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Analysis for Mechanical Properties of Spiral Accumulating Core Used for Permanent Magnet Motor

Nao-Aki NODA[1,a], Biao ZHANG[2,b], Kazuhiko YONEMARU[1,c]
Shota HIGO[1,d] and Yoshihiro TAKAMATU[1,e]
[1] Department of Mechanical Engineering, Kyushu Institute of Technology,
1-1 Sensui-cho, Tobata-ku,Kitakyushu, 804-8550 Japan
[2] Department of Mechanical Engineering, Kyushu Institute of Technology,
1-1 Sensui-cho, Tobata-ku,Kitakyushu, 804-8550 China
[a] noda@mech.kyutech.ac.jp, [b] f344156h@tobata.isc.kyutech.ac.jp
[c] f344156h@tobata.isc.kyutech.ac.jp, [d] f344156h@tobata.isc.kyutech.ac.jp
[e] f344156h@tobata.isc.kyutech.ac.jp

Key words: spiral, accumulating, finite element method, bending, deterioration

Abstract. Recently, permanent magnet motors are widely used in many industrial fields because they are suitable for compact mechanical system. The motor core is usually manufactured from magnetic steel sheet with press machine. However, usually most parts of the plate are scraped, and only small percent of the sheet is used for the core. The spiral accumulating core system is suitable for manufacturing the core more ecologically because in this system more than 50% of the magnet steel sheet can be used. In this study, therefore, the effective Young's modulus of the spiral accumulating core is considered in order to find out a good method to fix the core. In this analysis, the finite element method is applied to 3D models, whose layers and slits are periodically arranged. Stress and thickness distributions are also analyzed in the bending process. When the spiral core is manufactured through spiral accumulating system with plate-bending process, the thickness change should be minimized because that may deteriorate dimensional accuracy of the spiral core. Also residual bending stress is investigated because that may cause an electric loss. The results indicate that plastic zone is limited at localized regions and therefore an electric loss is not very large. The effective Young's modulus of the 3D dimensions model of the real spiral accumulating core is estimated about 127.5 GPa.

Introduction

The PM synchronous motor is a rotating electric machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface-mounted permanent magnets. Recently, permanent magnet motors are widely used in wide industrial fields because they are suitable for compact mechanical system. The motor core is usually manufactured from magnetic steel sheet with press machine. However, usually most parts of the plate are scalped, and only small percent of the sheet is used for the core. The spiral accumulating core system is suitable for manufacturing the core more ecologically because in this system more than 50% of the magnet steel sheet can be used (see Fig.1).

In this study, therefore, the effective Young's modulus of the spiral accumulating core is considered in order to find out a good method to fix the core. In this analysis, the finite element method is applied to 3D models, whose layers and slits are periodically arranged. Also stress distributions and thickness changes will be analyzed at the bending process. When the spiral core is manufactured through spiral accumulating system with plate-bending process, the thickness change should be minimized because that may cause deterioration of the dimensional accuracy of the spiral core. Also residual bending stress is investigated because that may cause an electric loss.

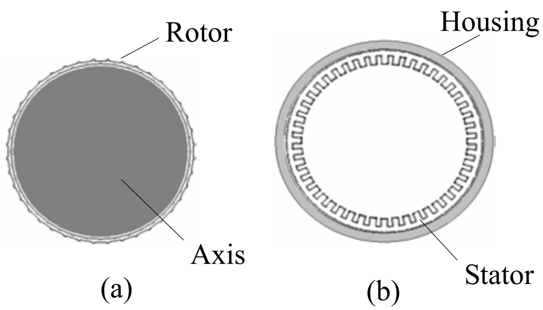
Method of analysis

Figure 2 shows (a) Axis and Rotor and (b) Housing and stator after shrink fitting. The compressive stress always acts in the direction of the circumference when the stator is fixed on the outside housing. Since the slit sustains the compressive stress, there is little effect on the Young's modulus. However, when the rotor is fixed on the axis, the tensile stress appears in the circumference direction. Therefore it is necessary to analyze the effective Young's modulus for rotor in order to fix it properly. Figure 3 shows three types of layers. Assume three layers are in the range of $\theta =$ 0° □ 90° (see Fig.3). For example, each layer of core shape in the range of 90° □ 180° coincide with that in the range of 0° □ 90°. The fourth layer is the same as the first layer. In this study, the effective Young's modulus of the spiral accumulating core is evaluated by applying the finite element method to this model.

