Compumag 2011

12 - 15 July 2011, Sydney, Australia

18th International Conference on the Computation of Electromagnetic Fields

(www.compumag2011.com)

TECHNICAL PROGRAM

(Draft on 22 June 2011)

PC10.14 (ID 771)
Design Criteria of Active Thrust Magnetic Bearing Using Improved Equivalent Magnetic Circuit Method and Finite Element Method
Jang, Seok-Myeong (1); Kim, Kwan-ho (1); Ko, Kyoung-Jin (1); Choi, Ji-Hwan (1); Sung, So-Young (2); Lee, Yong-Bok (3)
1: Chungnam National University, Korea, South (Republic of); 2: Korea Ocean Research & Development Institute, Korea, South (Republic of); 3: Korea Institute of Science and Technology, Korea, South (Republic of)

PC10.15 (ID 776)
Improved Design to Reduce Eddy Current Loss in Retain Ring in Superconducting Machines
Lee, Sang-Ho; Hong, Jung-Pyo
Hanyang University, Korea, South (Republic of)

Session PC11: Static Fields and Quasi-Static Fields (VI)
16:15-17:30 – Bayside Gallery

PC11.11 (ID 715)
Numerical Identification of Effective Multipole Moments of Polarizable Particles
Ogbi, Abdellah (1); Nicolas, Laurent (1); Perrussel, Ronan (1); Salon, Sheppard J. (2); Voyer, Damien (1)
1: Laboratoire Ampère (CNRS UMR5005); 2: Rensselaer Polytechnic Institute

PC11.12 (ID 733)
Considering Laminated Cores and Eddy Currents in 2D and 3D FE Simulation of Electrical Machines
Gyselinck, Johan (1); Geuzaine, Christophe (2); Sabariego, Ruth (2)
1: Université Libre de Bruxelles (ULB), Belgium; 2: University of Liège (ULg), Belgium

PC11.13 (ID 778)
Asymmetrical Arrangement of Coils in an Induction Heater to Improve Heat Distribution
Shi, Zhanghai (1); Cheng, K. W. E. (1); Xu, Wei (2)
1: Hong Kong Polytechnic University, Hong Kong S.A.R. - China; 2: University of Technology, Sydney

PC11.14 (ID 796)
Comparison of a Direct and a Vector Potential Integral Equation Method
Albert, Jan; Banucu, Remus; Reinauer, Veronika; Scheiblich, Christian; Rucker, Wolfgang
Institute for Theory of Electrical Engineering, Germany

PC11.16 (ID 810)
Conformal Mapping: Schwarz-Christoffel Method for Flux-Switching PM Machines
Ilhan, Esin; Motoasca, Emilia; Paulides, Johan; Lomonova, Elena
Technical University of Eindhoven, Netherlands, The

PC11.17 (ID 816)
Approaches for Lightning Return Stroke Current Reconstruction
Ceclan, Andrei
Technical University of Cluj-Napoca, Romania

Reduction Design of Eddy Current Loss in Retain Ring in Superconducting Machines

Sang-Ho Lee, Jae-Woo Jung, Jung-Pyo Hong, *Senior Member, IEEE*

Department of Automotive Engineering, Hanyang University, Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea

This paper describes the reduction method of eddy current loss generated into a retaining ring installed in wound-field superconducting machine. In order to suggest the reduction method of eddy current loss of the retaining ring, this paper is divided into three parts. Firstly, eddy current loss of prototype model is calculated. Secondly, eddy current loss versus material and shape of the retaining ring is compared. Finally, the material and the shape of the retaining ring to reduce coupling loss generated by a time-varying magnetic field are proposed. In this paper, eddy current loss is calculated by 3-dimensional transient analysis.

Index Terms— Eddy Current, Retain ring, Superconducting machine.

