Prediction of Hysteresis Characteristics Using Stress-Dependent Preisach Model and FEM

Jae-han Sim, Jae-woo Jung, Byeong-hwa Lee, Seung-hee Chai, and Jung-pyo Hong
Department of Automotive Engineering, Hanyang University
222 Wangsimni-ro, Seongdong-gu, Seoul 133-791, Korea
E-mail Address : hongjp@hanyang.ac.kr

***Abstract*— Inverse magnetostriction called Villari effect causes the change of the susceptibility of a material when a mechanical stress is exerted to. A housing of electric machines is required for connection and brings about the modification of hysteresis characteristics. This paper presents a method that interpolates hysteresis major and minor loops through stress-dependent Preisach model and Everett function. The model is applied to the post process using finite element methods. In addition, the data obtained from the theories enables to reflect the continuative stress distribution on a motor and the validation is demonstrated by a comparison with experimental results. As a result, it is probable that the corresponding phenomena including hysteresis loss and hysteresis torque are predicted more precisely than the existing resources.**

***Index Terms*—Finite element methods, Hysteresis motors, Magnetic hysteresis, Magnetic materials, Magnetostriction**

I. Introduction

When an external torque is applied to the axle of Permanent Magnet Synchronous Motor (PMSM) with no electrical sources, a torque against it is generated inside the motor. It can be assorted into two groups, cogging torque and hysteresis torque. Physically, the former is an alternating torque in PMSM and the latter is distinguished by an offset of cogging torque [1]. Besides, the two values depend on the figure and the configuration of magnets as well as those of slots and teeth.

Internally, ferromagnetic materials have a structure that is divided into domains, each of which is a region of uniform magnetic polarization. When a magnetic field is applied, the boundaries between the domains shift and the domains rotate; both of these effects cause a change in the material's dimensions. The mutual effect, the change of the susceptibility of a material when subjected to a mechanical stress, is called the Villari effect shown in Fig. 1.

Therefore, a model is required for analyzing the effect in electrical machines such as PMSM and Induction Motor. Known as the best in representing the hysteresis characteristics macroscopically, the Preisach model is a numerical technique handling the phenomenal quantity with data. Furthermore, it makes use of the reciprocal action and the distribution of coercive force density of domains as the input data and memorizes their transition process to consider the magnetostriction [2].

A probability density distribution, or density of a continuous random variable, should be determined to apply the Preisach model for the hysteresis characteristics of a material. In order to avoid a variety of computational procedures and errors from them, this paper aims at predicting the hysteresis characteristics such as hysteresis loop, torque and loss within a range of experiments by Preisach model and Everett function.

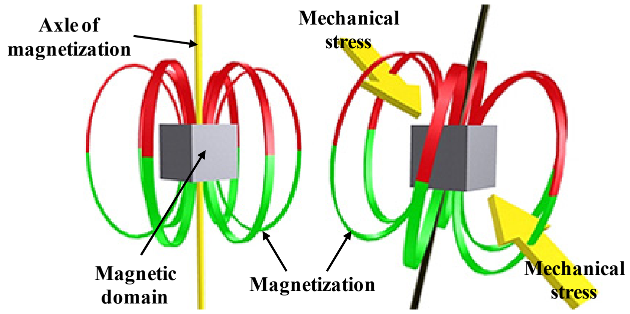

Fig. 1. Villari effect (Inverse magnetostrictive effect)

II. Stress-Dependent Preisach Model

Each magnetic polarization in the domains can be expressed on the plane of H_c and H_u, critical field and interaction field. The basic notion is that all domains are typified by setting up and down fields, H_α and H_β. Moreover, the expected values of probability density distribution $P(H_\alpha, H_\beta)$ define the magnetization value $M(t)$ on the switching field [3]. The relevant equations are expressed in (1), (2), and (3).

$$M(t)=\iint_{H_\alpha, H_\beta} P(H_\alpha,H_\beta)\, g(H_\alpha,H_\beta)\, H(t)\, dH_\alpha dH_\beta \quad (1)$$

$$\gamma(H_\alpha,H_\beta)H(t)=\begin{cases}+1, & if(H_\alpha,H_\beta)\in T^{(+)}\\ -1, & if(H_\alpha,H_\beta)\in T^{(-)}\end{cases} \quad (2)$$

$$M(t)=\iint_{T^{(+)}} P(H_\alpha,H_\beta)\, dH_\alpha dH_\beta - \iint_{T^{(-)}} P(H_\alpha,H_\beta)\, dH_\alpha dH_\beta \quad (3)$$

Where, $\gamma(H_\alpha,H_\beta)H(t)$ is an elementary hysteresis operator, or hysteron in Fig. 2, and $P(H_\alpha,H_\beta)$ is Everett function.

