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인슐레이션을 제거한 소형 초전도 회전자 디자인

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Design of a small size insulationless superconducting rotor

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Abstract - The purpose of this paper is to study the thermal and mechanical characteristics of HTS (high temperature superconductor) field magnet according to the design of a small size superconducting rotor without insulation. First, basic design data of superconducting rotor were acquired through electromagnetic analysis. Based on these data, analysis regarding mechanical and thermal characteristics of HTS field magnet was executed. Anisotropic condition was considered in the mechanical characteristics of HTS field magnet. Average values of specific heat and heat conductivity up to 30 K were used during the analysis of thermal characteristics. Analysis results show superior mechanical and thermal characteristics of insulationless HTS field magnet compared with insulated HTS field magnet.

1. Introduction

Superconducting wind turbine generator system has high energy efficiency, small size and environmentally friendly nature. Therefore, during last several years, superconducting wind turbine generator system has been researched and developed for large capacity wind turbine systems. The authors have been studying on a small size superconducting wind turbine generator using insulationless superconducting rotor coil.

Insulation is considered indispensable to the application area of superconducting magnet [1]. Superconducting rotor is operated by a DC energy source. Thus, the resistance of wire of superconducting rotor is zero and the normal operation of insulationless superconducting rotor is available. Also, in comparison to insulated superconducting rotor, insulation less method can improve mechanical and thermal characteristics as well [2], [3].

In this paper, the design of insulationless superconducting rotor for a small size superconducting wind turbine generator is described. The shape of superconducting rotor was designed by 2D CAD program and electromagnetic analysis method. Thermal and mechanical characteristic of superconducting rotor were analyzed using FEM program, and compared with the insulated superconducting rotor. These fundamental data will usefully be applied to design a real superconducting rotor.

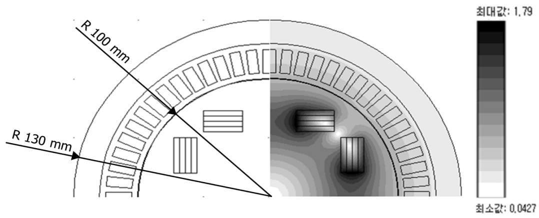
2. Electromagnetic design of superconducting rotor

The electromagnetic design of superconducting rotor is performed by using 2D FEM analysis. In this study, a 3-phase generator with rated voltage of 220 V (phase-to-phase) is considered and the rotating speed is 1800 rpm.

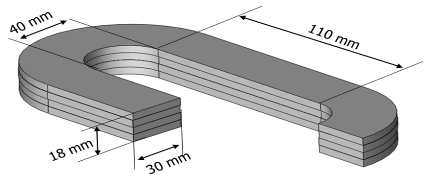
Fig. 1 shows the structure and magnetic flux density of the superconducting rotor. The HTS field magnet consists of total 16 pancake type racetrack coils generating 4-pole magnetic field. The stator has three-phase double layer armature windings, 60 slots conductor was considered by copper. The HTS field magnet and the armature radius of the superconducting rotor are 100 mm and 130 mm, respectively. Fig. 2 shows the structure of racetrack coil for HTS field magnet. The inner diameter and straight section length of racetrack coil are 20 mm and 110 mm, respectively, and its cross section is 30 mm × 18 mm. The bobbin was made by aluminum alloy. The racetrack coil was winded by BSCCO wire and the total length of wire is 480 m.

The operating temperature of superconducting rotor is 30 K. The operating current of the HTS field magnet is 180 A and maximum flux density of HTS field magnet becomes 1.79 T.

The magnetic field around the armature winding is around 0.4 T - 0.5 T. The analysis results indicate that the maximum magnetic flux density appears around the inner section of the HTS racetrack coil. Table 1 represents the specifications of the superconducting rotor with the capacity of 15 kW suggested in this paper.



<Fig. 1> Structure and magnetic flux density of superconducting rotor



<Fig. 2> Structure of the racetrack coil

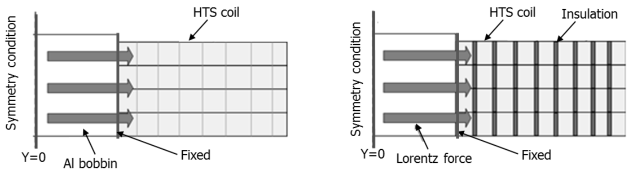
<Table 1> Specifications of superconducting rotor

Items	Values
Wire type	BSCCO
Operating current	180 A
Operating temperature	30 K
Number of poles	4
Outer radius of field magnet	100 mm
Cross section of racetrack	30 mm X 18 mm
Outer radius of armature	130 mm
Rotational speed	1800 rpm
Number of slot	60
Max. flux density	1.79 T
Output power	15 kW

3. Characteristic analysis of HTS field magnet

HTS field magnets experience a Lorentz force during operation. The Lorentz force acts as the final cause for triggering of structural deformation in HTS field magnet or HTS wire. Decreased performance or breakdown of HTS field magnet can occur in case of deformation reaches above standard level. Thus, it is important to consider the mechanical characteristic on the HTS coils and bobbin structure caused by the Lorentz force. As the deformation coefficient of insulation existing between turns of HTS wire is larger than other materials that compose the HTS magnet in the traditional insulation magnet, it acted as the cause for increasing the overall deformation rate of HTS magnet. For this reason, it can be predicted that the deformation of insulationless HTS magnet will be less than that of the insulated HTS magnet. Favorable mechanical characteristics are also expected.

