PM Magnetization Characteristics Analysis of a Post-Assembly Line Start Permanent Magnet Motor Using Coupled Preisach Modeling and Finite Element Method

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***Abstract*— This paper deals with the PM magnetization characteristics evaluations in a post-assembly Line Start Permanent Magnet Motor (LSPMM) using a coupled Finite Element Method (FEM) and Preisach modeling, which is presented to analyze the magnetic characteristics of permanent magnets. The focus of this paper is the characteristics analysis relative to magnetizing direction and quantity of permanent magnets due to the eddy current occurring in the rotor bar during magnetization of Nd-Fe-B.**

***Index Terms*— Permanent magnets, FEM, Preisach Modeling**

I. Introduction

The line start permanent magnet motor (LSPMM) combines a permanent magnet rotor for a better motor efficiency during synchronous running with an induction motor squirrel cage rotor to permit the motor starting by direct coupling to an AC power source.

This solution may lead to important technical advantages such as reduced manufacturing costs and or better performances as well as reduced running costs if the space of the rotor is properly negotiated between permanent magnets and squirrel cage.

The fact that the magnetizing field is generated by the permanent magnets means that no magnetizing current is drawn from the line finally leading to a much higher power factor in full load operation and lower losses in the stator winding.

The LSPMM can replace the common induction motor in many applications, one of the most appropriate being the centrifugal applications (Fans and pumps driving) due to their known torque-speed characteristic.

To simplify the manufacturing process and reduce the manufacturing cost, it is necessary to magnetize the permanent magnet in the post-assembly magnetization method [1]. However, the eddy current occurring in the rotor bar during magnetization disturbs the magnetization of Nd-Fe-B.

This paper deals with the PM magnetization characteristics evaluations in a post-assembly LSPMM using a coupled finite element method (FEM) and Preisach modeling, which is presented to analyze the magnetic characteristics of permanent magnets.

The focus of this paper is the characteristics analysis relative to magnetizing direction and quantity of permanent magnets due to the eddy current occurring in the rotor bar during magnetization of Nd-Fe-B.

The coupled Finite Elements Analysis (FEA) & Preisach model have been used to evaluate the nonlinear solution [2]-[4].

II. Analysis Model and Specifications

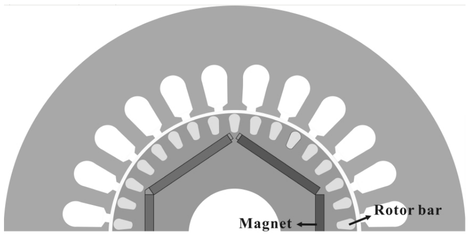

Fig. 1. Cross section of single phase LSPMM

TABLE I
Specifications of Analysis Model

Rate Power[kW]	2.8
Rate Voltage[V]	220
Rate Torque[Nm]	7.7
Rate Speed[rpm]	3600
Frequency [hz]	60
Phase	2
Pole	2
Slots/Phase	6
Rel. E-loading	173
Conductors/slot	20
Turns/phase	120
Stack length[mm]	93.1
Gap diameter[mm]	68.6
Sta. diameter[mm]	142.0
Sta. teeth width[mm]	4.3
Sta. yoke height	27.6
Magnet	Nd-Fe-B
Magnet thick.[mm]	2.2
Magnet Thick(SPM)[mm]	2.1
Magnet Thick(IPM)[mm]	2.8
Gap flux density	0.82
Rotor volume	4.327

III. Coupled FEM and Preisach's Modeling

A. *Governing Equation of LSPMM*

Maxwell's equations can be written as

$$\nabla \times \vec{H} = \vec{J}_0 + \vec{J}_e \tag{1}$$

$$\nabla \cdot \vec{B} = 0 \tag{2}$$

$$\vec{B} = \frac{1}{\upsilon_0}\vec{H} + \vec{M} \qquad \vec{B} = \frac{1}{\upsilon_0}\vec{H} + \vec{M}_{PM} \tag{3}$$