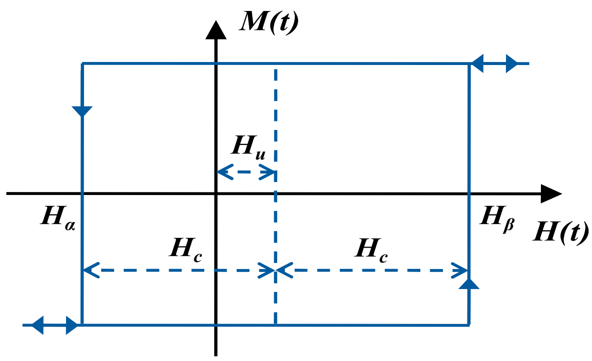

Fig. 2. Elementary hysteresis operator

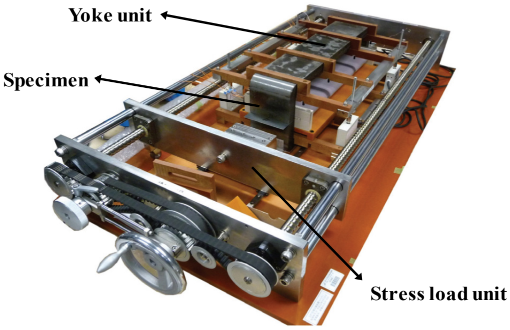

Fig. 3. Stress load type SST (100mm type)

III. Experiment and Prediction

A. Experimental Setup

The measurement is carried under the tensile and compressive stresses on non-oriented electrical steel sheets and amorphous sheet [4]. The measurement is carried out at the center part of the specimen from -30MPa to 30MPa with an interval of 5MPa, which has a uniform magnetic field strength distribution. Finally, the exciting frequency is 50Hz.

B. Comparison between Experiment and Estimation

Obtained using the theories, Preisach model and Everett function, hysteresis loops are estimated at -5, -15, and -25MPa from the above experimental results at 0, -10, -20, -30MPa and compared to verify the validity. In short, (4) and (5) are used in the procedures for calculation.

$$EHNR(I,J) = MHNR(I,1) - MHNR(I,J) \tag{4}$$

$$MHNR(I,J) = MHNR(I,1) - EHNR(I,J) \tag{5}$$

Where, *MHNR* and *MHNR* mean, relatively, the magnetization and Everett function values at each point.

IV. Hysteresis Characteristics

A. Analysis Model

A housing component is attached to the analysis model for connection to a system and brings about a continuous compressive stress distribution on it. Fig. 5 and Table I describe its configuration and specification.

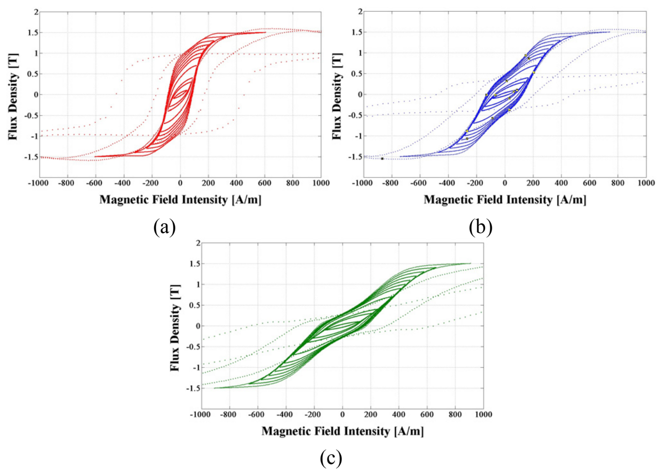

Fig. 4. Hysteresis loops at (a) -5MPa, (b) -15MPa, and (c) -25MPa by theories

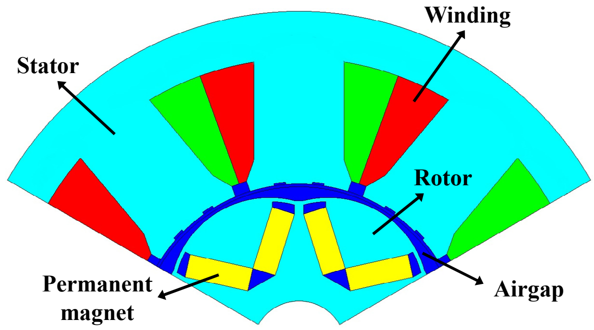

Fig. 5. Configuration of IPMSM for analysis

TABLE I
SPECIFICATION OF ANALYSIS MODEL

Division	Unit	Value
Number of poles	-	6
Number of slots	-	9
Inner / Outer diameter of stator	mm	42 / 86
Inner / Outer diameter of rotor	mm	/ 40.5
Inner / Outer diameter of housing	mm	85.93 / 91
Stack length	mm	50
Stator material	-	35PN440
Residual flux density of PM	T	1.23
Relative permeability of PM	-	1.05

B. Hysteresis loss

It can be computed by the region contoured by a major hysteresis loop under application of stress or force on a motor. The total loss stands for a sum of the area each element has and is expressed by (6).

$$P_{hys} = L_{stack} \times \sum_{i=0}^{N_e} \left[\frac{1}{T}\int_0^T H_m \frac{dB_m}{dt} + H_t \frac{dB_t}{dt}\right]^e \cdot \Delta^e \tag{6}$$

C. Hysteresis torque

The torque is associated with the combination of power and angular speed. It is separated from cogging torque and bearing friction. The results will be presented in the full paper.

V. Conclusion and Future Work

This paper suggests the estimation of comprehensive hysteresis characteristics such as hysteresis loop, hysteresis loss, and hysteresis torque and proves the validity through a comparison with measurement experiment results. In the future, the details about experiment and simulation analyzing the properties will be covered.

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