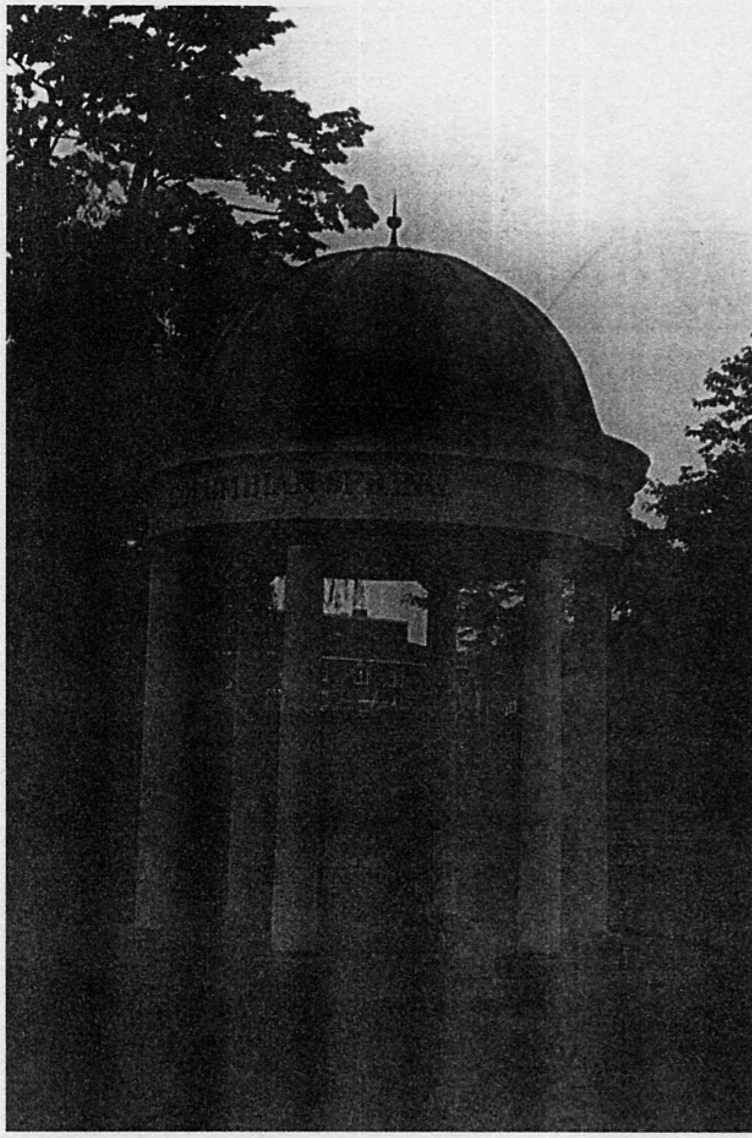

COMPUMAG 2003

Conference on the Computation of Magnetic Fields

Saratoga Springs, New York

July 13–17, 2003

Volume III

Devices III: Induction Heating and Superconductivity

Wednesday, July 16, 10:45am - 12:00pm

Chairmen
Prof. Jan Sykulski
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Vibration Reduction in Switched Reluctance Motor by Experimental Transfer Function and Response Surface Methodology

Kyung-Ho Ha, Young-Kyoun Kim, Geun-Ho Lee and Jung-Pyo Hong, *Senior Member, IEEE*
Dept. of Electrical Eng., Changwon National University
#9 Sarim-dong, Changwon, 641-773, Kyungnam, Korea
e-mail: agdokebi@cosmos.changwon.ac.kr, ensigma@hitel.com, motor@nc.namhae.ac.kr and jphong@sarim.changwon.ac.kr

***Abstract*—This paper deals with the vibration analysis and the optimal control for the vibration reduction in a Switched Reluctance Motor (SRM). To predict the vibration, the experimental transfer function coupled with the electromagnetic Finite Element Method (FEM) is proposed. Based on the proposed analysis method, the Response Surface Methodology (RSM) is applied to the optimal point for reducing the mechanical vibration according to switching angles. The experimental transfer function is obtained by the response of vibrations to harmonic components of electromagnetic forces. The electromagnetic and vibration characteristics are compared with the measured data.**

