Stator Pole and Yoke Design for Vibration Reduction of Switched Reluctance Motor

Jung-Pyo Hong, Kyung-Ho Ha and Ju Lee*
Dept. of Electrical Eng., Changwon National University, #9 Sarim-dong, Changwon, 641-773, Kyungnam, Korea
*Dept. of Electrical Eng., Hangyang University, Seoul, 133-791, Korea
e-mail: haroom@netian.com, jphong@sarim.changwon.ac.kr and julee@ email.hanyang.ac.kr

***Abstract* ¾ The influence of the various stator pole shapes and stator yoke structures in Switched Reluctance Motor (SRM) on the mechanical behavior caused by the electromagnetic force is investigated in this paper. The stator part in SRM produces the most vibrations. The geometric design of the stator is therefore necessary to reduce the vibration. The magnetic origin forced vibrations varied with the various structure of a SRM with 6/4 poles are analyzed by the coupled electromagnetic and structural Finite Element Method. Then a less vibration stator structure is proposed.**

INTRODUCTION

The wide application of SRM is limited by their higher vibration and acoustic noise. The interaction of magnetic radial forces and mechanical structure of SRM is the major cause of the noise and vibration [1]. To reduce the vibrations, many existing researches on the vibration of SRM can be classified into two ways: drive strategies and geometric design. The former approach is smoothing or current shaping, switch angle control and duty cycle according to control modes [2]. The second approach is mechanical designs related to vibration behavior, in particular the geometric design of the stator considering the magnetic force wave [3].

This study also deals with the geometric design of the stator for vibration reduction considering the magnetic radial force. The SRM is excited by large radial forces acting on opposite poles, which lead to deform the stator into an oval. This vibration motion becomes severe when the frequencies of electrical excitation pattern are close to the natural frequencies of the stator. It is necessary to design not only the magnet circuit but also the mechanical structure.

Therefore, five different stator pole shapes and four different stator yoke structures are proposed to examine the vibration characteristics in this work. In order to obtain a less vibration stator structure against the magnetic forces, the influence of the proposed geometric structure of the stator on the vibration behavior is analyzed by the structural and electromagnetic FEM. The radial forces are calculated by the electromagnetic FEM and the forced vibrations of the stator when the radial magnetic force applied at the surface of two opposite stator poles are investigated. The dynamic response in time domain by the structural FEM is used for analyzing the forced vibrations. Furthermore, The prediction of the vibration performances caused by the static electromagnetic force is derived from the mechanical stress, displacement of the stator.

PROPOSED ANALYSIS MODEL AND PROCEDURE

Fig. 1 shows the four different stator structures modified from a common SRM with 6 poles on the round stator. Fig. 2 shows the five different stator pole shapes. The electromagnetic and structural coupling using the analysis procedure as shown in Fig. 3 is helped to evaluate the different structure motors by examining their adherence to the mechanical and electromagnetic requirements. From the analysis results, a stator yoke and a pole shape are finally selected to reduce the vibration and the stator yoke combines with the pole shape to form a complete structure. Then a less vibration stator of the SRM is proposed.

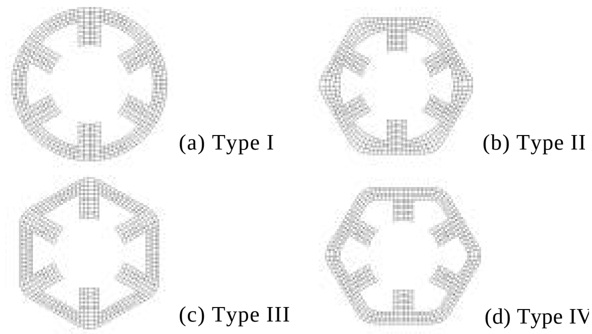

Fig. 1. Four different stator yoke structures

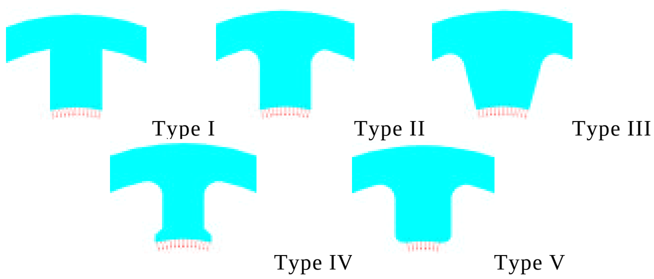

Fig. 2. Five different stator pole shapes

ELECTROMAGNETIC AND STRUCTURAL FEM

In transient electromagnetic field analysis, the governing equation with vector potential is as follows:

$$\nabla^2 \times \boldsymbol{A} = m\boldsymbol{J}_0 \quad (1)$$

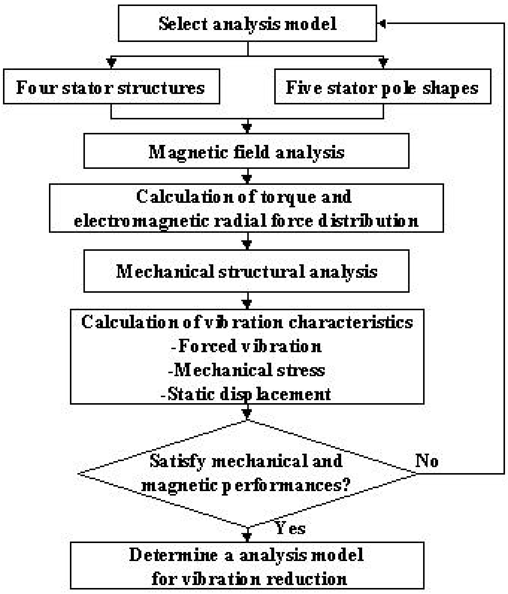

Fig. 3. Analysis procedure

After applying equation (1) and coupling the voltage equation and then system matrix is obtained by time difference sachems. From the Maxwell stress tensor, the electromagnetic force applied on the pole face of stator core in radial direction is evaluated by the equation (2).

