Improved Design to reduce Eddy Current Loss in Retain Ring in Superconducting Machines

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Abstract — This paper deals with the reduction of eddy current loss of retain ring in wound-field superconducting machine. In order to suggest the reduction method of eddy current loss of retain 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 retain ring is compared. Finally, the material and the shape of retain ring to reduced are proposed. In this paper, eddy current loss is calculated by 3-dimensional transient analysis.

I. Introduction

In the design of superconducting machine of 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 for 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 using silicon steel along axial direction in wound-field superconducting machine, retain ring used to magnetic or non-magnetic materials. However, leakage flux, which is generated from end-turns of filed winding in wound-field superconducting machine which has no magnetic core in both stator and rotor, is higher than that of general electric machine [3]. Therefore, leakage flux affects 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 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 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 selection method the material of 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.

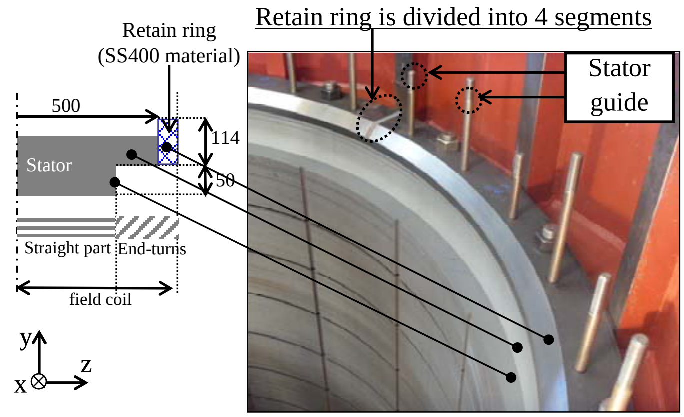

Fig. 1. Configuration of prototype model

II. Prototype Model

The wound field superconducting machine, it so-called prototype model, which has no 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. 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.

III. 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, 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.

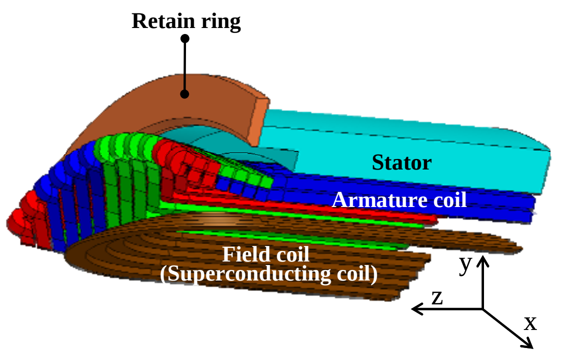

Fig. 2. Analysis model (1/12 model)

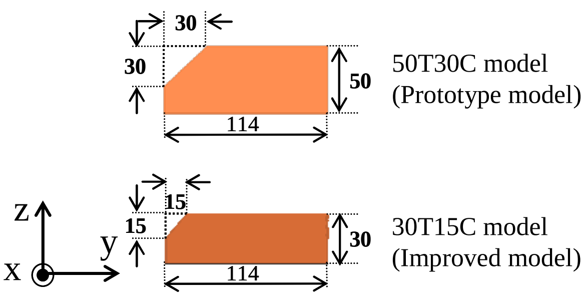

Fig. 3. Cross section view of retain ring

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 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.

Table I and Fig. 5 show material properties and B-H curve 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, retain ring is not manufactured by lamination structure. Accordingly, eddy current loss which is related with transition of flux variation and thickness of magnetic material is generated.

TABLE I
Material Properties

	SS400	Sus 316L	50PN600
Conductivity [S/m]	7.5×10^6	1.3×10^6	2.9×10^6

Fig. 4 shows the eddy current losses versus material of retain ring under no-load condition for 50T30C model, it 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 retain ring is 41.3 kW. The value occupies 0.8% of rated output of 5 MW superconducting motor. The target efficiency of 5 MW superconducting motor is more than 97%.

Fig. 5 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 of 5 MW superconducting motor.

IV. Conclusions and Review

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.

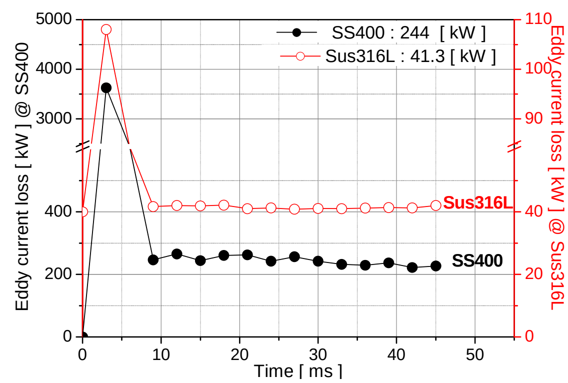

Fig. 4. Eddy current loss versus material of retain ring

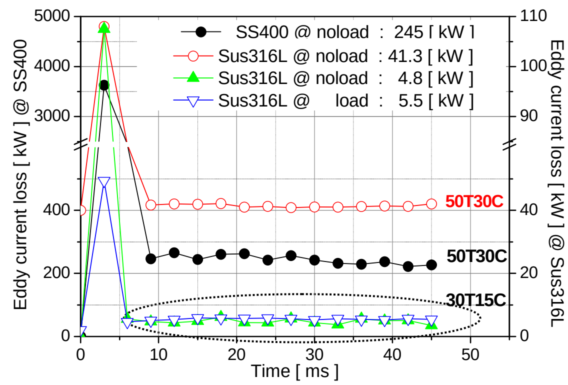

Fig. 5. Eddy current loss versus shape of retain ring and operating condition.

V. References

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