Characteristic Analysis Method of Irreversible Demagnetization in Single-phase LSPM Motor

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***Abstract* —This paper presents the effective analysis method of irreversible demagnetization for line-start permanent magnet (LSPM) motor considering magnetic field produced by secondary conductor bars. By using Finite Element Analysis (FEA) in transient magnetic field, currents in primary and secondary conductors are estimated and used for demagnetization analysis in magneto-static field. Therefore closer condition to actual situation can be achieved. General demagnetization analysis using primary currents only and presented analysis methods are compared and verified by experiments.**

***Index Terms*— B-H curve, Demagnetization, Line-start permanent magnet motor**

I. INTRODUCTION

LSPM motors have both conductor bars and permanent magnet (PM) in the rotor. Accordingly, line-start of induction motor (IM) is possible and operation in synchronous speed is possible at steady state by magnetic torque and reluctance torque. Therefore position sensor of general permanent magnet motor for starting and operation is not necessary, and conductor loss of general induction motor is small since LSPM motor operates at synchronous speed in steady state. Consequently, LSPM motor provides lower production cost than general permanent magnet motors and higher efficiency than general induction motors. The application of LSPM motor is suitable for home appliances which require low cost and high efficiency [1]. However, the large current at starting causes irreversible demagnetization of PM [2]. Generally the irreversible demagnetization of PM is decided by the operating point in *B-H* or *M-H* curve of PM when only primary part is excited. However, LSPM motor is operated as IM at starting and magnetic field by secondary conductors produced. This results in the reduced magnetic field acting on PM to be reduced. Therefore general demagnetization analysis leads to the over estimation of magnetic field acting on PM, and results in excessive PM usage.

This paper deals with demagnetization of LSPM motor by considering magnetic field by secondary conductor bars. By using FEA in transient magnetic field, currents in primary and secondary conductors are estimated and used for demagnetization analysis in field. Therefore closer condition to actual situation can be achieved. General demagnetization analysis using primary currents only and presented analysis methods are compared and verified by experiments.

II. STRUCTURE OF SINGLE-PHASE LSPM MOTOR

The configuration and winding connection of a single-phase LSPM motor with rare-earth PM are shown in Fig. 1(a) and (b) respectively. As shown in Fig. 1, both consist of main and subsidiary windings in the stator and conductor bars to produce the starting torque in the rotor. Starting capacitance Cs, running capacitance Cr, and positive temperature coefficient (PTC) are connected with the subsidiary windings to increase the starting torque and power factor. Accordingly, it could be considered as a two-phase motor. The motor has 2-pole rotor with 28-slot stator for household appliance.

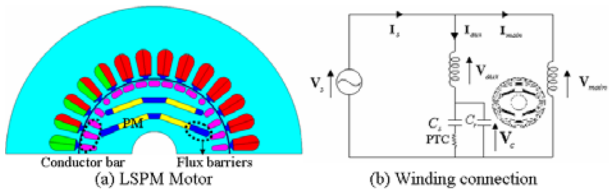


Fig. 1. Single-phase LSPM motor and their stator winding connection

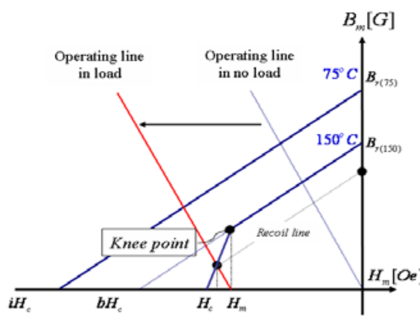


Fig. 2. Characteristic curve of permanent magnet

III. DEMAGNETIZATION OF PM

A. Nonlinear analysis of PM

The demagnetization analysis considers not only nonlinear characteristics of the core but also that of the PM on the B-H curve. Fig.2 shows an irreversible demagnetization curve of rare earth PM magnet each temperature. The equation (1) is approximate equation for Magnetization *M* [3].

$$M = B - \mu_0 f(B) = h(B)\,. \qquad (1)$$

Where H is $f(B)$ and μ_0 is permeability.

B. Calculation of demagnetizing current

On designing the thickness of PM, demagnetizing current is calculated in equation (2).

$$I \le h_m \frac{2}{m} \cdot \frac{\pi}{4} \cdot \frac{2pH_c}{\sqrt{2}Nk_w}\,. \qquad (2)$$

where H_c is coercive force, m is phase number, h_m is PM thickness, p is pole-pair, k_w is a winding factor and N is turn number.

C. Analysis process

General demagnetization analysis method (Method1) using primary currents only and presented analysis method (Method2) for LSPM motor are compared. Initially, irreversible demagnetization current of Method1 is calculated using equation (2) at the TABLE I, and then identical current is used to Method2 in order to consider the effect of secondary conductor bars current on the irreversible demagnetization of PM.