$$\boldsymbol{p} = [(\mathbf{n}\cdot\mathbf{B})\mathbf{B} - (1/2)B^2\mathbf{n}]/m_0 \qquad (2)$$

where $\boldsymbol{p}$ is the surface force density $\mathbf{n}$ is the direction of the normal unit vector on the pole face. $\mathbf{B}$ is the flux density.

When the timing varying force is applied at a point or surface on the stator structure, the forced vibration pattern is examined by using the mode superposition method. To characterize the response of the structure with the dynamic load F, the response equation for the n modes to be used in the modal analysis is as follows. The response as a function of time is obtained by the solution of equation (3).

$$[\mathbf{M}]\sum_{i=1}^{n}\{\Phi_i\}\ddot{y}_i(t) + [\mathbf{C}]\sum_{i=1}^{n}\{\Phi_i\}\dot{y}_i(t) + [\mathbf{K}]\sum_{i=1}^{n}\{\Phi_i\}y_i(t) = \{F(t)\} \qquad (3)$$

where y_i is response, $\{\Phi_i\}$ is the mode shape factor of mode i and $\{F(t)\}$ is the forcing term including the magnetic force.

ANALYSIS RESULTS AND CONCLUSIONS

Fig. 4 shows the calculated radial force acting on a pole according to the stator pole shape as shown in Fig. 2. The pole shape of Type IV produces the smaller radial force than the other pole shapes. Fig. 5 shows the forced vibrations for each stator yoke structure as shown in Fig. 1. The displacements at the stator pole surface are observed while the same radial force is applied at the surface of two opposite stator poles in each model. We note that the structure moves into the stator center to reach a maximum displacement before the current is commuted and the stator moves back toward its origin state and then oscillates as a damped vibration. Type II model shown in Fig. 1 has the smallest displacement in the four different stator yoke structures. This model can reduce an oval stator deformation of SRM.

The electromagnetic and mechanical performances result from radial forces will be reported in extended paper in detail.

ACKNOWLEDGEMENT

This work has been sopported by International Common Research Grant No.1-00-047, which is funded by Ministry of Science & Technology

REFERENCES

[1] R. S. Colby, F. M. Mottier and T. J. E. Miller, "Vibration modes and acoustic noise in a four-phase switched reluctance motor," *IEEE Trans. Ind. Applicat.*, vol. 32, pp. 1357-1364, November/December, 1996.
[2] C. Pollock and C. Y. Wu, "Acoustic noise cancellation techniques for switched reluctance drives," *IEEE Trans. Ind. Applicat.*, vol. 33, pp. 477-484, March/April 1997.
[3] A. Strassis and A. M. Michaelides, "The design of low vibration doubly salient motors," *Electric Machines and Power Systems*, vol. 27, pp. 967-981, 1999.

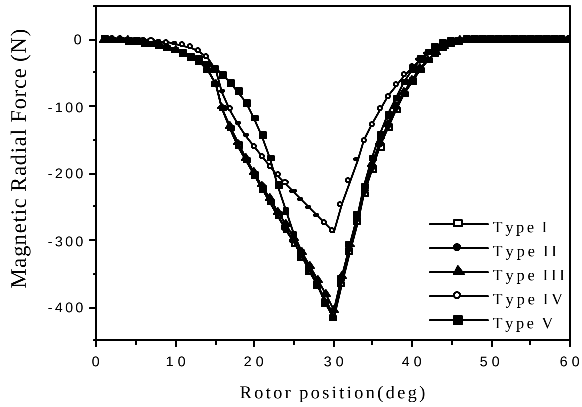

Fig. 4. Electromagnetic radial force according to each stator pole shape

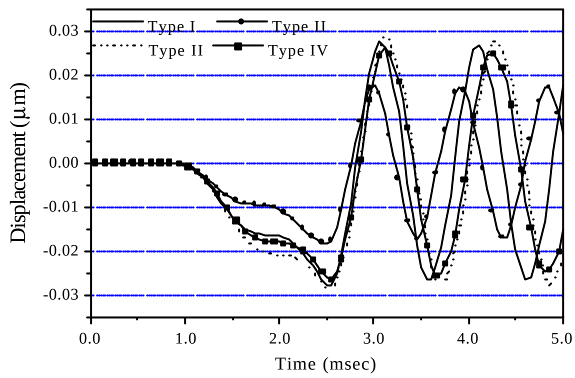

Fig. 5. Dynamic response due to magnetic force according to each stator yoke