Design and Analysis of a Revolving Armature type Axial Flux High-Temperature Superconducting Motor

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1 Introduction

In this paper, a rotating armature type axial flux high temperature superconducting (HTS) motor was designed and its characteristics were analyzed. A 5.5 kW axial flux motor operating at a rated voltage of 220 V, a temperature of 83 K, and a rotational speed of 1,000 rpm was designed by applying the HTS field coil. In this axial flux HTS motor, the rotating armature was chosen because a solid vacuum must be maintained for stable cooling of the HTS field coil. The electromagnetic and thermal characteristics of the designed motor were analyzed using a 3D finite element method program. As a result, the torque and output of the de-signed axial flux superconducting motor were 55 Nm and 5.5 kW, respectively. Effective current lead and cooling system design can reduce heat loss. These results can be effectively utilized to design various types of HTS axial flux motors in the future.

2 Design of a revolving armature type axial flux HTS motor

A. Design of the HTS field coil of the revolving armature type axial flux HTS motor

The field coil of the revolving armature type axial flus HTS motor was designed using Y-Ba-Cu-O (YBCO) wire. The primary factors related to the selection of manufacturer were economic efficiency and superior performance. The detailed specifications of the YBCO wire are summarized in Table I.

Fig. 1 shows the $I_c - B$ curves of the YBCO wire. The critical characteristics of a superconducting wire depend on the magnitude of magnetic field and the angle of incidence. In this case, the critical current was selected based on the perpendicular magnetic field because the YBCO wire was tape type that was significantly affected by the perpendicular magnetic field. The operating current of the superconducting field coils was determined by applying 25% safety margin of the critical current of the wire.

TABLE I
Characteristics of the superconducting wire

Items	Value
Width	4 mm
Thickness	0.15 mm
Critical bend diameter	35 mm
Critical tensile stress	250 MPa
Critical tensile strain	0.30 %

