Magnetic Field Analysis Taking Account of Stress-Dependent Magnetic Properties of Non-Oriented Electrical Steel Sheets

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Abstract — In order to increase reliability of numerical analysis of magnetic fields in electric motors, stress-dependent magnetic properties of non-oriented electrical steel sheet should be examined because the magnetic properties are very sensitive to the stress and are easily deteriorated. This paper describes the effect of stress-dependent properties on the operating characteristics of a typical IPM motor.

I. INTRODUCTION

Progress of numerical analysis of magnetic fields enables us to investigate complicated operating characteristics of electrical machines [1], [2]. In recent years, the analyses of electric motors are vigorously carried out because of development of electric vehicles. It is said that expected improvement of efficiency is not achieved when the core material is changed from a lower-grade electrical steel sheet to a higher-grade one. One of the principal reasons may be deterioration of magnetic properties due to stress [3] imposed at manufacturing process such as cut by punching and shrink fit. Therefore, it is fairly important to model stress-dependent magnetic properties to make the analysis more reliable.

In this paper, stress-dependent magnetic properties of a typical non-oriented electrical sheet are examined. Then, they are applied to the magnetic field analysis of a typical IPM motor to demonstrate the effectiveness of a proposed strategy.

II. STRESS DEPENDENT MAGNETIC PROPERTIES

A. Measuring Equipment

Fig. 1 shows the schematic diagram of a single sheet tester [4] equipped with mechanics for stress application of both tension and compression. In order to get magnetic properties appropriate to the magnetic field analysis, the double H-coil method [5] is adopted to evaluate the magnetic field strength. It is confirmed that the current equipment can apply the stress from 100 MPa (tension) to -90 MPa (compression) to a single sheet specimen of various non-oriented electrical steels with the thickness of 0.5 mm.

B. Magnetic Properties

Magnetic properties of a typical non-oriented electrical steel sheet are measured, which is JIS grade 50A350 (thickness: 0.5 mm, $W_{15/50}$ (iron loss at 1.5 T and 50 Hz) ≤ 3.50 W/kg). The direction of stress application is the same as that of magnetization.

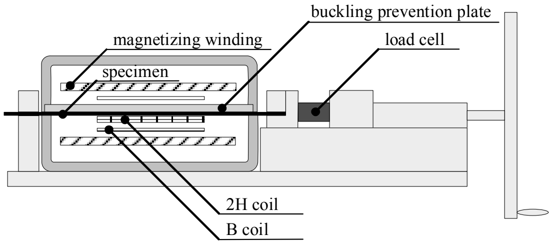
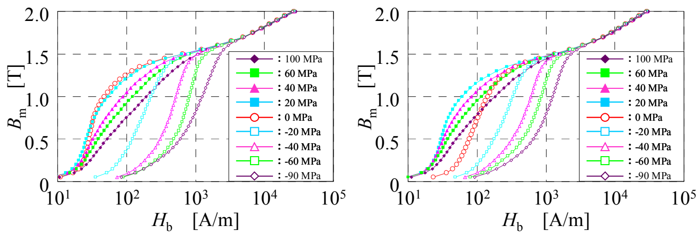
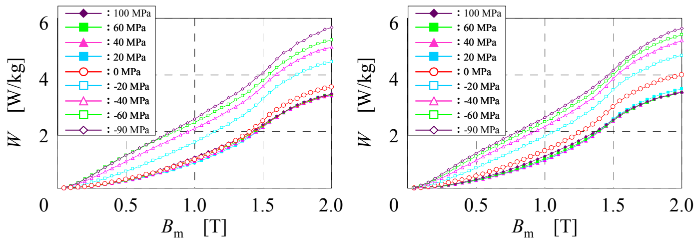


Fig. 1. Schematic diagram of a single sheet tester equipped with mechanics for stress application.



(a) rolling direction (b) transverse direction
Fig. 2. Magnetization property:



(a) rolling direction (b) transverse direction
Fig. 3. Iron loss property.

Fig. 2 shows the magnetization property (B_m: the maximum flux density, H_b: the magnetic field strength at the instance of B_m). When the stress is not applied (σ = 0 MPa), the magnetization property in the rolling direction is obviously different from that in the transverse direction. When the stress is applied, the difference becomes smaller. Especially in the case of tensile-stress application, the magnetization property in the transverse direction is improved under a certain condition as shown in (b).

