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Volume IV

**Local Electric Field Analysis for Evaluation of Charge Transfer System
 Using Sequential Sub-window Technique** IV - 96
 P44174
 Joon-Ho Lee, Young-Ki Chung, Il-Han Park
*Sungkyunkwan University - School of Information and Communication Eng.
 Suwon - Korea*

**Electrostatic Comb Accelerometer - Filed and Equivalent Circuit
 Modeling** IV - 98
 P14784
 Sławomir Wiak, Krzysztof Smółka
*Technical University of Lodz - Institute of Electrical Machines and Transformers
 Lodz - Poland*

Optimization IV
 Thursday, July 17, 1:30pm - 2:45pm

Chairman
 Dr. Nathan Ida

**Optimization of Permanent Magnet Shape for Minimum Cogging Torque
 Using a Genetic Algorithm** IV - 100
 P31609
 M. Łukaniszyn, M. Jagieła, R. Wróbel
*Technical University of Opole - Dept. of Electrical Engineering and Automatic Control
 Opole - Poland*

**A Novel Topology Optimization using Density Method Combined with
 Modified Evolution Strategy** IV - 102
 P11318
 Yoshifumi Okamoto, Norio Takahashi
*Okayama University - Dept. Electrical and Electronic Eng.
 Okayama - Japan*

**Crossover-Controlled Genetic Algorithm and Its Application to Inverse
 Problem in SF6 Interrupter** IV - 104
 P11274
 Youhua Wang, Xiaoguang Yang, Weili Yan, Egon Sommer
*Hebei University of Technology - School of Electrical Engineering & Automatization
 Tianjin - China*

**An Emigration Genetic Algorithm and its Application to Multiobjective
 Optimal Designs of Electromagnetic Devices** IV - 106
 P72415
 Yuhuai Wang, Shiyu Yang, Guangzheng Ni
*Zhejiang University - Electrical Engineering College
 Hangzhou - China*

**Analysis of Cogging Torque Considering Tolerance of Axial Displacement
 on BLDC Motor by Using a Stochastic Simulation Coupled with 3D-
 EMCN** IV - 108
 P72742
 Young-Kyoun Kim, Jeong-Jong Lee, Jung-Pyo Hong, Yoon Hur
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 Kyungnam - Korea*

Analysis of Cogging Torque Considering Tolerance of Axial Displacement on BLDC Motor by Using a Stochastic Simulation Coupled with 3D-EMCN

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Abstract—This paper describes a tolerance analysis concerned with an axial displacement on a BLDC motor. The axial displacement occurring in productions of a BLDC motor directly affect its torque ripple. Therefore, the tolerance analysis is very important for improving a robustness of its production and this work is accomplished by a stochastic simulation introduced to overcome a disadvantage of Monte Carlo Simulation.

is proposed to analyze the cogging torque having the axial displacement on the BLDC motor.

CONCEPT OF FORMULATION METHOD

Concept of Stochastic Response Surface Methodology

In the SRSM, a relationship of the uncertainty between the outputs and inputs is addressed by the series expansion of standard normal variables in terms of Hermite polynomials. Therefore, the output can be approximated by an expansion known as polynomial chaos expansion as follows [1];

$$y = a_0 + \sum_{i1=1}^n a_{i1} \Gamma_1(\xi_{i1}) + \sum_{i1=1}^n \sum_{i2=1}^n a_{i1i2} \Gamma_2(\xi_{i1}, \xi_{i2}) + \sum_{i1=1}^n \sum_{i2=1}^n \sum_{i3=1}^n a_{i1i2i3} \Gamma_3(\xi_{i1}, \xi_{i2}, \xi_{i3}) + \dots \quad (1)$$

where, y is the random variable representing the output of a model, the $\Gamma_p(\xi_{i1}, \dots, \xi_{ip})$ are Hermite polynomials of degree of p and a 's are unknown coefficients to be estimated.