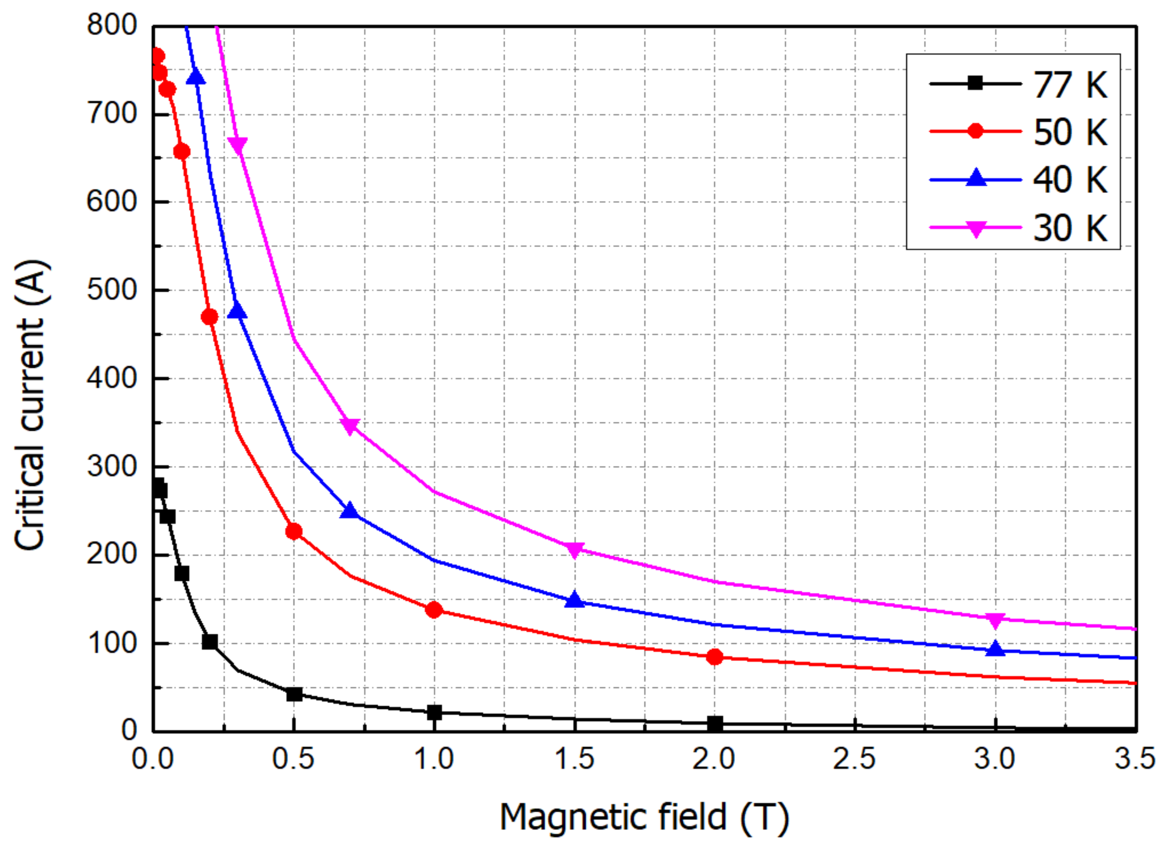

Fig. 1. Ic-B curves of YBCO depending on the operating temperature

Fig. 2 shows the HTS field coil of a revolving armature type axial flux HTS motor. At the operating temperature of 83 K, the critical current of this superconducting coil was 62.7 A, and the operating current was designed to be 46 A considering the safety margin of 25%.

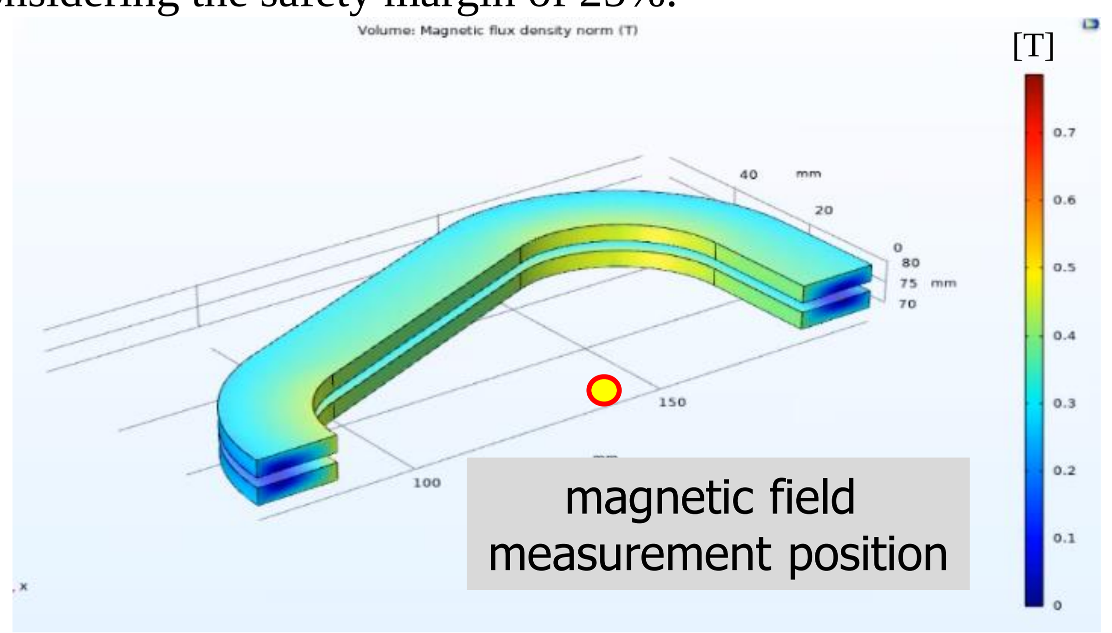

Fig. 2. The HTS field coil configuration of the revolving armature type axial flus HTS motor

B. Fundamental structure of the revolving armature type axial flux HTS motor

The revolving armature type axial flux HTS motor can be divided into a rotor part and a stator part. The difference between this motor and commercial motors is that they use superconducting wires for the field coil. The stator section consists of a superconducting field coil, a cryostat and a stator body. The rotor consists of a rotor coil, a rotor body and a magnetic shield.