Fig. 3 shows the iron loss property. The compressive-stress application increases the iron loss both in the rolling direction and in the transverse direction. In the rolling direction, the tension is not sensitive to the change of iron loss as shown in (a). In the transverse direction, however, the tension decreases the iron loss as shown in (b).

III. NUMERICAL ANALYSIS

A. Analyzed Model

Fig. 4 shows the analyzed model of typical IPM motor. It has been proposed by a technical committee on numerical analysis of magnetic fields in rotating machines established in the Institute of Electrical Engineers of Japan (IEEJ) [6]. TABLE I shows the analyzed conditions.

Fig. 5 shows an example of residual stress distributions measured by means of the X-ray technique at Enokizono laboratory (Oita University) [7]. Although the measured model is different from the model analyzed in this paper, these results are referred when determining the magnetic properties to be assigned to magnetic material regions. Fig. 6 shows the stress levels estimated from Fig. 5. The magnetic properties with the tensile stress of 60 MPa are assigned to the edge region cut by punching. The width is set at twice of the thickness of electrical steel sheet. In the other regions, the compressive stress of -20 MPa, -40 MPa and -60 MPa is assigned and the effect of its level is investigated.

As the magnetic properties assigned to magnetic material regions, the average properties of the rolling and transverse directions are used.

B. Numerical Results

The distribution of flux density near the teeth is obviously changed by the stress application. Its change gives the large increase of iron loss. The hysteresis loss is more sensitive to the stress than the eddy current loss as shown in TABLE II.

Fig. 7 shows the load torque. The change in the maximum value due to the stress is about 2.55 %.

The effect of stress-dependent magnetic properties of various grades on machine characteristics will be reported in the full paper.

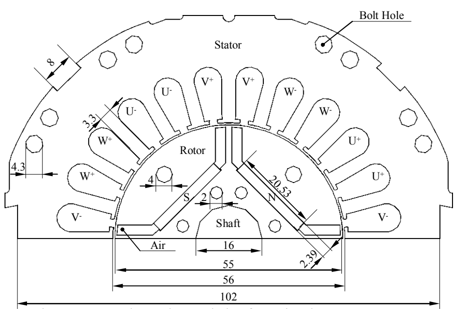


Fig. 4. Analyzed model of typical IPM motor.

TABLE I
ANALYZED CONDITIONS.

material of core		50A350
material of shaft		S45C
magnet	B_r [T]	1.25
	H_c [kA/m]	947.4
	μ_s	1.05
current phase [deg]		0 - 80
number of nodes		12,852
number of elements		24,818

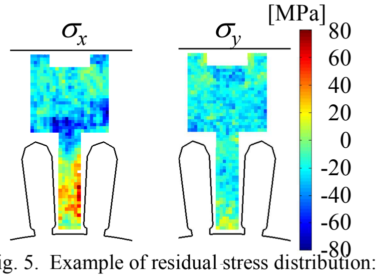


Fig. 5. Example of residual stress distribution:

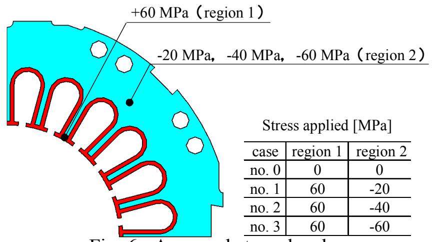


Fig. 6. Assumed stress level.

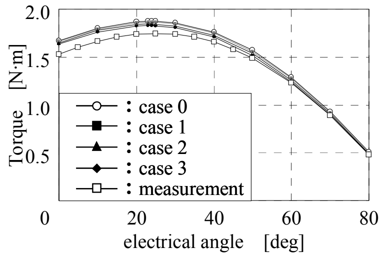


Fig. 7. Load torque.

TABLE II
HYSTRESIS LOSS AND EDDY CURRENT LOSS.

case		no. 0	no. 1	no. 2	no. 3
W_h [W]	stator	2.19	2.85	3.61	4.00
	rotor	0.09	0.08	0.08	0.08
	sum	2.28	2.93	3.69	4.07
W_e [W]	stator	1.22	1.52	1.74	1.86
	rotor	0.33	0.32	0.31	0.30
	sum	1.55	1.84	2.06	2.16

IV. REFERENCES

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