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<b>Path Loss Prediction Model for Indoor Wireless Communication using TLM Method</b>	<b>I - 162</b>
A.D. Rosa, H. Domínguez, Adroaldo Raizer GEMCO/EEL/CTC/UFSC, C.P. 476 Florianópolis - Brazil	P25656

---

<b>Machines I: Linear, SR, SynRel</b>	<b>Chairman</b>
<b>Monday, July 14, 1:30pm - 2:45pm</b>	<b>Dr. Tan H. Pham</b>

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<b>Prediction of Torque Characteristic on Barrier Type SRM Using Stochastic Response Surface Methodology Combined with Moving Least Square</b>	<b>I - 164</b>
Young-Kyoun Kim, Geun-Ho Lee, Jung-Pyo Hong, Jin Hur Changwon National University - Dept. of Electrical Engineering Kyungnam - Korea	P32943

<b>Loss Analysis and Efficiency Evaluations of Synchronous Reluctance Motor Using Coupled FEM &amp; Preisach Modelling</b>	<b>I - 166</b>
Jung Ho Lee, Min Myung Lee, Eun Woong Lee National University - Dept. of Electrical Engineering Daejeon - Korea	P42394

<b>A Novel Stator Design of Synchronous Reluctance Motor by Loss &amp; Efficiency Evaluations Related to Slot Numbers using Coupled Preisach Model &amp; FEM</b>	<b>I - 168</b>
Jung Ho Lee, Min Myung Lee, Eun Woong Lee Hanbat National University - Dept. of Electrical Engineering Daejeon - Korea	P12895

<b>Static Characteristics of Linear BLDC Motor using Equivalent Magnetic Circuit and Finite Element Method</b>	<b>I - 170</b>
J.P. Hong, J.K. Kim, S.W. Joo, Sung-Chin Hahn, D.H. Kang, D.H. Koo Dong-A University - Dept. of Electrical Engineering Busan - Korea	P33799

<b>Design of Slotless Type PMLSM for High Power Density using Divided PM</b>	<b>I - 172</b>
Mi-Yong Kim, Yong-Chul Kim, Gyu-Tak Kim Changwon National University - Dept. of Electrical Engineering Kyungnam - Korea	P44451

<b>Minimization of Detent Force for PMLSM using the Moving Model Node Technique and the Neural Network</b>	<b>I - 174</b>
Dong-Yeup Lee, Ki-Chae Lim, Gyu-Tak Kim Changwon National University - Dept. of Electrical Engineering Kyungnam - Korea	P24152



# Prediction of Torque Characteristic on Barrier Type SRM Using Stochastic Response Surface Methodology Combined with Moving Least Square

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**Abstract**—This paper describes a design of switched reluctance motor with rotor poles having inserted barriers. A shape of the rotor barrier leads to improvement of torque characteristics. As well, dimensional tolerances of the barrier directly affect electrical performances of the motor. Therefore, the torque characteristic prediction of the motor is accomplished by a combination technique employing Stochastic Response Surface Methodology and Moving Least Square Method.

seriously vary according to the shape of flux barrier. Therefore, the geometric shape design of the barrier is required to find the design variables that consider manufacturing tolerance as well as improve the performance and exactly predict the torque characteristics. These tolerances can affect the machine performance, such as operating efficiency.

## INTRODUCTION

Switched Reluctance Motor (SRM) has some advantages, such as, a high speed, efficient variable speed and a high reliability. Therefore, an application of switched reluctance motors is recently received attention in various industrial fields. However, a SRM is strongly nonlinear and suffer from high torque ripple. Also, the torque per volume of SRM strongly depends on the designed shape of salient poles. This paper proposed a barrier type SRM, which is designed by inserting separated barriers in the rotor. Separated barriers lead the reduction of a torque ripple and the improvement of torque performances. What is more describing in this paper, dimensional tolerances of electric machines can effect on electrical performances, and besides, the larger tolerance in manufacturing processes, the lower it is to cost of manufacturing electric machines [1]. A design of the barrier type SRM needs allowance for dimensional tolerances on especially barrier part of the SRM, because of limitations on the manufacturing, measuring precision and so on.

Therefore, the design techniques are required to find the tolerance band of design variables in order to minimize the cost and satisfy required performance. The torque characteristic, according to tolerances of the dimensional barrier, of barrier type SRM is predicted by using Stochastic Response Surface Methodology (SRS). SRS can be illustrated as an extension of Response Surface Methodology (RSM), and it is then combined with Moving Least Square (MLS) to enhance the accuracy of stochastic response modeling in SRS.

## STRUCTURE OF BARRIER TYPE SWITCHED RELUCTANCE MOTOR

Fig. 1 shows the proposed barrier type 8/6 SRM, which is designed to improve torque characteristics. With a proposed rotor inserted the flux barrier, the motor characteristics

## FRAMEWORK FOR TOLERANCE ANALYSIS

### Stochastic Response Surface Methodology

In the SRS, 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. The output function can be approximated by an polynomial chaos expansion and the approximation is sampled to calculate a statistical distribution of outputs as described in [1].