Tables 1 and 2 show the specifications of the revolving armature type axial flus HTS motor. The rated power and torque are designed to be 5.5 kW and 55 Nm. The field coil is composed of an 8-pole quadruple pancake.

The total length of HTS wire used in this motor is 0.92 km.

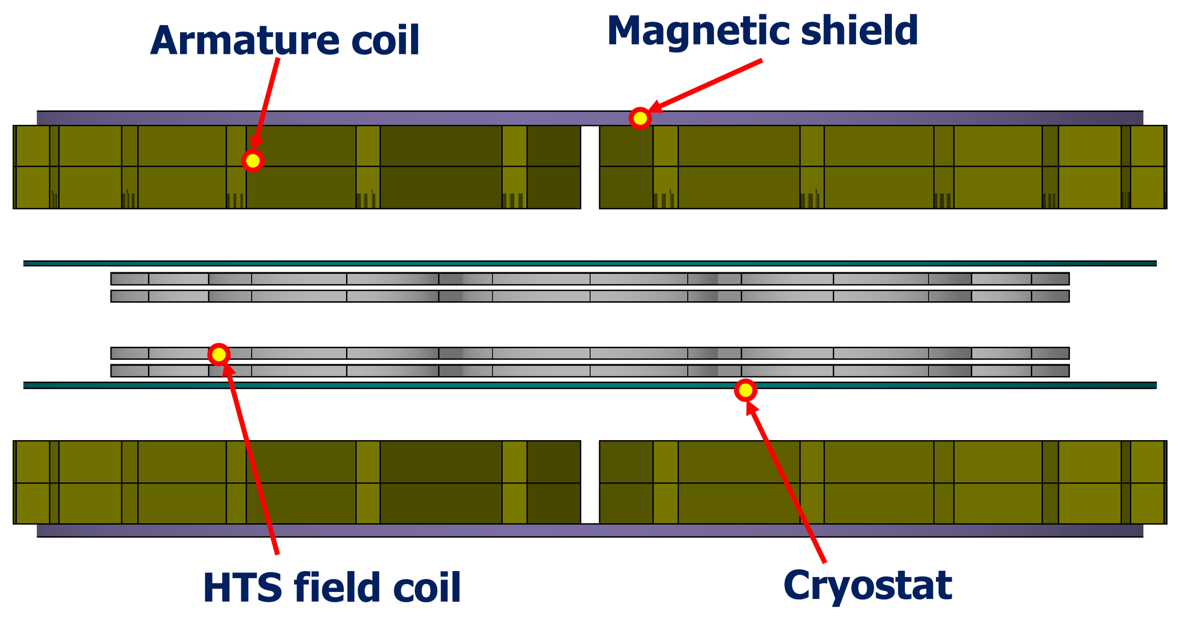

Fig. 3. The front view of the revolving armature type axial flus HTS motor

TABLE II
Basic design condition of the revolving armature type axial flus HTS motor

Items	Value
Rated output power	5.5 kW
Rated L-L voltage	380 V
Rated armature current	15.56 A
Rotating speed	1,000 rpm
Rated torque	55 N·m
Number of poles	8
Operating temperature	83 K

TABLE III
Basic specifications of the revolving armature type axial flus HTS motor

Items	Value
Number of poles	8
Number of SPC layers	4
Number of turns of SPC	115 turn
Number of turns of stator coil	83 turn
Diameter of the HTS motor	0.4 m
Length of the HTS wire required	0.92 km

C. Design of the current lead and cooling system

The important factors for designing the current leads are the thermal conductivity of the materials, the length and the cross-sectional area of the current lead. The minimum heat load and the optimal length of the current lead can be calculated by equations (1), and (2).

$$Q_{op} = I\sqrt{2\int_{T_L}^{T_H} \rho(T)k(T)dT} \quad (1)$$

$$\frac{L}{A} = \frac{1}{I}\int_{T_L}^{T_H} \frac{k(T)}{\sqrt{2\int_{T_L}^{T_H} \rho(T)k(T)dT}}dT \quad (2)$$

The block to which the cooling pipe through which liquid nitrogen circulates and the current lead and the field coil are connected was designed of copper.

