Orbital Analysis of Rotor Due to Unbalance Electromagnetic Force for Switched Reluctance Motor

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***Abstract* – The purpose of this paper is to analyze the transient response of rotor due to unbalance electromagnetic force for Switched Reluctance Motor (SRM). In order to reduce vibration of SRM, it is necessary to predict the mechanical dynamic behavior of rotor-bearing system. So the orbital of rotor according to rotating speed is analyzed by using the combined methodologies of Finite Element Method (FEM) and Transfer Matrix Method (TMM), and unbalance force induced by dynamic eccentricity is calculated by the Maxwell stress tensor. From the result, the stability of the rotor and effect of eccentricity are determined.**

INTRODUCTION

Generally, the SRM is a fascinating machine with all kinds of interesting application possibilities because it has many advantages such as the possibility of high-speed operation and simplicity of mechanical construction. However, the most striking disadvantages of SRM are high level of the vibration and torque ripple. The evaluation of the above problems is very important because of the stability of electric motor resulting from high vibration. There are many possible sources of vibration and noise in SRM, such as the relationship between magnetic and mechanical origin. The dominant source is radial deformation of the stator and dynamic rotor eccentricity due to radial magnetic attraction. This phenomenon is strong when the frequency of exciting force coincides with the natural frequency of stator and rotor [1, 2]. This paper focuses on the rotor eccentricity caused by unbalance force.

The eccentricity causes a force on the rotor that tries to pull it even further from the stator bore center, the dynamic eccentricity produces an unbalanced magnetic force that acts on the rotor and rotates at rotor with rotational velocity. The sources of vibration associated with the eccentricity cause excessive stress of the machine and deteriorate performance of SRM. Therefore, it is necessary to monitor rotor eccentricity to prevent serious operational problems.

This paper proposes the procedure of orbital analysis of rotor for SRM by using combined time domain finite element transfer matrix method, namely Transient Property Transfer Approach (TPTA) [3]. In case of FEM, the size of a system matrix is proportion to Degree of Freedom (DOF) of the whole system. Therefore, it takes a lot of time and expense to compute. TMM is independent to the total DOF so it can have the fixed matrix size and reduce the computing time. On the other hand, TMM is difficult to analyze complex structure and is inadequate to regard instantaneous behaviors.

Transient response at each node point has been obtained by using TPTA equipped with the merit of TMM and FEM. Fig. 1 shows the analysis procedure of transient response of rotor for SRM due to unbalance magnetic force

THE ANALYSIS METHOD

Analysis model and structure

Table I presents the specification of 6/4 SRM.

Table I. Specification of analysis model

Item	Value	Item	Value
Rated power	1 (kW)	Rated speed	2000 (rpm)
No. of stator / rotor pole	4 / 6	Stack length / Rotor diameter ratio	1.3

Unbalance force

The governing equation of the magnetostatic field problem with magnetic vector potential $\boldsymbol{A}$ is generally expressed as follows:

$$n\nabla^2 \boldsymbol{A} = \boldsymbol{J} \tag{1}$$

where n is the magnetic reluctivity of core, J is the applied current..

The flux distribution is obtained by solving equation (1). The surface force density derived from the Maxswell stress formulation has the following expression.

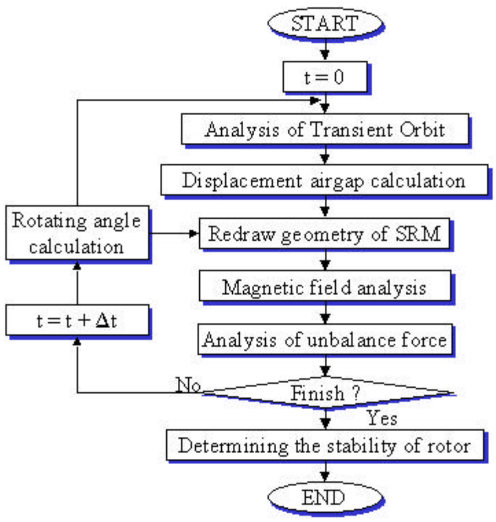

Fig. 1. The analysis procedure

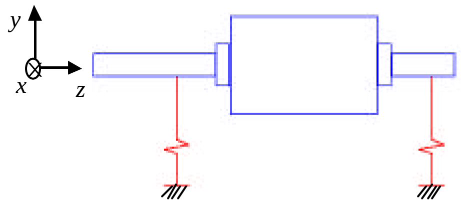

Fig. 2 Rotor-bearing system of the SRM

$$F_s = [H_1(B_1 \cdot n_{12}) - (B_1 H_1/2) n_{12}] - [H_2(B_2 \cdot n_{12}) - (B_2 H_2/2) n_{12}] \quad (2)$$

where H_i is the magnetic field intensity, B_i is flux density of surface element adjacent to boundary and n_{12} is unit normal vector in the direction from region 2 to 1.