Introduction

The practical use of SRMs in industrial applications is limited by their higher vibration and torque ripple. The interaction of electromagnetic forces and mechanical structure is the major cause of noise and vibration [1-3]. The existing research on how to reduce the vibration can fall into two categories: drive strategies and geometric design. The former approach includes current waveform, turn-off and on angle, and duty cycle, etc. [2]. The second approach is a mechanical design to suppress the vibration against magnetic forces and to avoid resonance frequencies excited by harmonic magnetic forces [3].

It is necessary to predict the vibration level caused by the electromagnetic phenomenon under control techniques. Generally, the vibration characteristics are evaluated by the coupled electromagnetic and structural analysis based on the numerical method. For the prediction of mechanical vibrations by the structural FEM, a 3D analysis model and accurate mechanical properties are needed to obtain reliable estimates [3]. Hence, it takes a large time to compute and the process is complicated. Therefore, a more simple method is required to analyze the effects of changing the operating parameters of the power electronic controller on the vibration.

In this paper, the experimental transfer function instead of the structural FEM is coupled with the electromagnetic FEM to predict the vibration. The experimental transfer function is defined as the vibration response versus harmonic magnetic force components. This function is measured by the response of acceleration to harmonic components of magnetic force. It represents the inherent properties of the tested SRM. Based on this function, the vibration level is calculated very easily, accurately and simply by the magnetic force that is obtained from the electromagnetic FEM. From the proposed method, the electromagnetic and vibration characteristics according to switch on and off angles are investigated.

And this paper deals with the optimization to minimize the vibration. An optimization technique by the response surface methodology is applied to find the optimal switching angle. The response surface provides the designer with an overall perspective of the vibration response according to the behavior of the switching angle within a control space. It can be leading to great savings in time without very large repetition and computations [4]. The computation of the vibration response concerning the switching angle is achived by using the proposed analysis method. The various analysis results are compared with measurments.

Analysis Procedure

Fig. 1 presents the analysis process to find the optimal switching angle. The experimental transfer function coupled with electromagnetic FEM helps to evaluate the mechanical and electromagnetic performances of the SRM controlled by the switching angle. The response surfaces of the vibration and the magnetic torque is obtained from the RSM. The tested motor is a 6/4 SRM with three phases winding.

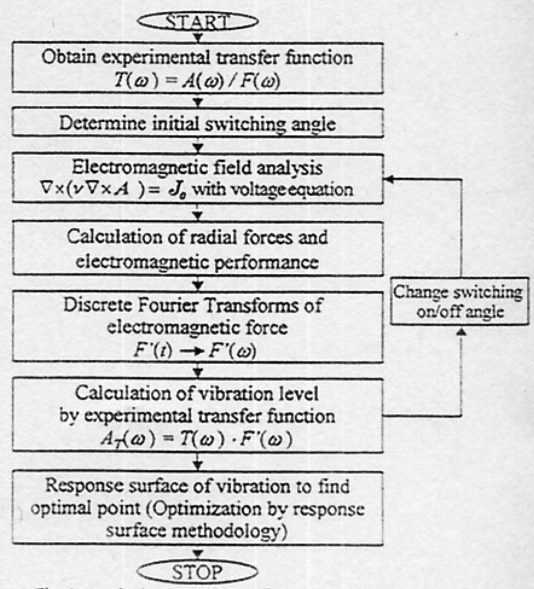

Fig. 1. Analysis procedure to find the optimal switching angle

Analysis Method

A. Experimental Transfer Funciton

The experimental transfer function is defined as the output response of acceleration versus the input of magnetic force. The acceleration response $A(\omega)$ is measured when only one phase of three phases is excited. The electromagnetic radial force acting on the stator pole $F(\omega)$ is calculated by the electromagnetic FEM. The experimental transfer function $T(\omega)$ in the frequency domain is determined as follows:

