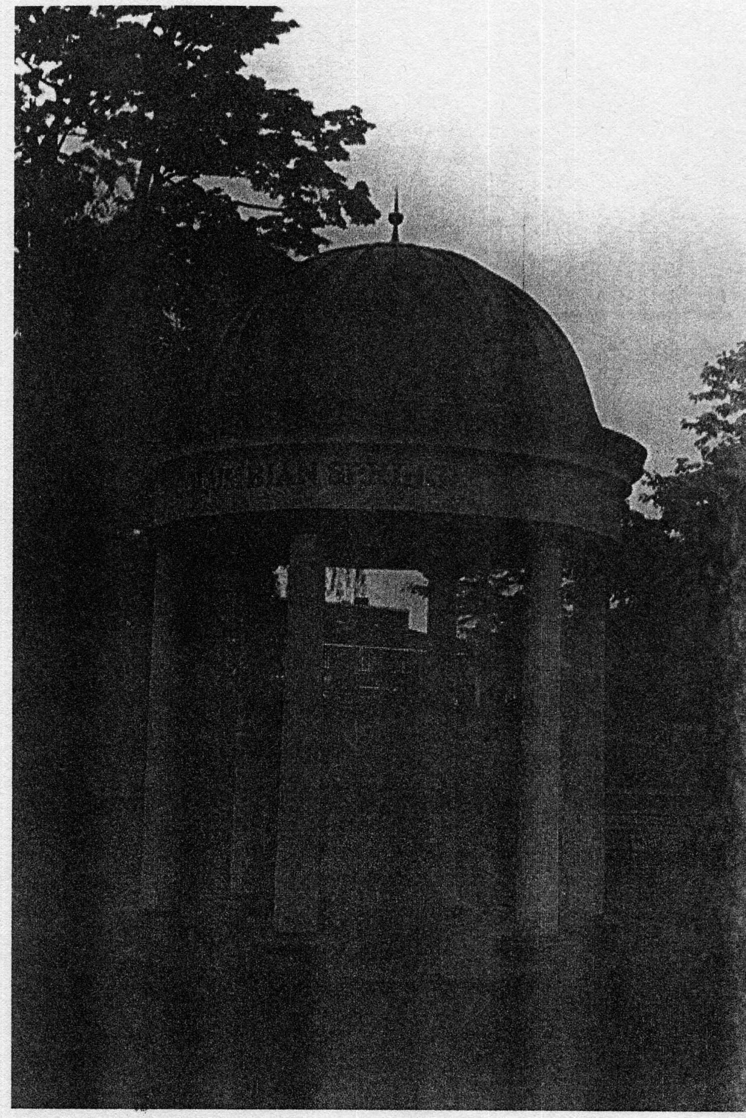

COMPUMAG 2003

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Volume IV

Local Electric Field Analysis for Evaluation of Charge Transfer System Using Sequential Sub-window Technique IV - 96

Joon-Ho Lee, Young-Ki Chung, Il-Han Park
Sungkyunkwan University - School of Information and Communication Eng.
Suwon - Korea

P44174

Electrostatic Comb Accelerometer - Filed and Equivalent Circuit Modeling IV - 98

Sławomir Wiak, Krzysztof Smółka
Technical University of Lodz - Institute of Electrical Machines and Transformers
Lodz - Poland

P14784

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

M. Łukaniszyn, M. Jagieła, R. Wróbel
Technical University of Opole - Dept. of Electrical Engineering and Automatic Control
Opole - Poland

P31609

A Novel Topology Optimization using Density Method Combined with Modified Evolution Strategy IV - 102

Yoshifumi Okamoto, Norio Takahashi
Okayama University - Dept. Electrical and Electronic Eng.
Okayama - Japan

P11318

Crossover-Controlled Genetic Algorithm and Its Application to Inverse Problem in SF6 Interrupter IV - 104

Youhua Wang, Xiaoguang Yang, Weili Yan, Egon Sommer
Hebei University of Technology - School of Electrical Engineering & Automatization
Tianjin - China

P11274

An Emigration Genetic Algorithm and its Application to Multiobjective Optimal Designs of Electromagnetic Devices IV - 106

