COMPUMAG Shenyang, China
June 26 - 30, 2005

Optimal Design of Synchronous Reluctance Motor by Loss & Efficiency Evaluations Related to Slot Number using Response Surface Methodology

Seong June Park
Dept. of Electrical Engineering
Hanbat National University
Daejeon, 305-719, KOREA
e-mail: mll2@naver.com

Jung Ho Lee
Dept. of Electrical Engineering
Hanbat National University
Daejeon, 305-719, KOREA
e-mail: limotor@hanbat.ac.kr

Jung Pyo Hong
Dept. of Electrical Engineering
Changwon National University
Changwon, 641-773, KOREA
e-mail: jphong@sarim.changwon.ac.kr

***Abstract*--** This paper presents the application of response surface methodology (RSM) to design optimization for two types of synchronous reluctance motors (SynRMs); one has 12 slots with distributed winding, and the other has 6 slots with concentrated winding, to improve the ratio between torque ripple and average torque. The usefulness of RSM in optimization problem of SynRM is verified as compared with the results of finite element analysis. In the end, the optimized two SynRMs are compared with SynRM currently used in air-conditioning compressor in connection with torque performance and loss.

I. Introduction

Synchronous Reluctance Motor (SynRM) has advantage such as low cost and higher efficiency than induction machines. However, vibration and noise of SynRM caused by torque ripple are relatively greater than other machines. Accordingly, In designing SynRM, it is important to select appropriate combination of the design parameters to reduce torque ripple.

In general, an optimal design is a natural process in motor design to improve performance of the motor. The design can be complex due to many design variables and interactions between the design variables.

Response surface methodology has recently been recognized as an effective optimization approach for modeling performance of electrical devices by using statistical fitting method. So, RSM is well adapted to make an analytical model for the complicated design [1].

In RSM, a polynomial model is generally to be constructed to represent the relationship between performance and design parameters. Therefore, this model can be used to predict the performance as a function of design variables, and design optimization can be carried out much easily.

The quality of the fitted model is evaluated by checking the statistics indexes based on the data of numerical experiments. The approach is expected to produce useful results for optimal design [2].

This paper deals with optimization procedure of SynRMs to improve torque performance by RSM. The RSM is introduced as a powerful method to build the statistical approximation to show the relationship between input and output of complex design problems considering interaction of design variables in this paper.

Moreover, optimized SynRMs according to number of slot is compared with SynRM currently employed in air-conditioning compressor with respect to torque performance and loss.

II. Analysis Model

A. Response Surface Methodology

RSM seeks the relationship between design variables and response in interest area through statistical fitting method, which is based on the observed data from system. The response is generally obtained from real experiments or computer simulations.

Thus, 2-dimensional finite element analysis (2D FEA) is performed to analyze SynRMs in this paper. It is supposed that the true response of a system η can be written as

$$\eta = F(\zeta_1, \zeta_2, \ldots, \zeta_k) \tag{1}$$

where the variables $\zeta_1, \zeta_2, \ldots, \zeta_k$ in Eq. (1) are expressed as natural units of a measurement , so called natural variables. The form of true response function F is unknown and very complicated, so it is approximated. In many cases, the approximating function Y of the function F is normally chosen to be either a first-order or a second-order polynomial model. In order to predict a curvature response more accurately, the second-order model is used in this paper. The approximating function Y of true response function F is

$$\mathrm{Y} = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x^2{}_j + \sum_{i \neq j}^{k} \beta_{ij} x_i x_j + \varepsilon \tag{2}$$

where β is regression coefficients, ε is a random error treated as statistical error. The observation response vector **Y** at n data point of function Y may be written as matrix notation as follow

$$\mathbf{Y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{3}$$

where X is a matrix of the levels of independent variables, $\boldsymbol{\beta}$ is a vector of the regression coefficients, $\boldsymbol{\varepsilon}$ is a vector of random error.

B. Design Algorithm And Model

The process of optimization design is shown in Fig.1. Fig. 2 shows the configurations of distributed and concentrated winding SynRM, respectively. In this paper, the slot number of each SynRM is considered 24, 12 (distributed winding: 36 turns/slot), 6 (concentrated winding: 144 turns/ slot). The slot number and slot open width, Kw are variables, which is related to torque ripple and efficiency together with the number of flux barrier in a SynRM.

RSM is applied to optimal design minimizing loss and torque ripple from each SynRM, which is different from slot number. This optimization method not only can predict the loss of each model on all variations of slot open width and Kw from several sample points but also search optimal point, and experimental frequency of the method is relatively few, too.