I. INTRODUCTION

In the design of superconducting machine with high efficiency, accurate prediction of losses such as copper loss, core loss, mechanical loss, and stray load loss is very important. Due to the complexity of magnetic geometries, it is difficult to find a general analytical solution to reduce the eddy current loss [1]. In addition, the resultant eddy current loss causes a substantial temperature rise for having relatively high electrical conductivity [2].

In order to fix stator which is laminated structure by using silicon steel sheet with 0.5 mm of thickness along the axial direction in a wound-field superconducting machine, a retain ring used to magnetic or non-magnetic materials. However, leakage flux, which is generated at the end-turns of filed winding in the wound-field superconducting machine which has not a magnetic core in both stator and rotor, is higher than that of general electric machine [3]. Therefore, the leakage flux has affect on the retain ring. Although field current is direct current, field winding in rotor is rotated in operation condition. Accordingly, flux density at the retain ring versus rotor position is changed and then, this phenomenon generates the eddy-current loss in retain ring. As the result of the eddy-current loss in retain ring, performance of superconducting machine is downed and thermal problem occurs. In addition, additional cooling system is required.

This paper deals with an improved design to reduce the eddy-current loss in retain ring. Firstly, 3-dimensional (3D) transient analysis versus materials under the same retain ring shape is performed. Secondly, distribution and quantity of eddy current are compared and optimal selection of the material to manufacture the retain ring is suggested. Finally, the shape of retain ring to reduce the eddy-current loss is suggested. This study will be usefully used to decide the material and the shape of retain ring.

II. THEORY

Generally, if the transition of flux density is periodically changed by basic frequency, general equation reflecting hysteresis and eddy current coefficient is expressed as follow:

$$w = B^2 \left\{ \sigma_H \left(\frac{f}{100} \right) + \sigma_E d^2 \left(\frac{f}{100} \right)^2 \right\} [W/kg] \quad (1)$$

where, w is the core loss per unit weight, B is the flux-density of magnetic core, σ_H is the loss coefficient of hysteresis, σ_E is the loss coefficient of eddy current, f is frequency, and d is thickness of magnetic core for alternating field.

III. PROTOTYPE MODEL

The wound field superconducting machine, it so-called prototype model, which has not magnetic core in both stator and rotor, has 6 poles and 72 slots. It is operated by sine-wave method and its nominal operating speed range is about 200~400 rpm and rated torque is 160 kNm at 300 rpm.

Fig. 1 shows the configuration of prototype model about the stator of machine. The retain ring is located at the end of stator along z-axis direction and it is divided into 4 segments. In addition, it is manufactured by SS 400 material. The main function of the retain ring is to fix the stator laminated by silicon steel along the z-axis direction in superconducting machine.
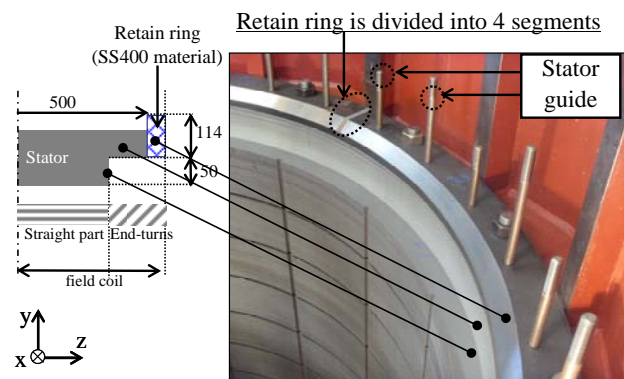

