# Magnetization Characteristics Analysis in a Pole Changing Memory Motor using FEM & Preisach modeling

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**Abstract — This paper deals with the PM performance evaluations in a pole changing memory motor (PCMM) using a coupled transient 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 evaluation relative to magnetizing direction and the pole number of machine on re-demagnetization condition in a pole changing memory motor.**

## I. INTRODUCTION

Memory motors combine the flux controllability of a PM(permanent magnet) machine with the high power density of conventional electric machines[1]-[2].

They utilize the flux concentration principle that allows the generation of air-gap flux densities that are typical for high-efficiency machines. Memory motors can be built either as variable-flux or pole-changing machines. In both machine types, the magnetization of PMs can be simply varied by a short current pulse, with no need for permanent demagnetizing current as in conventional internal PM machines at flux weakening mode.

Electric drives in which discrete speed control is required are today equipped exclusively with squirrel-cage induction motors, due to the property of the squirrel cage to always have the same number of poles as the stator winding. Conventional permanent-magnet (PM) machines have a constant number of poles and can be operated from a constant frequency source only at one speed. If a PM machine is built after the principles of memory motors, one can change its number of poles as simply as in a squirrel-cage machine.

The operation of a memory motor is based on its ability to change the magnetization of its magnets with a low amount of stator current. It is illustrated how the magnetization of rotor magnets can be continually varied by applying a short pulse of stator current [1], [2].

Issues such as magnetizing direction and quantity are important in evaluating the performance of the memory motor.

Such characteristics depend upon the characteristic of material and, therefore, require a numerical evaluation.

Whereas in other kinds of machines a rough estimation of hysteresis and magnetizing characteristics can be accepted, their importance in a memory motor justifies a greater effort in calculating them more precisely. The Preisach model is now generally accepted to be a powerful hysteresis model, and is therefore intensively studied [3], [4].

In this paper, a coupled finite element analysis and Preisach modeling for a PCMM are presented and characteristics analysis are performed under the situations of pole changing due to short pulse current.

## II. PRINCIPLE OF OPERATION A PCMM

### A. Principle of operation of PCMM

If the rotor of a memory motor is built following the same sandwich principle shown in [1], but with more than one magnet per pole one can group equally magnetized magnets in various manners. As a consequence, the number of rotor poles changes. This is the basic principle of operation of a pole-changing memory motor, as illustrated in Figs. 1 and 2.

In Fig. 1, the cross-sectional view of a pole-changing memory motor with 32 tangentially magnetized magnets is shown. On the rotor side there are four magnets per pole, all of them being magnetized in the same direction. PMs along with iron segments build the rotor wreath which is mechanically fixed to a nonmagnetic shaft. After the stator winding is reconnected into six-pole configuration, a short pulse of stator current changes the rotor eight-pole magnetization into a six-pole one, as shown in Fig. 2. Since the number of magnets per pole is not any more an integer (32/6=5.333...), same magnets can remain demagnetized.

### B. Magnetic equivalent Circuit and Determination of Flux per Pole

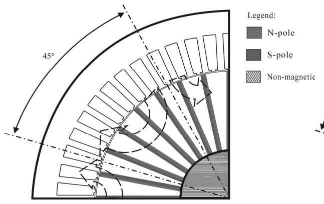

Fig. 1 8-pole magnetized PCMM

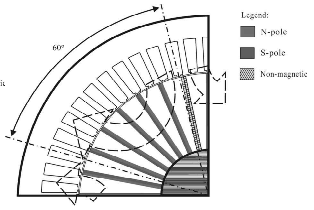

Fig. 2 6-pole magnetized PCM

Assume that the rotor is built with 4 magnets per pole, and that all magnets are magnetized. Approximate flux density distribution in that case is shown in Fig. 3.

Flux $\Phi_1$ in Fig. 3 goes through the whole area of the left and right magnet, but only through a portion of the center magnet with radial height $b_m$-$b_0$. Flux $\Phi_2$ in Fig. 3 goes only through a portion of the center magnet with radial height $b_0$.

Since the magnets are tangentially magnetized, and there is no current in the rotor slots, one may write for tangential component of rotor slot flux density: The height $b_0$ in Fig. 3 can be evaluated by using the magnetic equivalent circuit of one machine pole, shown in Fig. 4.