In Fig. 1, design area of the slot open width and Kw is determined to reduce torque ripple and increase efficiency of the concentrated winding SynRMs. And then, analysis data is obtained through finite element method (FEM) and Preisach model based on central composite design (CCD) mostly used in RSM, and optimal point is determined through analysis of the data. In the end, the characteristic of the SynRMs is estimated through comparisons between SynRM of distributed winding and optimized SynRMs of concentrated winding considering variations of slot open width and Kw.

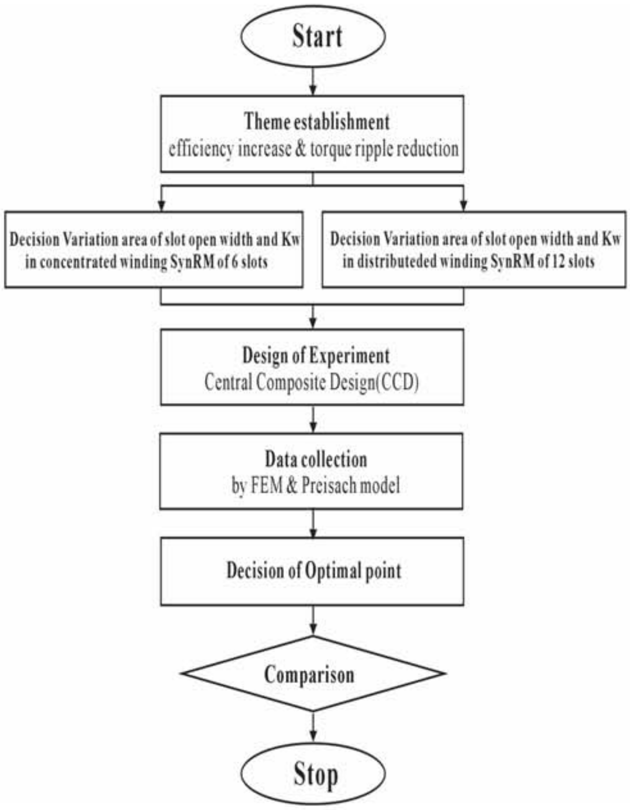
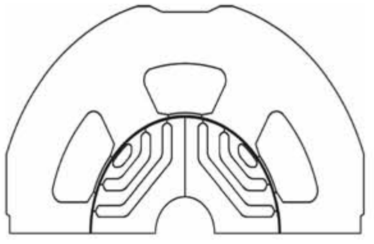
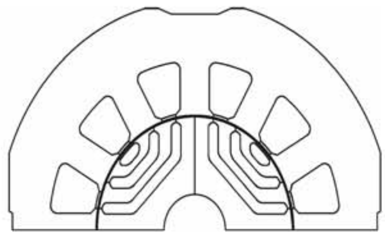


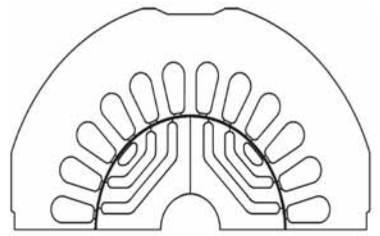
Fig. 1 flow chart of design procedure



(a) concentrated winding (6 slots)



(b) distributed winding (12 slots)



(c) distributed winding (24 slots)
Fig. 2. Design solution of SynRMs

III. CONCLUSIONS

Application process of RSM in optimization design of SynRM is introduced in this paper and usefulness of RSM in optimization method is verified by the result of optimized SynRM. Therefore, RSM approach is considered as optimization method for optimal design of SynRM and other machines. Moreover, characteristic change of SynRM according to number of slot and winding way is confirmed through this paper.

REFERENCES

[1] Y.K. Kim, Y.S. Jo, J.P. Hong : Approach to the shape optimization of racetrack type high temperature superconducting magnet using response surface methodology, Cryogenics, Vol 41, No 1, 2001, pp. 39-47.
[2] J.T. Li, Z.J. Liu, M.A. Jabbar, X.K. Gao : Design optimization for cogging torque minimization using response surface methodology, IEEE Transactions on Magnetics, Vol 40, No 2, 2004, pp.1176-1179.
[3] Raymond H. Myers and Douglas C. Montgomery, *Response Surface Methodology: Process and Product Optimization Using Design Experiments*, JOHN WILEY & SONS, 1995.
[4] A.I. Khuri and J.A. Cornell, *Response Surface: Designs and Analyzes*, New York: Marcel Dekker, 1996.
[5] S.H. Park, *Modern Design of Experiments*, Minyoungsa, 2001.
[6] J.H. Lee, D.S. Hyun : Hysteresis Analysis for the permanent magnet assisted synchronous reluctance motor by coupled FEM & preisach modeling, IEEE Transactions on Magnetics, Vol 35, No 3, 1999, pp.1203-1206.