Yuhuai Wang, Shiyou Yang, Guangzheng Ni
Zhejiang University - Electrical Engineering College
Hangzhou - China

P72415

Analysis of Cogging Torque Considering Tolerance of Axial Displacement on BLDC Motor by Using a Stochastic Simulation Coupled with 3D-EMCN IV - 108

Young-Kyoun Kim, Jeong-Jong Lee, Jung-Pyo Hong, Yoon Hur
Changwon National University - Dept. of Electrical Engineering
Kyungnam - Korea

P72742

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 occuring in productions of a BLDC motor directly affect its torque ripple. Therefore, the tolerance analysis is vary 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.**

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. Therefor, it is necessary for an 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 ouputs can be accomplished by a stochatc simulation. One of the widely used methods, which is based on sampling for the stochatc 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 Suface 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 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];

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

where, y is the random variable representing the output of a model, the $\Gamma_p(\xi_{i1},\cdots,\xi_{ip})$ 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];

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

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;

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

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

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

where, μ_{yi} is a mean, σ^2_{yi} is a variance and σ_{yi} is a standard deviation, respectively.

Analysis Model and Proposed Analysis Method

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 bult 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.

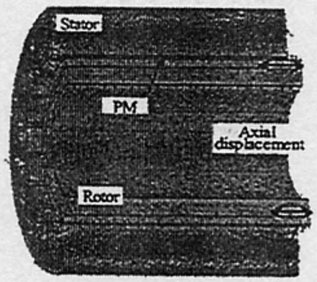

Fig. 1. Longitudinal cross-section of analysis model

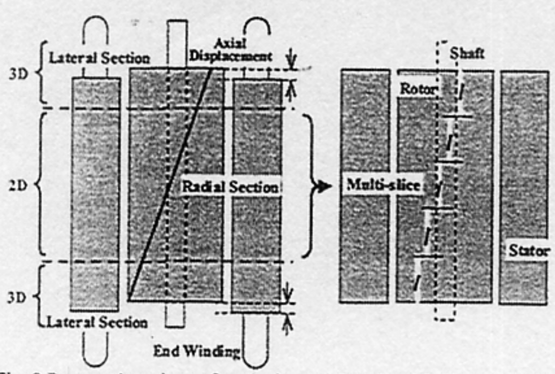

Fig. 2 Proposed sections of analysis model and multi-slice technique

Results and Discussion

Fig. 3 shows a comparison between both results of the cogging torque obtained form 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 centralizd 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 ananlysis 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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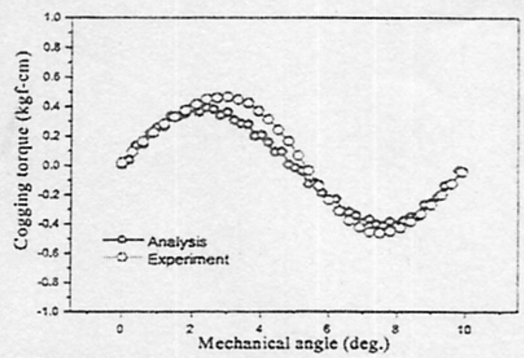

Fig. 3 Comparison of cogging torques at axial displacement = 0 (mm)

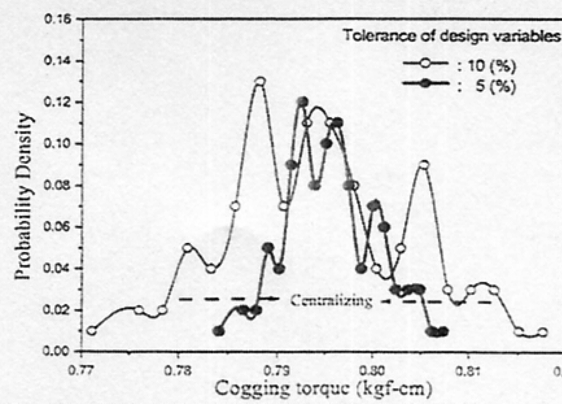

Fig. 4 Estimated probability distribution of cogging torque