Figure 4 shows the example of FEM mesh for 3D model. In this study, the linear hexahedron element is used. The total number of elements is 60450, and total number of nodes is 77868. Figure 5 shows the boundary condition of the model. As shown in Fig.5, the displacement in the y direction at $\theta = 0^{\circ}$ is fixed, and displacement in the x direction at $\theta = 90^{\circ}$ is fixed, that is, $u_x=u_y=0$ at $\theta=0,90^{\circ}$. The displacement in the z direction is fixed at the top and bottom surface of the 1st layer and of the 3rd layer, that is $u_z=0$ at the top and bottom surfaces. Then the constant displacement in the r-direction $u_r=\Delta R$ is given at $r = R$.

The effective Young's modulus of the 3D dimensions model is given by Eqs. (1). In Fig.6, $\sigma_{\theta 1}$, $\sigma_{\theta 2}$, $\sigma_{\theta 3}$ are the average stress of first layer, second layer and third layer of the model respectively, the stress $\sigma_{\theta av}$ is the average stress of three layer accumulating model, and ε_{θ} is a strain of the

Fig.1 Automatic spiral accumulating



(a) (b)

Fig.2 Shrink fit for (a) rotor and (b) stator

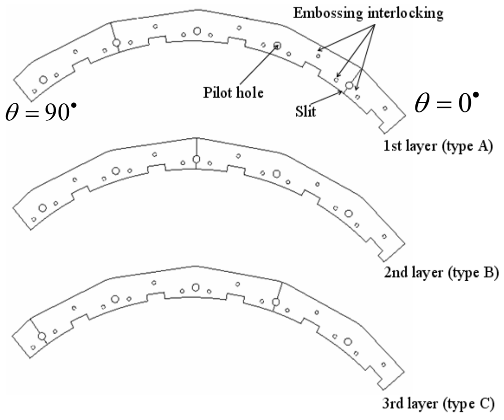


Fig.3 Three types of layers

$$E^* = \frac{\sigma_{\theta av}}{\varepsilon_\theta} = \frac{\sigma_{\theta 1}+\sigma_{\theta 2}+\sigma_{\theta 3}}{3(\Delta R/R)} \quad \ldots(1)$$