Introductory Statistics for tolerance Analysis

A variation band and uncertainty of design variables with assuming the distribution of a normal distribution. In this symmetrical distribution, the tolerance band of design variables is easy to quantify in terms of the percentage of the area that will occur between one, two and more standard deviation from the mean μ as follows [1];

$$\Delta x = \pm n\sigma \quad (n = 1, 2, 3, \dots) \quad (2)$$

Modeling variation of outputs according to tolerance of design variables is built by the SRSM. From a set of N samples, the basic moments of the distribution of an output y_i can be calculated as follows;

$$\mu_{y_i} = E\{y_i\} = \frac{1}{N} \sum_{j=1}^N y_{i,j} \quad (3)$$

$$\sigma_{y_i}^2 = E\{(y_i - \mu_{y_i})^2\} = \frac{1}{N-1} \sum_{j=1}^N (y_{i,j} - \mu_{y_i})^2 \quad (4)$$

$$\sigma_{y_i} = \sqrt{\sigma_{y_i}^2} \quad (5)$$

where, μ_{y_i} is a mean, $\sigma_{y_i}^2$ is a variance and σ_{y_i} is a standard deviation, respectively.

INTRODUCTION

Permanent magnet BLDC motors are increasingly being used in high performance applications. In many case of applications, torque ripple characteristics of BLDC motor are of basic concern. There is no exception for a BLDC motor employed as the electric power steering of vehicles. This motor is requiring low level of the torque ripple for comfortable steering of a vehicle [1].

Generally, the production of the electric machine needs allowance for dimensional or positional tolerances of design variables due to limitations on the manufacturing and measuring precision on every part. These dimensional tolerances, however, can effect on a electrical performance of electric machines. A axial displacement between the stator and the rotor occurs when the BLDC motor is produced. And the axial displacement has an influence on a cogging torque of the BLDC motor. So, this torque directly affect a torque ripple of the motor. Therefore, it is necessary for a tolerance analysis concerned about the axial displacement on a design stage before manufacturing the BLDC motor.

The tolerance commonly can be treated as random parameters, and an expression for an uncertainty of design variables and outputs can be accomplished by a stochastic simulation. One of the widely used methods, which is based on sampling for the stochastic simulation, is Monte Carlo Simulation. This method is powerful tool to predict the effects of manufacturing variation. But, the biggest disadvantage of the Monte Carlo Method is that it requires large samples to achieve reasonable accuracy. On the other hand, introduced in this paper, the Stochastic Response Surface Methodology (SRSM) treats the uncertainty of design variables as stochastic variables. And the SRSM approximates the output function by using a polynomial fitting and samples the approximation to calculate statistical distribution of outputs.

The SRSM is based on sample points, which could be obtained by using 3D-EMCN combined with 2D-FEM, which

Fig. 1 shows the longitudinal cross-section of the analysis model. The stator of the permanent magnet BLDC motor has 18 slot and the rotor is built with 12 tiles of radial and skewed magnetic. Axial displacement in the manufacturing of the skew mounted permanent magnet BLDC motor needs to be analyzed by a full 3D-analysis, such as, 3D-FEM. This approach, however, is too computationally expensive to produce results in a reasonable time, therefore, an alternative method must be found. In this paper, a proposed method is taken with two sections shown in fig. 2, so called, lateral section and radial section. The former is constructed with both the lateral flux and the radial flux, flowing from the rotor to the stator. The latter is composed of radial flux only crossing from the rotor to the stator. In order to analyze the cogging torque of each section, the lateral section employed the 3D-EMCN [2], and the radial section used a multi-slice technique based on 2D-FEM, where is assumed that the radial flux only acting on the air-gap. The totality of the analysis is found by superimposing both the 3D-analysis and the 2D-analysis.

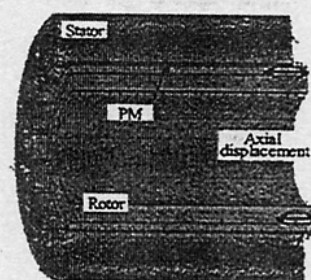


Fig. 1. Longitudinal cross-section of analysis model

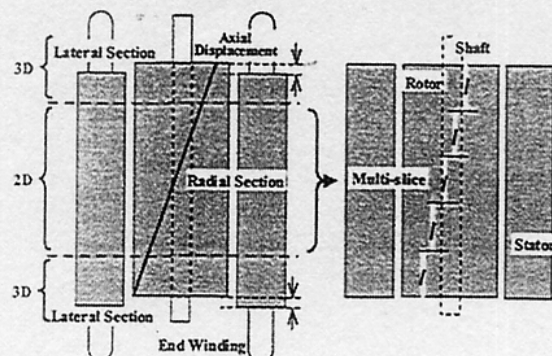


Fig. 2. Proposed sections of analysis model and multi-slice technique

RESULTS AND DISCUSSION

Fig. 3 shows a comparison between both results of the cogging torque obtained from the actual experiment and the proposed analysis method. So, a validity of proposed analysis method is verified from the experimental results. And then, by using a combination technique employing the SRSM and

