A Novel Stator Design of Synchronous Reluctance Motor by Loss & Torque Evaluations Related to Slot Numbers using Coupled Preisach Model & FEM

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Abstract — This paper deals with the stator design solution of a synchronous reluctance motor (SynRM) with various slot number by loss & torque evaluations related to the slot open, teeth width using coupled Preisach modeling & FEM.

The coupled Finite Elements Analysis (FEA) & Preisach model have been used to evaluate the nonlinear solution.

Comparisons are given with characteristics of SynRM according to stator winding, slot number, slot open, teeth width variation, respectively.

I. INTRODUCTION

Synchronous reluctance motor (SynRM) has a simple structure, rugged characteristics and high efficiency because of negligible rotor loss. It doesn't have rotor winding and rotates at synchronous speed, so the controller is simpler than other types of AC machines. Many works have been carried out in the field of SynRM rotor design because they have many advantages [1]-[7].

If stator slot numbers of a SynRM are reduced from conventional one, the decreasing of both copper loss and the production cost due to the simplification of winding in factory is obtained. However, it is difficult to expect a good performance from reduced slot number SynRM without considering the defects of torque ripple, lower inductance ratio and difference (efficiency, power factor), etc.

The focus of this paper is the stator design relative to torque density, losses and inductances on the basis of stator slot number and open, teeth width, in order to improve performance and production cost problem of a SynRM. The coupled Finite Elements Analysis (FEA) & Preisach model have been used to evaluate the nonlinear solution [8].

II. COUPLED FEM AND PREISACH'S MODELING

A. Governing Equation of SynRM

The governing equation in 2D is given as follows:

$$\frac{\partial}{\partial x}\upsilon_0\left(\frac{\partial A_z}{\partial x}\right)+\frac{\partial}{\partial y}\upsilon_0\left(\frac{\partial A_z}{\partial y}\right)=-J_z-J_m \quad (1)$$

$$J_m=\upsilon_0\left(\frac{\partial M_y}{\partial x}-\frac{\partial M_x}{\partial y}\right) \quad (2)$$

Where, A_z : z component of magnetic vector potential, J_z : current density, υ_0 :magnetic resistivity, M_x, M_y : Magnetization of magnetic material with respect to the magnetic intensity H_x, H_y

B. System Matrix in steady state

The system matrix can be written as

$$[K^{(e)}]\{A^{(e)}\}+\{F^{(e)}\}+\{M^{(e)}\}=0 \quad (3)$$

where, $K_{ij}^{(e)}=\frac{\upsilon_0^{(e)}}{4\Delta^{(e)}}(c_{ie}c_{je}+d_{ie}d_{je})$, $F_i^{(e)}=-\Delta^{(e)}\frac{Ni}{3S}$

$$M_i^{(e)}=\upsilon_0^{(e)}(M_x^{(e)}d_{ie}+M_y^{(e)}c_{ie})$$

The overall model is described by following matrix.

$$[K]\{A\}+\{F\}+\{M\}=0 \quad (4)$$

C. System Matrix in transient state

The circuit equation is written as:

$$\{V\}=[R]\{I\}+[L_0]\frac{d}{dt}\{I\}+\{E\} \quad (5)$$

Where, $\{E\}$: E.M.F. vector in the winding , $\{V\}$: supplying voltage vector, $\{I\}$: phase current vector, $[L_0]$: leakage inductance. To solve (1), we used the Galerkin finite element method. For the time differentiation in (5), a time stepping method is used with backward difference formula. Coupling (1), (2) and (5), the system matrix is given as follows:

$$\left[\begin{bmatrix}\upsilon_0[S] & -[N]\\ [0] & [R]\end{bmatrix}+\frac{1}{\Delta t}\begin{bmatrix}[0] & [0]\\ [LG]^T & [L_0]\end{bmatrix}\right]\begin{Bmatrix}\{A\}\\ \{I\}\end{Bmatrix}_t = \quad (6)$$

$$\frac{1}{\Delta t}\begin{bmatrix}[0] & [0]\\ [LG]^T & [L_0]\end{bmatrix}\begin{Bmatrix}\{A\}\\ \{I\}\end{Bmatrix}_{t-\Delta t}+\begin{Bmatrix}\{M\}\\ \{V\}\end{Bmatrix}_t$$

Where, [LG] is a coefficient matrix related to emf, the magnetization {M} is calculated by preisach modeling.