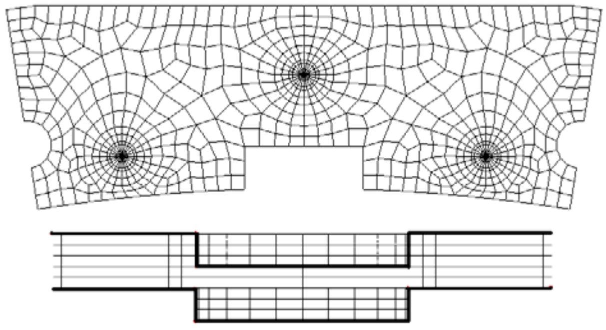


Fig.4 Example of FEM mesh for 3D model

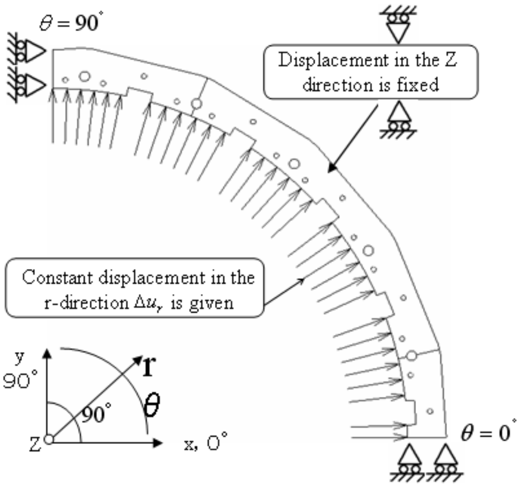


Fig.5 Boundary conditions of the model

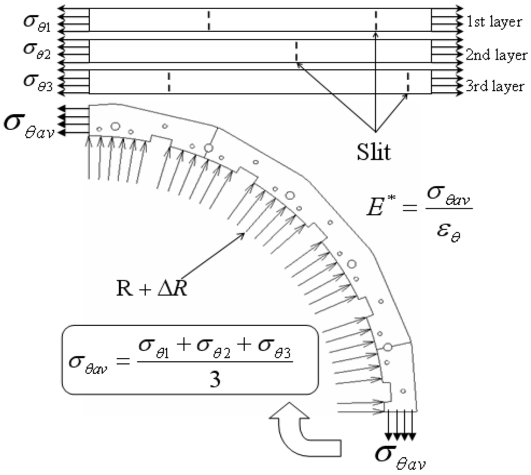


Fig.6 Method of analysis

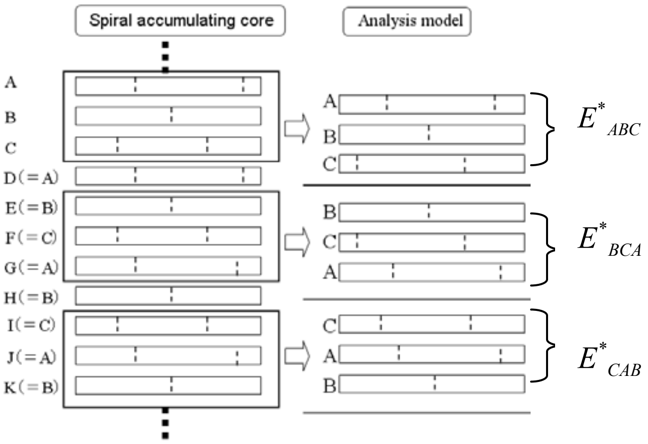


Fig.7 Three kinds of models analyzed

direction of θ, and the value is equal to the strain value of the direction of R. Moreover, R is a radius in the core, and ΔR is constant displacement in the radial direction.

Results and discussion

Three kinds of models are analyzed as shown in Fig.7. The effective Young's modulus of three kinds of model are E^*_{ABC} = 124.5 GPa, E^*_{BCA} = 129.6 GPa, E^*_{CAB} = 128.4 GPa. The average effective Young's modulus is E^*_{av} = 127.5 GPa. Since periodic conditions at the top and bottom surfaces can't be applied, the results are slightly different.

Figures 8 and 9 show the thickness distributions after the spiral accumulating core is bended. When the rotor and stator are subjected to the bending stress, the largest thickness change appears at y=0, and y=0.7 mm. The difference of the thickness between FEM and experiment results is less than 0.02mm. Figures 10 and 11 show the thickness distributions in the section A-A' in Fig.8 and Fig.9. Figure 12 and 13 show the equivalent stress over the yield stress σ_{yield} for stator and rotor at the plasticity zone after bending. The results indicate that plastic zone is limited at the localized region and therefore an electric loss is not very large.