the proposed analysis method, results according to the analysis of the tolerances were obtained with 10 (%) and 5(%) tolerance of all design variables, as shown in Fig 4. These results show that, when design variables are controlled with tighter tolerance, the scatter of the set of the cogging torque is extremely centralized in the mean of its population.

CONCLUSIONS

In this paper, the tolerance analysis is accomplished by the SRSM combined with 3D-EMCN and 2D-FEM. It offers the predicted variations of the cogging torque according to the axial displacement of the motor. In most cases of manufacture the axial displacement can be inevitably happening in the BLDC motor. Therefore, the tolerance analysis must be considered on the design stage, because that would lead a production of the BLDC motor to be robust. In full paper, more descriptions of this work will be presented in detail.

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- [2] Jin Hur et al "A Method Reduction of Cogging torque in Brushless DC Motor Considering the Distribution of Magnetization by 3DEMCM", *IEEE Transactions on Magnetics*, vol. 34, No. 5, pp. 3532-3535, Sep., 1999.

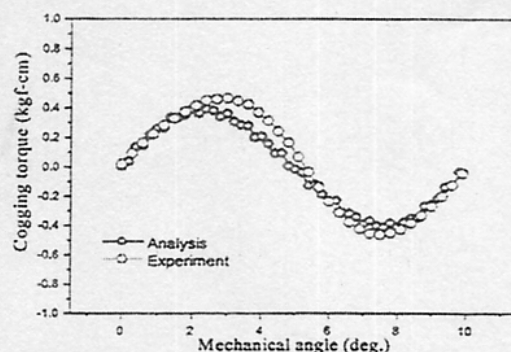


Fig. 3. Comparison of cogging torques at axial displacement = 0 (mm)