D. Analysis Model & Application of Preisach's Model

The magnetization M can be expressed as a scalar model, because the rotor rotates according to the input current angle θ synchronously. Therefore, it can be supposed that the domain in stator is an alternating field with reference to x axis and y axis. B and H of the domain in rotor is constant and is a rotating field, but it is an alternating field with reference to x axis and y axis, also [5]-[8]. It is natural that M, H which is calculated on the same axis has a same vector direction.

$$M(t)=\iint_{\alpha\geq\beta}\mu(\alpha,\beta)\gamma_{\alpha\beta}(H(t))d\alpha d\beta \quad (7)$$

$$=\iint_{S^+(t)}\mu(\alpha,\beta)d\alpha d\beta-\iint_{S^-(t)}\mu(\alpha,\beta)d\alpha d\beta$$

where, S(t) is the triangular region $H_{sat} \geq \alpha \geq \beta \geq -H_{sat}$ on the (α,β) plane in the Fig.2, (known as the Preisach's diagram), H_{sat} is the saturation magnetic field strength, α and β are the magnetic field strengths in the increasingly positive and negative directions, $\mu(\alpha,\beta)$ is the distribution function of the dipoles, $\mu(\alpha,\beta) = \mu(-\alpha,-\beta)$, and $\mu(\alpha,\beta)$ = 0 if $(\alpha,\beta) \notin S$, $\gamma_{\alpha\beta}(H(t))$ = 1 on the $S^{+}(t)$, and $\gamma_{\alpha\beta}(H(t))$ = -1 on the $S^{-}(t)$. The interface between $S^{+}(t)$ and $S^{-}(t)$ is determined by the history and the present state of magnetization. A more convenient treatment of this model is also to substitute the Everett plane for Preisach's one as shown in (8) [9].

$$E(\alpha,\beta) = \iint_{\alpha \geq \beta} \mu(\alpha,\beta)\gamma_{\alpha\beta}(H(t))d\alpha d\beta \qquad (8)$$

In the Everett plane, the distributions of M, which is accepted from experimental data of material S40 and ferrite magnet, are Gaussian ones.

III. ANALYSIS MODEL AND DESIGN PROCEDURE

The study concerns the SynRM with rotor flux barriers that present, respect to the axially laminated one, a simplicity in the mechanical construction, lower manufacturing cost, and the rotor skewing possibility.

Comparing from a standard motor of a conventional SynRM(24slot), several designs have been found according to design strategy of Fig.2.

In this paper the slot number of a SynRM is considered those of 24, 12 (distributed winding: 36 turn/slot, 72 turn/slot), 6 (concentrated winding: 144 turn/ phase). The width of slot open (SO) is a variable, which is related to torque ripple production in 6, 12 slot machines. And the number 24, 12 and 6 of stator slot is considered, because it is limited by mechanical and electrical constraint of 3-phase motor.

The shape coordinates of stator slot and teeth have been drawn as a condition from open to closed slot, symmetrically as shown in Fig. 1.

And then new CAD file is redrawn with regard to the change of slot and teeth width automatically as shown in fig.2.

Next the process of automatic mesh generation follows. In mesh generation, mesh data doesn't change node number, element number, region, boundary condition, etc., but only x, y-coordinate data of stator slot and teeth at 6, 12 slot numbers.

In this way the proposed Pre-processor procedure can be performed in a short period of time.

The comparison between present value and the past one for inductance, loss and torque ripple evaluation are performed.

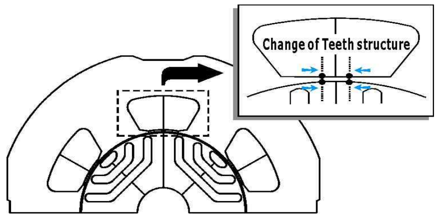

Fig. 1 the shape coordinates of stator slot and teeth

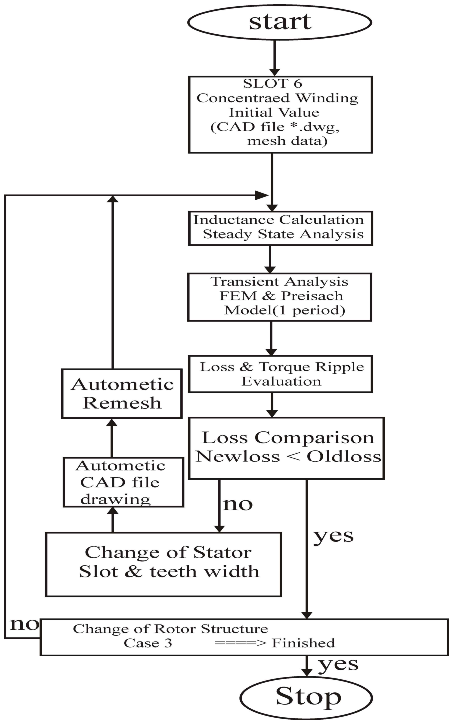

Fig.2 flow chart of design procedure

IV. REFERENCES

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