### Moving Least Square Method

Unknown coefficients of the Stochastic response modeling are estimated by MLS method. The main idea of the MLS method is that a whole approximation  $U^*(x)$  of a sampling space can be accomplished by going through a moving process and written as follows [2]:

$$U^*(x) = \sum_{i=1}^N P(0)^T M(x)^{-1} P(x - x_i) W(\bar{x} - x_i) U_i \quad (1)$$

$$M(\bar{x}) = P W(\bar{x}) P^T \quad (2)$$

where  $W$  is weight function having form of a quartic spline,  $P$  and  $U$  are composed with a set of sample point regarding design variables and outputs, respectively.

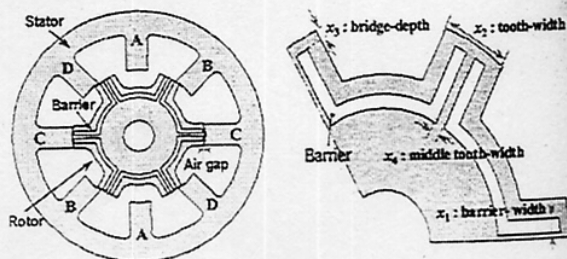


Fig. 1. Analysis model and design variables

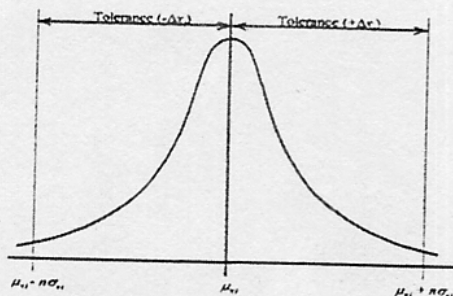


Fig. 2. Tolerance band of design variables

### Introductory Statistics for tolerance Analysis

A variation band of design variables with assuming the distribution of a normal distribution is shown in Fig. 2. 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  $\mu$  as follows [1];

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

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

### RESULTS AND DISCUSSION

Fig. 3 shows the torque profile of one stroke of the proposed motor, the electromagnet field within the motor is computed by using the two-dimensional finite element method (2D-FEM). And then the manufacturing process is running at the design variable tolerance of 10 (%) based on the six-sigma level. The variation of the outputs is distributed as shown in both Fig. 4 and Fig. 5, which are concerned about both the average torque and the torque ripple, respectively. In order to reduce the scatter of outputs from their population, design variables need to be regulated at a tighter tolerance than 10 (%).

### CONCLUSIONS

In this paper, the barrier salient pole applied to the rotor of conventional SRM to a enhancement of the torque performance, and it is then accomplished by tolerance

analysis to predict torque variations according to the geometric shape of the barrier. Tolerance analysis is achieved by SRSM combined with MLS method. From the result, proposed approach will provide a great potential for improving robustness of production and reducing production cost. In full paper, more detailed descriptions of tolerance analysis will be presented.

### REFERENCES

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- [2] Simore. A. Viana et al "Moving Least Reproducing Kernel Method for Electromagnetic Field Computation", *IEEE Transactions on Magnetics*, vol. 35, No. 3, pp. 1372-1375, MAY 1999.

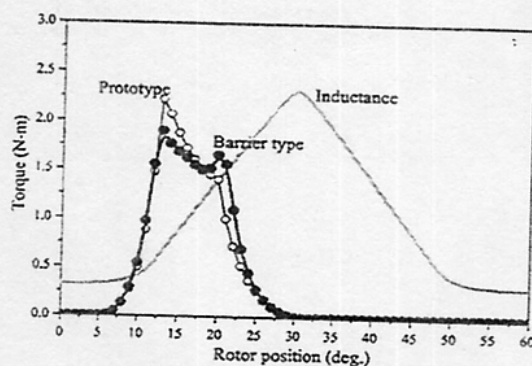


Fig. 3. Torque profile of one stroke

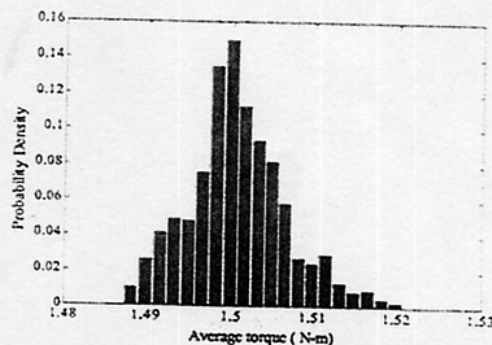


Fig. 4. Predicted probability distribution for the average torque.

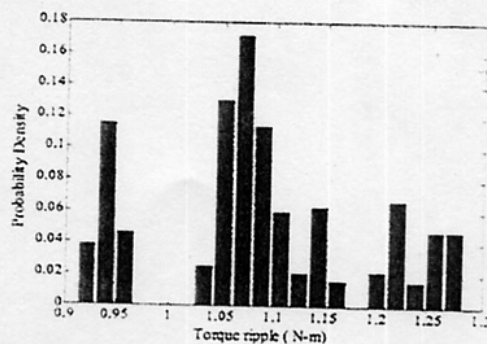


Fig. 5. Predicted probability distribution for the torque ripple.



- 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