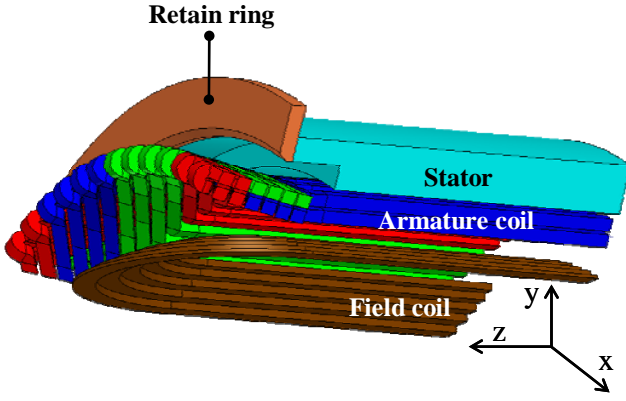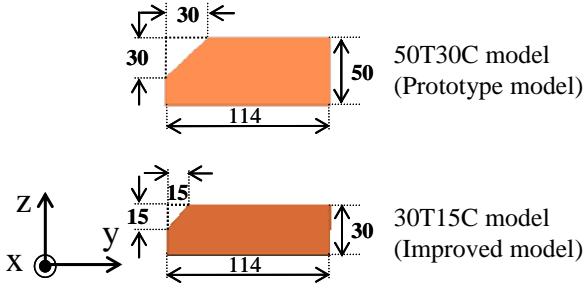Fig. 1. Configuration of prototype model

Fig. 2. Analysis model

50T30C model
(Prototype model)

30T15C model
(Improved model)
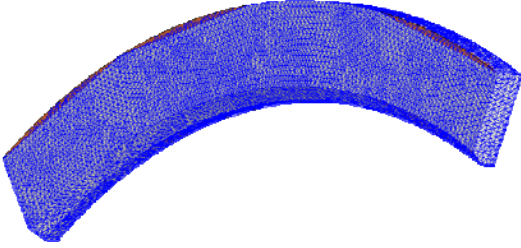
Fig. 3. Cross section view of retain ring
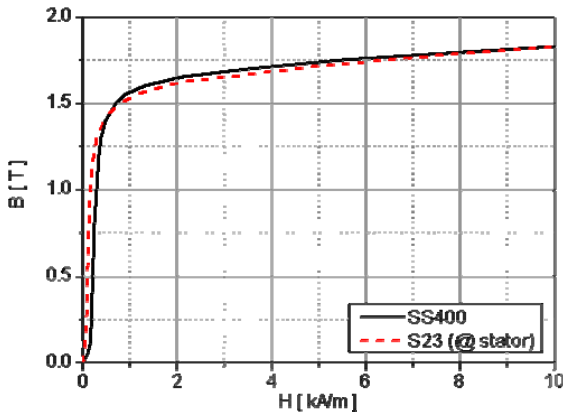

Fig. 4. Mesh generation

Fig. 5. B-H curve

IV. ANALYSIS METHOD

Analysis model, which is to calculate the eddy-current loss generated from retain ring, is shown in Fig. 2. The eddy-current loss is calculated by time transient analysis based on 3D finite element analysis (FEA). In order to reduce computation time for calculation of the eddy-current loss, the analysis model only considers one pole part using boundary conditions. In addition, a half part along z-axis direction is

considered. Therefore, magnetic circuit of retain ring assumes short connection. However, retain ring in prototype model is divided into 4 segments. Accordingly, calculated the eddy-current loss in retain ring is less than that of prototype model.

Fig. 3 shows the cross section view of retain ring in prototype model. The dimension of chamfer in left side is decided by manufacture of armature coil. In order to know effects of shape of the retain ring, investigated model, which thickness is reduced 20 mm along z-axis direction, is also described in Fig. 3. However, thickness along y-axis direction is constant because mechanical stability of stator laminated by silicon steel is demanded.

Mesh generation for the retain ring in prototype model is shown in Fig. 4. When the eddy-current loss is calculated, mesh generation should be considered skin effect which is related with conductivity, permeability, operating frequency, and so forth. Mesh generation considered skin effect reduces the computation time for the calculation of eddy-current loss.

TABLE I
MATERIAL PROPERTIES.

	SS 400	SUS 316L	S23 (50PN600)
Conductivity [S/m]	7.5×10^6	1.3×10^6	2.9×10^6
Relative permeability	@ Fig. 5.	1.008	@ Fig. 5.