As shown in fig. 3, the analysis process of demagnetization for LSPM motor is as following. Firstly, using transient analysis, currents in primary and secondary conductor bars are estimated. Then calculated currents by transient analysis are applied to irreversible demagnetization analysis in every rotor position considering not only nonlinear characteristic of the core but also that of the PM on the *B-H* carve. When the operating point of PM is below its knee point, the residual flux density of the PM is renewed. Finally, with renewed flux density of the PM elements, no-load back-EMF is calculated. By comparing no-load back-EMF before and after demagnetization field, irreversible demagnetization of PM is determined.

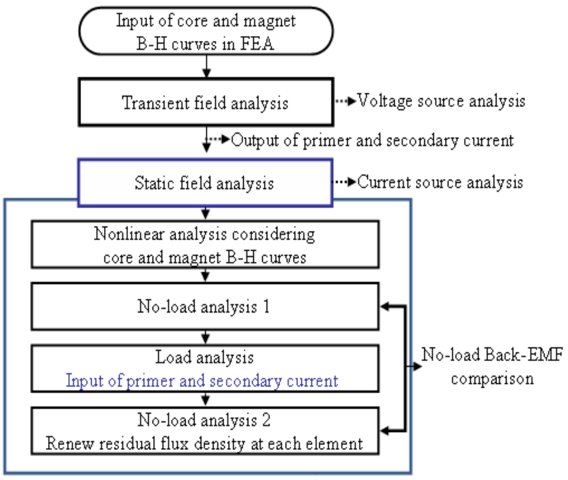


Fig. 3. The process of Method 2

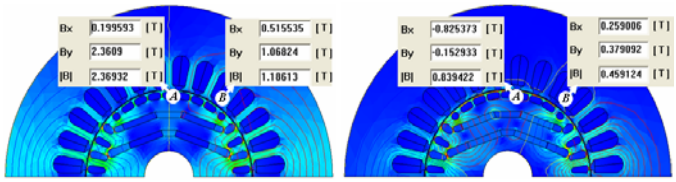
TABLE I
INPUT CURRENT AT THE ROCKED-ROTOR STATE

Temperature [℃]	Magnetizing current [A]	Magnetization ratio [%]
120	60	8.20
150	28	12
165	15	8.81

IV. RESULT AND DISCUSSION

Fig. 4 shows comparison of magnetic flux density from Method1 and Method2 when external demagnetization field is applied. Using Method2, magnetic field by primary current reduced by secondary conductor current can be observed. Experiments are conducted under identical current and temperature conditions. To verify results according to analysis method by the test, DC current is excited in Method1 and AC current is excited in Method 2. Fig. 5 shows the input current and temperature of conductor bars and PM at experiments. As seen in Fig. 6 and TABLE II, using Method1, 8.8% of PM is irreversibly demagnetized from analysis and experimental results. Meanwhile, no irreversible demagnetization occurs with Method2.

The effect of reduced primary field by secondary conductor field is clearly shown, therefore Method2 is closer to actual situation. Using presented analysis method 2, effective estimation of irreversible demagnetization of PM and cost reduction of LSPM motor reasonably can be achieved.



(a) Current density according to Method 1 (b) Current density according to Method 2

Fig. 4. Current density by Method1 and Method 2

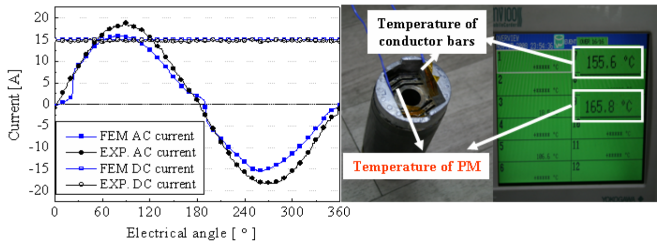
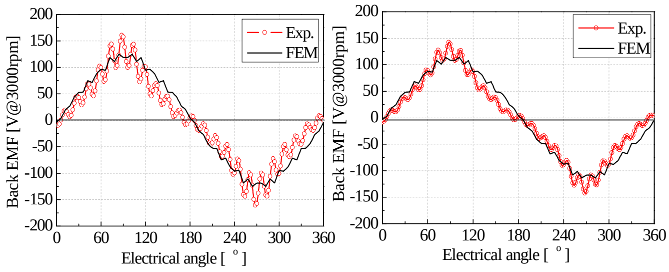


Fig.5. Input current and temperature of PM and conductor bar



(a) Back-EMF before demagnetization (b) Back-EMF after demagnetization

Fig.6. Back EMF comparison of analysis and experiment result

TABLE II
BACK EMF COMPARISON OF ANALYSIS AND EXPERIMENTAL RESULT

	FEM result		Experiments result	
	Method1	Method2	Method1	Method2
Back EMF after demagnetization [V_{rms}]	81.99	81.99	78.42	78.42
Back EMF before demagnetization[V_{rms}]	74.77	81.99	72.35	78.41
Demagnetization ratio [%]	8.80	0.00	7.74	0.00

V. REFERENCES

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