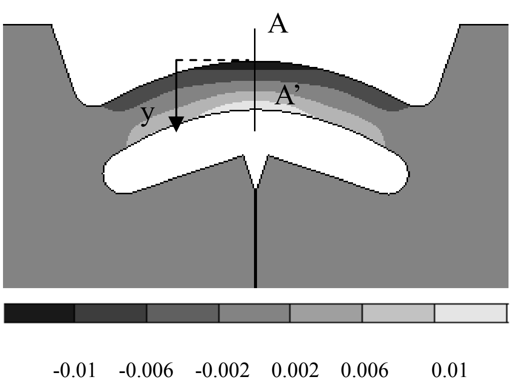


Fig.8 Thickness distribution

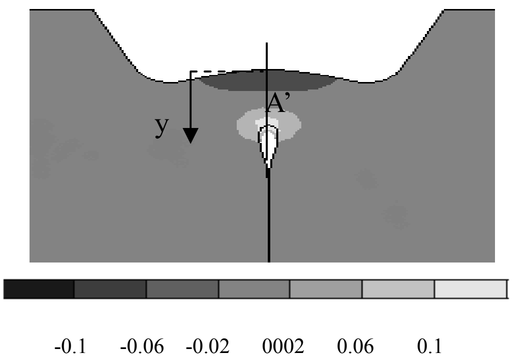


Fig.9 Thickness distribution

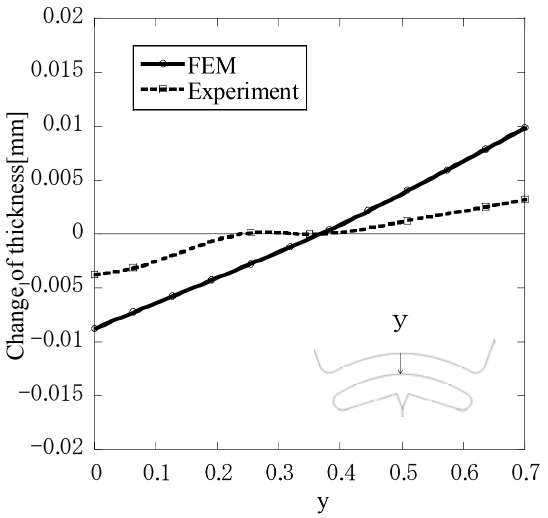


Fig.10 Thickness distribution at A-A'

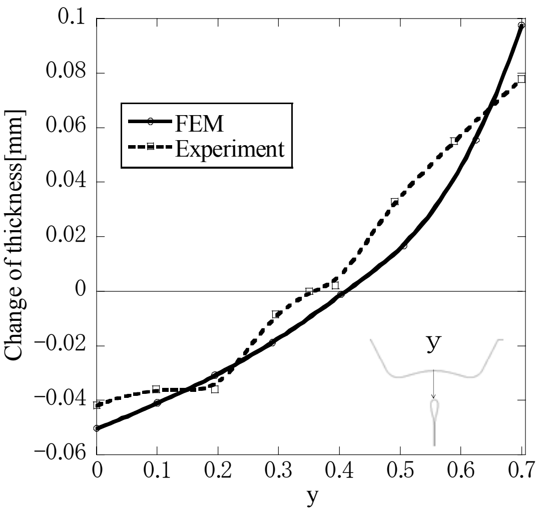


Fig.11 Thickness distribution at A-A'

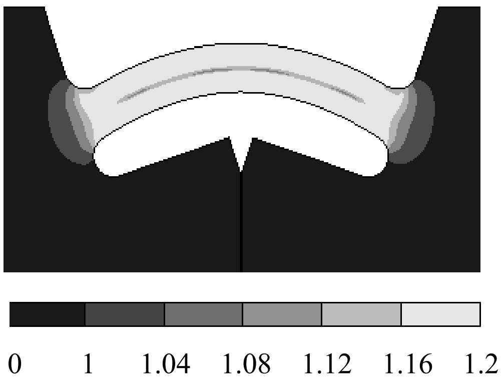


Fig.12 $\sigma_{eq} / \sigma_{yield}$ in stator

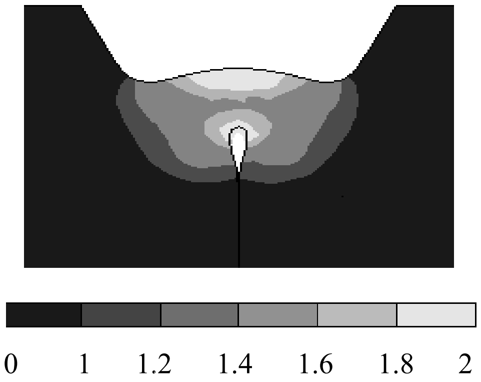


Fig.13 $\sigma_{eq} / \sigma_{yield}$ in rotor

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