Table I and Fig. 5 show material properties and B-H characteristics which are used to manufacture the retain ring. As the material of retain ring of prototype model, relative permeability of SS 400 is quite similar to 50PN600 which is used to manufacture the stator of superconducting machine. Therefore, flux density and the conductivity of retain ring are higher than 50PN600. In addition, the retain ring is not manufactured by lamination structure. Accordingly, the eddy-current loss which is related with transition of flux variation and thickness of magnetic material is generated.

In order to compare with the effect of material of the retain ring, SUS 316L, which has low conductivity and has similar relative permeability of air, is considered.

Considering 50T30C model, Fig. 6 shows the flux and eddy current distribution versus material of retain ring under no-load condition. When the material of retain ring is SS400, direction of main flux path in retain ring is azimuthal angle which is the same as of the flux direction in stator. Therefore, paths of eddy current induce perpendicular direction for the azimuthal angle. When the material of retain ring is SUS 316L, direction of main flux path in the retain ring is z-axis direction. The paths of eddy current are changed by the effect of leakage flux which is generated by end-turns of field winding. In addition, flux density of retain ring is very lower than that of SS400 and eddy current loss is reduced.
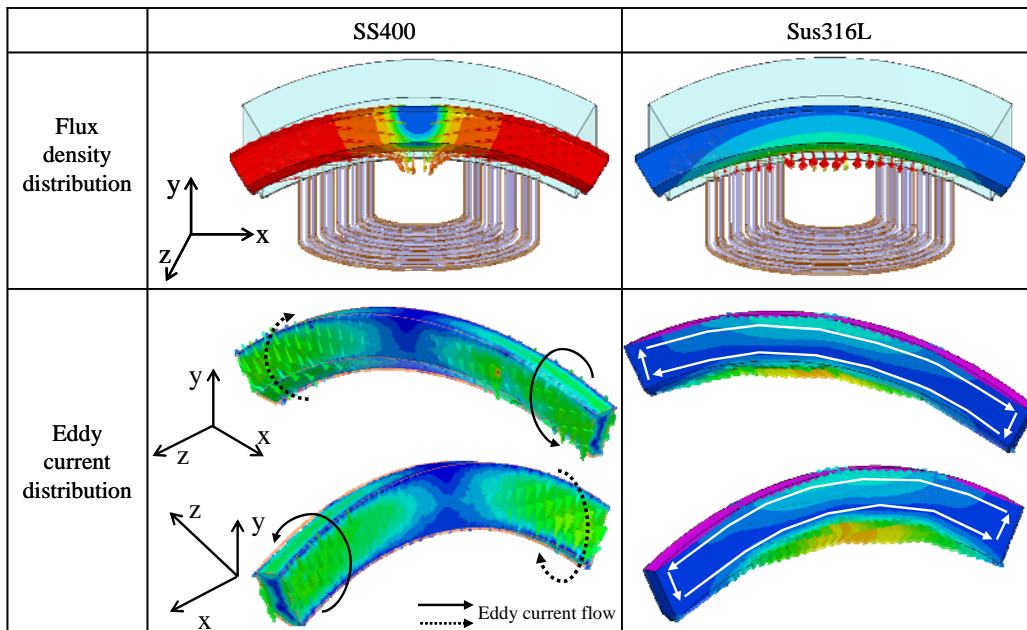
Fig. 6. Flux and eddy current distribution in retain ring versus material (@ 50T30C model, no-load condition)
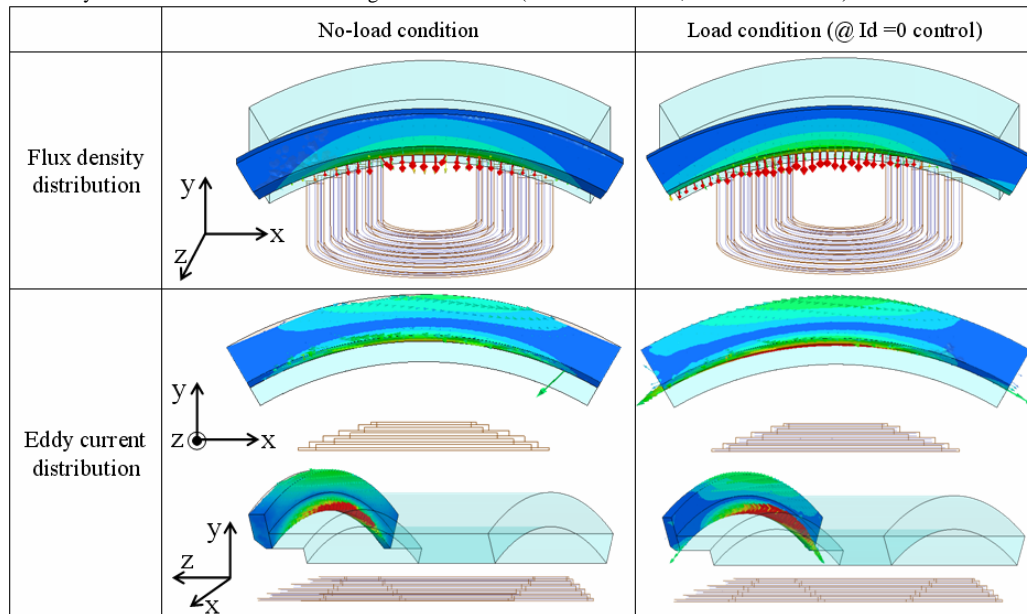