where, $\vec{M}$, $\vec{M}_{PM}$ are the magnetization of magnetic material and permanent magnet with respect to the magnetic intensity $\vec{H}$. The magnetic vector potential $\vec{A}$ and the equivalent magnetizing current $\vec{J}_m$, $\vec{J}_{PMm}$ are expressed as follow

$$\vec{B} = \nabla \times \vec{A} \tag{4}$$

$$\vec{J}_m = \upsilon_0(\nabla \times \vec{M}),\ \vec{J}_{PMm} = \upsilon_0(\nabla \times \vec{M}_{PM}) \tag{5}$$

$$\vec{J}_e = \sigma \vec{E} = \sigma(-\frac{\partial \vec{A}}{\partial t} + \vec{v} \times \vec{B} + \nabla \phi)$$

The governing equation derived from (1)-(5), is given by

$$\upsilon_0(\nabla \times \nabla \times \vec{A}) = \vec{J}_0 + \vec{J}_e + \vec{J}_m + \vec{J}_{PMm} \tag{6}$$

When the moving coordinate system is used, the governing equation in 2D is given as follows:

$$\frac{\partial}{\partial x}\upsilon_0(\frac{\partial A_Z}{\partial x}) + \frac{\partial}{\partial y}\upsilon_0(\frac{\partial A_Z}{\partial y}) =$$

$$-J_Z + \sigma\frac{\partial A_z}{\partial t} + \sigma\frac{\partial \varphi}{\partial z} - J_m - J_{PMm} \tag{7}$$

$$J_m = \upsilon_0(\frac{\partial M_y}{\partial x} - \frac{\partial M_x}{\partial y}),\ J_{PMm} = \upsilon_0(\frac{\partial M_{PMy}}{\partial x} - \frac{\partial M_{PMx}}{\partial y}) \tag{8}$$

Where, A_z : z component of magnetic vector potential, J_z : current density , υ_0 : magnetic resistivity, M_x, M_y, M_{PMx}, M_{PMy} : Magnetization of magnetic material and PM with respect to the magnetic intensity H_x, H_y, σ : conductivity of the rotor bar, ϕ : scalar potential.

In this model, $\sigma\frac{\partial \phi}{\partial z}$ should equal zero, because the periodic boundary condition is used.

B. *System Matrix*

The circuit equation is written as:

$$\{V\} = [R]\{I\} + [L_0]\frac{d}{dt}\{I\} + \{E\} \tag{9}$$

Where, {E} : E.M.F. vector in the winding

$\{V\}$: supplying voltage vector

$\{I\}$: phase current vector

$[L_0]$: leakage inductance

To solve (7), we used the Galerkin finite element method. For the time differentiation in (9), a time stepping method is used with backward difference formula. Coupling (7), (8) and (9), the system matrix is given as follows:

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

$$= \frac{1}{\Delta t}\begin{bmatrix} [P] & [0] \\ [LG]^T & [L_0] \end{bmatrix}\begin{Bmatrix} \{A\} \\ \{I\} \end{Bmatrix}_{t-\Delta t} + \begin{Bmatrix} \{M\} \\ \{V\} \end{Bmatrix}_t \tag{10}$$

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

The magnetization M can be expressed as a scalar model, because the rotor rotates according to the input current angle 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]-[6]. It is natural that M, H which is calculated on the same axis have a same vector direction.

$$M(t) = \iint_{\alpha \ge \beta} \mu(\alpha,\beta)\gamma_{\alpha\beta}\left(H(t)\right)d\alpha d\beta \tag{12}$$

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

Through certain function transforms, the area integration can be related to the hysteresis loops. A more convenient treatment of this model is to substitute the Everett plane for Preisach's one [7].

$$E(\alpha,\beta) = \iint_{\alpha \ge \beta} \mu(\alpha,\beta)\gamma_{\alpha\beta}\left(H(t)\right)d\alpha d\beta \tag{13}$$

In the Everett plane, the distributions of M, which are accepted from experimental data (stator, rotor: S18, PM: Nd-Fe-B), have Gaussian ones.

In this paper, Everett planes are two those (one of stator and rotor (S18, isotropy) and those of PM (Nd-Fe-B: isotropy)).

More detailed analysis procedure, results and discussion will be given in final paper.

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