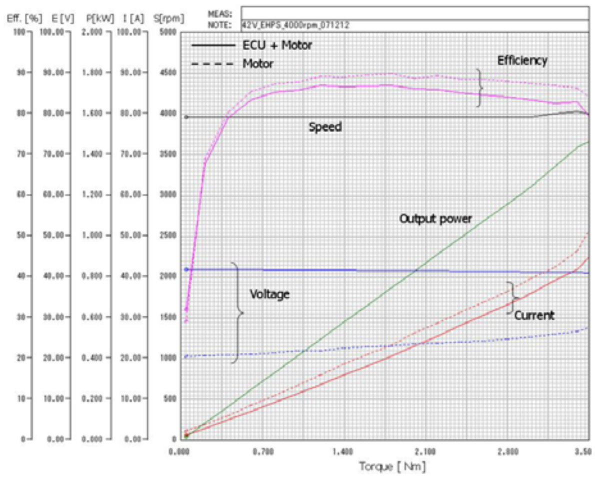


Fig. 7 Performance of the IPMSM when constant speed, 4000 rpm

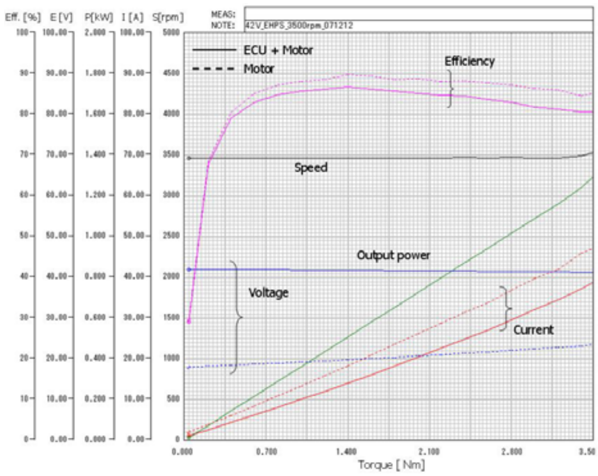


Fig. 8 Performance of the IPMSM when constant speed, 3500 rpm

V. Conclusion

In order to reduce the cogging torque of the IPMSM for the EHPS system of 42V automobile, this paper presents the optimal design by using the response surface method, and investigates the performance of the optimal designed IPMSM as measurement. It is confirm that the IPMSM is well adapted to make the electric driven pump unit for the EHPS system.

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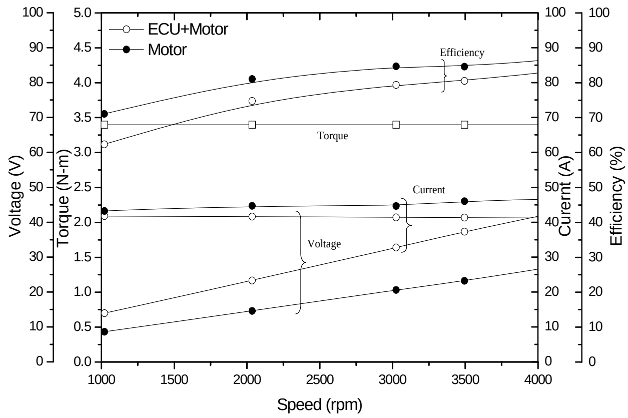

Fig. 9 Performance of the IPMSM when constant torque, 3.5 N-m

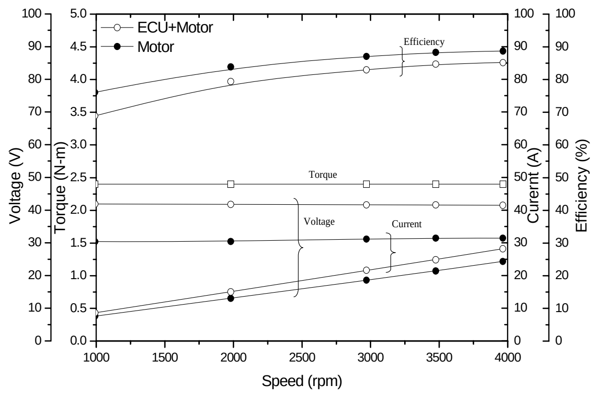

Fig. 10 Performance of the IPMSM when constant torque, 2.4 N-m