Fig. 7. Flux and eddy current distribution in retain ring versus operating condition (@ 50T30C model, SUS 316L)

In order to compare the effect of armature reaction, the flux and eddy current distribution versus operating condition for 50T30C model and SUS 316L are shown in Fig. 7. The expectation amplitude of flux and eddy current generated by the armature reaction, field distribution according to load condition, which is operated by Id = 0 control method, is really similar compared with no-load condition control compared with no-load condition.

3D FEA results regarding the eddy-current loss versus material and shape of retain ring are shown in Fig. 8 and Fig 9.

Fig. 8 shows the eddy-current losses versus material of the retain ring under no-load condition for 50T30C model, it is so-called prototype model. When the material of the retain ring is changed from SS400 to SUS 316L, the quantity of eddy current loss under no-load condition is reduced by 83% and

then, the eddy-current loss in the retain ring is 41.3 kW.

The value occupies 0.8% of the rated output power of 5 MW superconducting motor. The target efficiency of 5 MW superconducting motor is more than 97%. Because the summation of copper loss by armature coil and core loss at the stator under rated operating condition occupies 2.1% of rated output, the reduction of eddy current loss in retain ring using 30T15C model is necessary. From the result of Fig. 8, low conductivity and relative permeability having materials are suitable for reduce eddy current loss of retain ring.

Fig. 9 shows the eddy current losses versus shape of retain ring and operating condition. When the material of the retain ring is SUS 316L for 30T10C model, the quantities of eddy current loss under no-load and load condition are 4.8 kW and 5.5 kW, respectively. The value occupies about 0.1% of rated

output power of 5 MW superconducting motor. Although eddy current loss of improve model is reduced compared with prototype model, cooling using fan is applied.

From the results of the eddy current losses versus the material, the shape, and operating condition, suggested configuration of retain ring to reduce the eddy-current loss is shown in Fig. 10. In order to reduce the eddy-current loss generated at the retain ring, the dimension of chamfer in left side which is decided by manufacture of armature coil is increased. In addition, the thickness along z-axis direction is decreased.

V. CONCLUSIONS

This paper deals with the calculation of eddy-current loss of retain ring versus the material, the shape, and operating condition in superconducting machine.