Denoting by $Br$ the residual magnetism of rotor magnets, and $H_c$ their coercive force, one can define quantities from the magnetic equivalent circuit in Fig. 4 as:

$$G_M = \frac{\Phi_r}{\Theta_c} = \frac{B_r l b_m}{H_c d}, R_{\delta,1} = \frac{1}{\mu_0}\frac{\delta}{l\frac{b_S}{2}},$$

$$R_{\delta,2} = \frac{1}{\mu_0}\frac{\delta}{l b_s}, B_t(r)=const \tag{1}$$

Solution for fluxes $\Phi_1$ and $\Phi_2$ in Fig. 4 helps one find the flux per pole $\Phi_{pole}$ as a function of magnet residual flux $\Phi_r$ as

$$\frac{\Phi_{pole}}{\Phi_r} = 2\frac{5y+1}{5y^2+5y+1} \tag{2}$$

With y denoting the ratio between the air gap and magnet reluctance

$$y = \frac{R_{\delta,2}}{R_M} = R_{\delta,2}G_M \tag{3}$$

An increase of the number of magnets per pole results in a higher ratio of flux per pole to magnet residual flux $\Phi_{pole}/\Phi_r$.

The dependence of the ratio $\Phi_{pole}/\Phi_r$ on the dimensionless ratio δ/d (Fig. 3) for various numbers of magnets per pole is shown in Fig. 5.

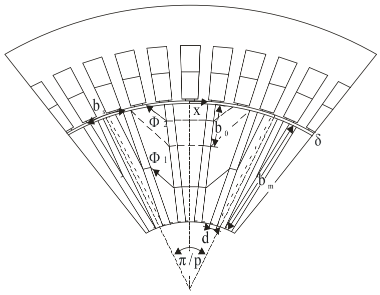

Fig. 3. Cross-sectional view of the PCMM with four magnets per pole

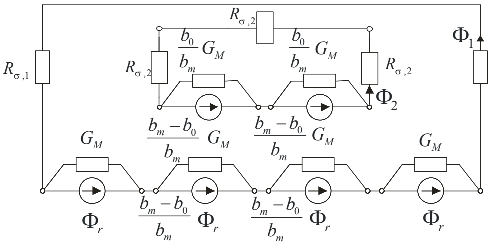

Fig. 4. Magnetic equivalent circuit of proposed model

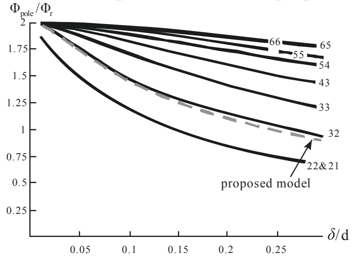

Fig. 5. Relative flux per pole as a function of airgap width to magnet thickness ratio of proposed model

## III. 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 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 [4]. It is natural that M, H which is calculated on the same axis has a same vector direction.

$$M(t) = \iint_{\alpha\geq\beta}\mu(\alpha,\beta)\gamma_{\alpha\beta}(H(t))d\alpha d\beta \tag{4}$$

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

A more convenient treatment of this model is also to substitute the Everett plane for Preisach's one as shown in Eq. (5).

$$E(\alpha,\beta) = \iint_{\alpha\geq\beta}\mu(\alpha,\beta)\gamma_{\alpha\beta}(H(t))d\alpha d\beta \tag{5}$$

In the Everett plane, the distributions of M, which is accepted from experimental data of material S18 and ferrite magnet, are Gaussian ones.

## IV. ALGORITHM OF COMPUTING

### A. Computing Algorithm

Fig. 6 shows the block diagram of whole analysis mechanism. The field-oriented control algorithm with PWM fed inverter is applied to the proposed analysis model for the example of dynamic characteristics and magnet characteristic due to PWM input source, as shown in Fig. 6.

Through the more detailed analysis, the variable performance of the pole changing memory motor will be represented in next extended version.

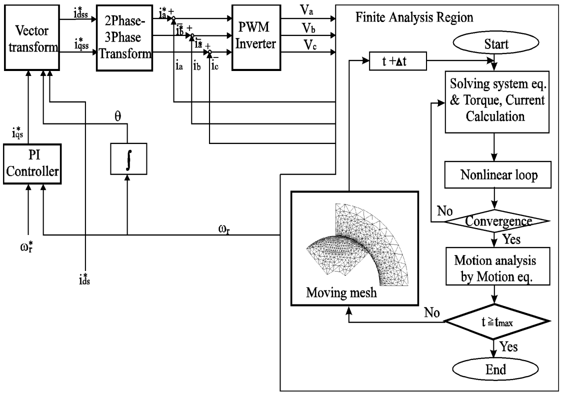

Fig. 6. Block diagram of analysis system

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