$$T(\omega) = \frac{A(\omega)}{F(\omega)} \tag{1}$$

B. Vibration Analysis

The vibration according to the variation of switching angles can be easily calculated by above the experimental transfer function $T(\omega)$and the radial force $F'(\omega)$ obtained by the electromagnetic FEM. The vibration response $A_T(\omega)$ by three phase excited is the sum of the vibration responses emitted from the sequential excitation of each phase, which is expressed as:

$$A_T(\omega) = T(\omega)\times F_A'(\omega) + T(\omega)\times F_B'(\omega)\cdot e^{j\omega\Delta t} + T(\omega)\times F_C'(\omega)\cdot e^{j\omega 2\Delta t} \tag{2}$$

C. Response Surface Methology

The response surface methodology procedures seek to find the relationship between the switching angle and the vibration response through statistical fitting method [4], which is based on the observed data obtained from the proposed analysis method. We suppose that the true response can be written as

$$\eta = F(\zeta_1, \zeta_2, \cdots, \zeta_k) \tag{3}$$

where, the variables ζ_1, ζ_2,..., ζ_k in (1) are expressed in natural variables, such as switch-on and off angle. Because the form of the true response function F is unknown and perhaps very complicated, we must approximate it. In many cases, the approximating function is normally chosen to be either a first-order or a second-order polynomial model, which is based on Taylor series expansion.

Analysis Results and Conclusions

Fig. 2 shows the experimental transfer function of the tested SRM that is obtained by the measeured acceleration response to the calculated magnetic force in the frequency domain. The transfer function in the dwell angle 20 degrees is almost identical to that in 30 degrees. Therefore, the change of the switching angle has no influence on the experimental transfer function, because this function results from the material properties and the dimensions. Fig. 2 represents the inherent characteristic of the SRM structure. The effects of the switching angles on the vibration level and the electromagnetic torque are investigated by using the experimental trânsfer function of Fig. 1. The analysis results, as shown in Fig. 3., are similar to the experimental values. Based on the proposed analysis method, the results related to optimal control by the RSM to minimize vibrations will be reported in extended paper in detail.

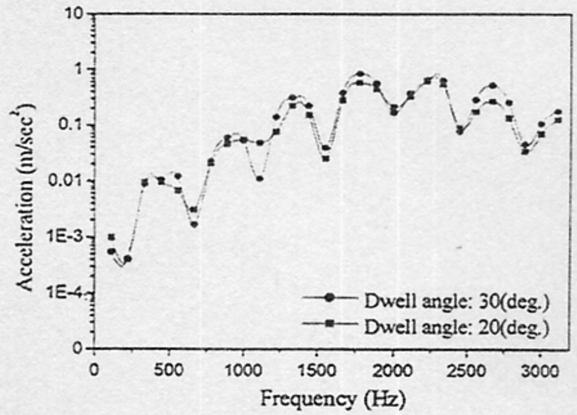

Fig. 2. Experimental transfer function of the tested SRM

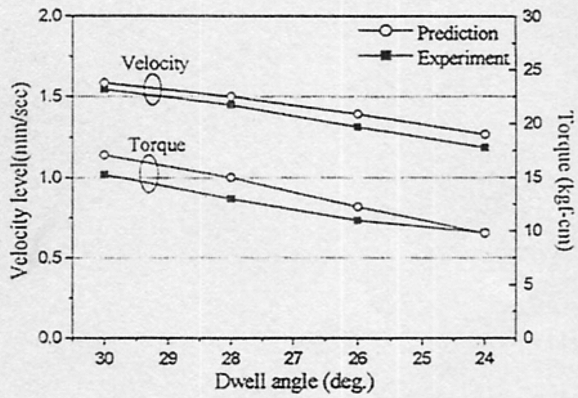

Fig. 3. Comparison of analysis results and measurements of the mechanical vibration and magnetic torque

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