When the material of the retain ring is SS400, the quantity of eddy current loss under no-load condition occupies about 4.9% and this value is not satisfy the efficiency of rated output of 5 MW superconducting machine. Therefore, the material of retain ring is changed from SS400 to SUS 316L. In addition, the thickness of retain ring and the dimension of chamfer should be reduced and increased, respectively

REFERENCES

[1] Xi Nan, C. R. Sullivan, "Simplified High-Accuracy Calculation of Eddy Current Losses in Round-wire Windings," *IEEE Power Electronics Specialists Conference*, pp.873-879, June 2004.
[2] Dahaman Ishak, A. Q. Zhu, and David Howe, "Eddy Current Loss in the Rotor Magnets of PM Brushless Machines having a Fractional Number of Slots per Pole," *IEEE Trans. Magn.,* vol. 41, no. 9, pp.2462-2469, Sept. 2005.
[3] Sang-Ho Lee, Jung-Pyo Hong, Ji-Young Lee, et al., "Parametric Design for Superconducting Synchronous Motor with 3D EMCN Model," *IEEE Trans. Appl. Supercond.*, vol. 17, no. 2, pp.1541-1544, June 2007.
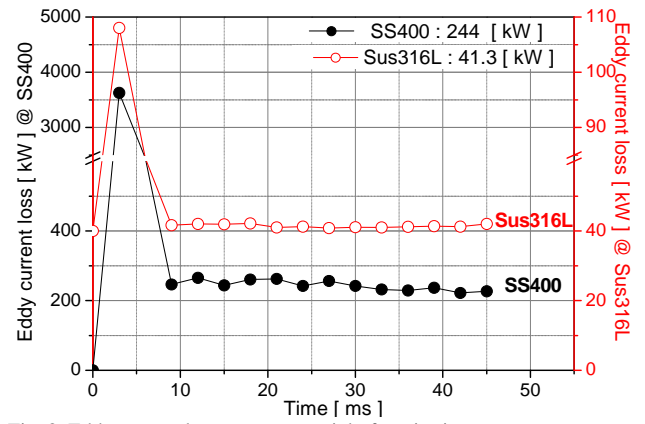

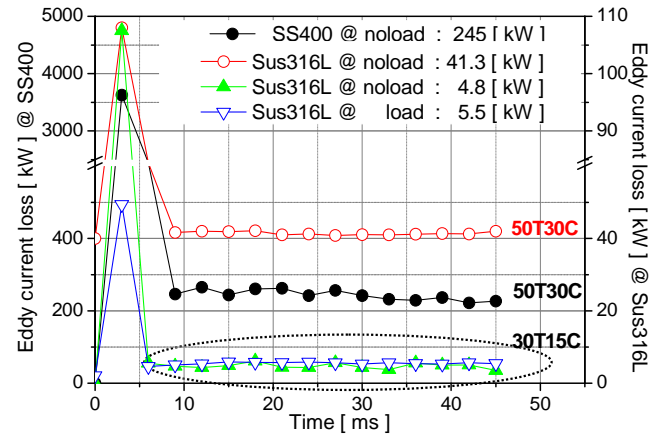Fig. 8. Eddy current loss versus material of retain ring

Fig. 9. Eddy current loss according to shape of retain ring and operating condition.
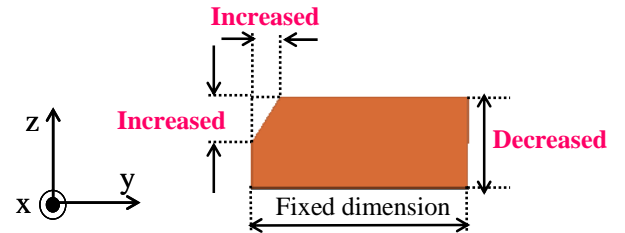

Fig. 10. Suggested configuration of retain ring to reduce eddy current loss