Orbital analysis of rotor [3]

Fig. 2 shows Rotor-bearing system of the SRM to analyze transient response with TPTA. Based on this finite element model, the matrix equations of motion for the element can be written as

$$[M]^e\{\ddot{q}(t)\}^e + [C]^e\{\dot{q}(t)\}^e + [K]^e\{q(t)\}^e = \{F(t)\}^e \quad (3)$$

where $[M]^e$, $[C]^e$ and $[K]^e$ are the element mass, damping and stiffness matrices (8 by 8), respectively.

The acceleration and velocity of the discrete time TMM expressed as displacement q_n in time instant t_i is following:

$$\ddot{q}_n(t_i) = A_n(t_i)q_n(t_i) + B_n(t_i) \quad (4)$$

$$\dot{q}_n(t_i) = D_n(t_i)q_n(t_i) + E_n(t_i) \quad (5)$$

Substitution of the equation (4), (5) into equation (1) is following equation (6).

$$\begin{Bmatrix} q_2 \\ f_2 \\ 1 \end{Bmatrix} = \begin{Bmatrix} -K_{12}^{-1}K_{11} & K_{12}^{-1} & s_1 \\ K_{21} - K_{22}K_{12}^{-1}K_{11} & K_{22}K_{12}^{-1} & s_2 \\ 0 & 0 & 1 \end{Bmatrix} \begin{Bmatrix} q_1 \\ f_1 \\ 1 \end{Bmatrix} \quad (6)$$

$$\{S\}_2^L = [F]_1\{S\}_1^R \quad (7)$$

The form of field matrix [F] in equation (7) is similar to the form of TMM. The point matrix [P] is derived by the same procedure as field matrix.

$$\{S\}_2^R = [P]_1\{S\}_1^L \quad (8)$$

The transfer matrix [T] for finite element consist of the product field and point matrix. Repetitive application of transfer matrix [T]=[F][P] for element results in the fo llowing transfer relation for the entire rotor bearing system.

$$\{S\}_n^L = [T]_n[T]_{n-1}\cdots\cdots[T]_2[T]_1\{S\}_1^L \quad (9)$$

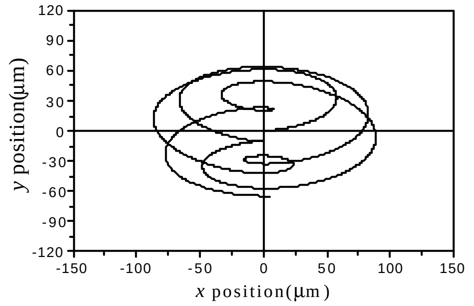

Fig. 3. Transient response orbit at middle node without magnetic force

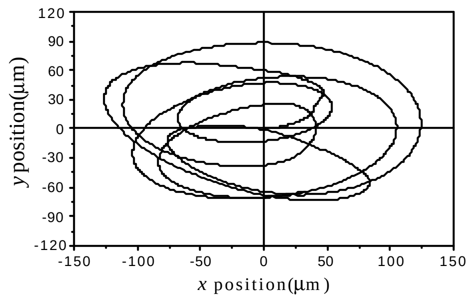

Fig. 4. Transient response orbit at middle node due to magnetic force

The nodal displacement at subsequent time instants, which is orbit of rotor according to a change of time, has been solved by repetitively following the same steps.

CONCLUSION

Fig. 3 shows the transient response at the middle node of rotor due to residual unbalance, such as mass unbalance and worn bearings. Fig. 4 shows the transient response orbit by unbalance magnetic force. From this result, we take notice that the orbit without magnetic force has a tendency period and converges to the stator bore center. The result due to magnetic force presents complicated orbit and greater eccentricity about 30(μm) than the eccentricity of Fig. 4. It effects on the performance of SRM with small airgap. Furthermore, the orbit of rotor in near natural frequency will be analyzed, and the stability will be estimated.

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