Fig. 3 shows the analysis models used for mechanical characteristic of HTS field magnet. In table 2, young's modulus and Poisson's ratio in each direction are presented [4].



(a) (b)

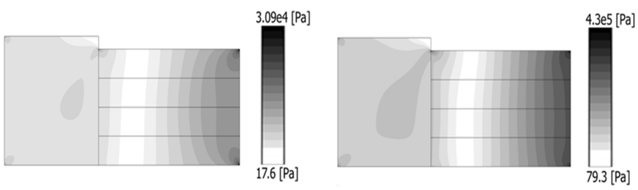
<Fig. 3> Mechanical analysis model of HTS field magnet : (a) Model-1, (b) Model-2

<Table 2> Equivalent material properties

Model-1		Model-2	
Young's modulus	Possion ratio	Young's modulus	Possion ratio
Ex 25.5 GPa	Vxy 0.118	Ex 32.7 GPa	Vxy 0.118
Ey 73.4 GPa	Vyz 0.33	Ey 91.5 GPa	Vyz 0.33
Ez 73.4 GPa	Vxz 0.118	Ez 91.5 GPa	Vxz 0.118

Model-1 is insulationless HTS field magnet model and model-2 is insulated HTS field magnet model. Because an analysis model for HTS field magnet has symmetry at the Y=0 plane, only half of the HTS field magnet was analysed. A fixed boundary condition was given to the inner side of THS field magnet. Furthermore, a symmetry boundary condition was given to the Y=0 plane. In the direction of the X-axis, HTS wire was stacked with various different layers. Thus, in the mechanical characteristic of superconducting rotor, anisotropic analysis is indispensible when it comes to representing these properties. Because the thickness of each layer of HTS field magnet is so thin, it is necessary to calculate an equivalent model of the material.

Fig. 4 represents the result of mechanical analysis of HTS field magnet. The maximum Von Mises stress of the model-1 and model-2 are 3.1e4 MPa and 4.3e5 MPa, respectively. The deformation of model-1 and model-2 were measured as 0.42% and 1.56%, thus it has been verified that the insulationless HTS field magnet presents less strain than the insulated HTS field magnet.



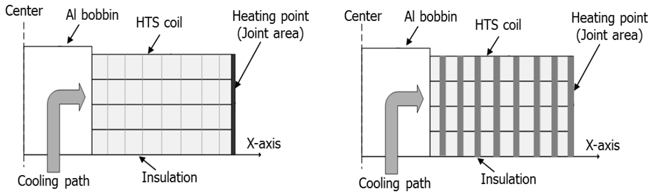
(a) (b)

<Fig. 4> Analysis results of mechanical characteristic of HTS field magnet : (a) Model-1, (b) Model-2

Fig. 5 describes analysis model for comparison of the thermal characteristics between insulationless HTS field magnet and insulated HTS field magnet. Cooling method of the HTS field magnet designed in this paper is conduction cooling method. Aluminum bobbin, which is located in the center of the HTS field magnet, acts as the cooling path and the cooling is achieved in X-axis direction.

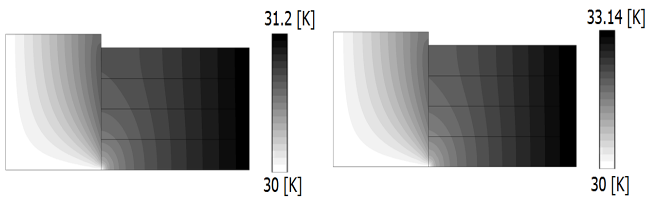
Thermal characteristic is a very important factor when designing superconducting applied devices. The higher the cooling performance, the more excellent is superconducting system stability. Cooling efficiency is determined according to the material composing HTS field magnet. For example, X-axis direction cooling efficiency of insulated HTS field magnet is bad. Because, thermal conductivity of insulation is very low. Thus, higher cooling characteristics can be expected in insulationless HTS field magnet compared with insulated HTS field magnet.

Fig. 6 shows the temperature distribution of HTS field magnet. Superior cooling characteristics of insulationless field magnet can be observed through the analysis results of Fig 6.



(a) (b)

<Fig. 5> Thermal analysis model of HTS field magnet : (a) Model-1, (b) Model-2



(a) (b)

<Fig. 6> Analysis results of thermal characteristic of HTS field magnet : (a) Model-1, (b) Model-2

4. Conclusions

This paper designed a small size HTS rotor and compared the thermal and mechanical characteristics of insulationless HTS field magnet with insulated HTS field magnet. The analysis results presented superior mechanical and thermal characteristics in insulationless HTS field magnet than in insulated HTS field magnet. Thus, it is confirmed that the performance of superconductive rotary machine can be enhanced by applying insulation less magnet instead of the conventional insulated magnet.

Acknowledgement

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