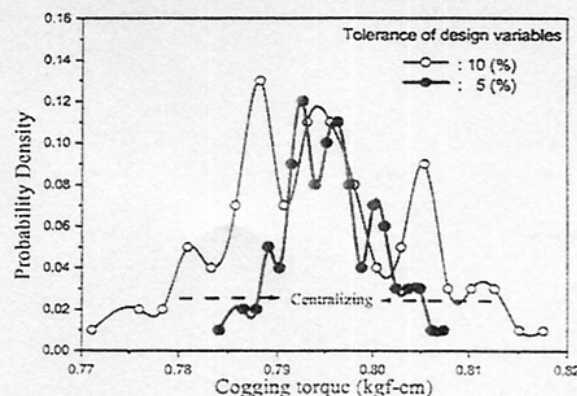


Fig. 4. Estimated probability distribution of cogging torque

- Jung, S.J. IV - 74
 Jung, Sang-Yong I - 180
 Jung, T. III - 122
 Kaehler, Christian II - 58, III - 88, IV - 180
 Kahler, G.R. III - 190
 Kaido, Chikara IV - 56
 Kaltenbacher, M. II - 192
 Kameari, Akihisa I - 188
 Kamitani, Atsushi I - 34, IV - 28, IV - 30, IV - 138
 Kanai, Yasushi I - 144
 Kang, D.H. I - 170, IV - 74
 Kang, Do-Hyun IV - 66
 Kang, Dong-Sik II - 68
 Kang, Gyu-Hong III - 150, III - 152
 Kang, J. III - 122
 Kang, Mi-Hyun IV - 124
 Kang, S.I. I - 124
 Kangas, Jari I - 216
 Kanki, Takashi IV - 40
 Kantartzis, Nikolaos V. I - 148
 Kashiwa, Tatsuya I - 144
 Kawase, Yoshihiro I - 18, IV - 56, IV - 184
 Kawashima, Takuji I - 202
 Kebaili, Badr II - 134
 Kebbas, Mounir III - 78
 Keradec, Jean-Pierre III - 86
 Keranen, Janne I - 158
 Kettunen, Lauri I - 158, I - 216, II - 150
 Kildishev, Alexander V. II - 82, III - 160
 Kim, B.S. I - 124
 Kim, B.T. I - 182, III - 168
 Kim, C. III - 122
 Kim, D.W. II - 22
 Kim, Dong-Hee II - 68, IV - 66
 Kim, Dong-Hun II - 112
 Kim, Gina IV - 92
 Kim, Gyu-Tak I - 172, I - 174, I - 176, II - 118
 Kim, H.K. II - 22
 Kim, H.S. I - 182
 Kim, Hong-Kyu II - 24, II - 190, IV - 110
 Kim, Hyeong-Seok III - 56
 Kim, J.K. I - 170
 Kim, Jae-Kwang I - 180
 Kim, Ji-Hoon III - 68
 Kim, Jin-Yong IV - 92
 Kim, K.Y. I - 124
 Kim, Ki-Chan III - 166, III - 170
 Kim, M.C. I - 124
 Kim, Mi-Yong I - 172, II - 118
 Kim, S. I - 124
 Kim, T.H. III - 162
 Kim, Y.S. II - 22
 Kim, Y.Y. II - 38
 Kim, Yong-Chul I - 172
 Kim, Yong-Joo II - 68, IV - 66
 Kim, Young-Kyoun I - 164, III - 50, IV - 108
 Kim, Young-Kyun II - 70
 Kim, Youn-hyun IV - 140
 Kirk, A. IV - 172
 Kis, Peter III - 194
 Kitamura, Masashi IV - 68
 Kitamura, Shingo IV - 56
 Kladas, Antonios G. II - 98, II - 206
 Knight, Andrew M. III - 8
 Kocer, Fatma III - 110
 Koch, Wigand I - 198
 Koh, Chang Seop I - 30, II - 114, III - 112, III - 114
 Koljonen, Emmi I - 158
 Koltermann, P.I. I - 196
 Koo, D.H. I - 170
 Kost, Arnulf I - 82, II - 166
 Kotiuga, P. Robert IV - 12
 Krähenbühl, Laurent I - 200, II - 126, IV - 154
 Krawczyk, Andrzej I - 72
 Krozer, Viktor I - 142
 Kuczmanski, Miklós IV - 24
 Kuilekov, Milko IV - 122
 Kuo-Peng, P. II - 74, III - 200
 Kurz, Stefan II - 88
 Kwon, B.I. I - 182, III - 168, IV - 72, IV - 94
 Kwon, Hyuk-Chan I - 66, IV - 6
 Kwon, O-Mun IV - 64
 Labie, Patrice I - 52, IV - 188
 Lage, C. I - 106
 Lai, Changxue I - 122
 Lai, H.C. I - 58, IV - 82
 Laporte, B. II - 72, IV - 44
 Laskar, J. I - 150
 Laudani, Antonio I - 132, I - 218
 Lavers, J.D. II - 186, III - 72, IV - 52
 Lean, Meng H. II - 140
 Lebensztajn, Luiz III - 118, IV - 164
 Le Bihan, Y. I - 206
 Leconte, Vincent I - 36
 Lee, C.K. III - 168
 Lee, Cheol-Gyun I - 180, IV - 124
 Lee, Dong-yeup I - 176
 Lee, Dong-Yeup I - 174
 Lee, Erping IV - 120
 Lee, Eun Woong I - 166, I - 168
 Lee, Geun-Ho I - 164, III - 50
 Lee, J. III - 162
 Lee, J.F. II - 18
 Lee, J.W. I - 182
 Lee, Jeong-Jong II - 70, IV - 108
 Lee, Jin-Fa I - 214, II - 136
 Lee, Joon-Ho III - 98, III - 124, IV - 96
 Lee, Ju II - 26, III - 166, III - 170, IV - 112, IV - 140
 Lee, Jung Ho I - 166, I - 168
 Lee, Kab-Jae III - 166, III - 170
 Lee, Min Myung I - 166, I - 168
 Lee, Se-Hee III - 98