TABLE V
Design specifications of current lead

Items	Value
Room temperature (T_H)	300 K
Operating temperature (T_L)	83 K
Length of the current lead (L)	300 mm
Cross section area (A)	24 mm^2
Operating current (I)	46 A

3 Analysis results and discussion

A. Electromagnetic analysis of the revolving armature type axial flux HTS motor

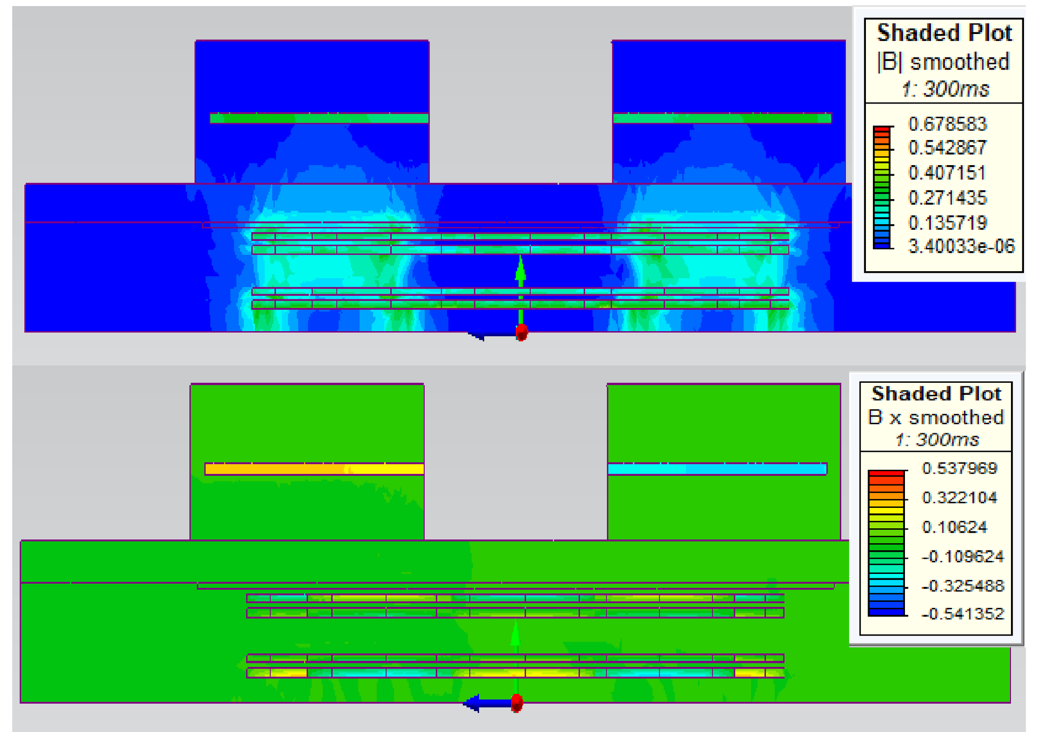

Fig. 5. (left) Magnetic field distribution and (right) perpendicular magnetic field of the revolving armature type axial flux HTS motor

Fig. 5 presents the distribution of the magnetic field for 1/2 model of the revolving armature type axial flux HTS motor. The maximum magnetic field and the perpendicular magnetic field were 0.67 T and 0.54 T, respectively.

B. Thermal analysis of the revolving armature type axial flux HTS motor

The temperature of the current lead was 81 K. However, the total heat load was 6.59 W.

TABLE VI
Heat load of each component in the stator

Items	Value
Current leads	6.59 W
Current terminals and joints	1.2 W
Radiation load	12 W
Total heat load	19.79 W

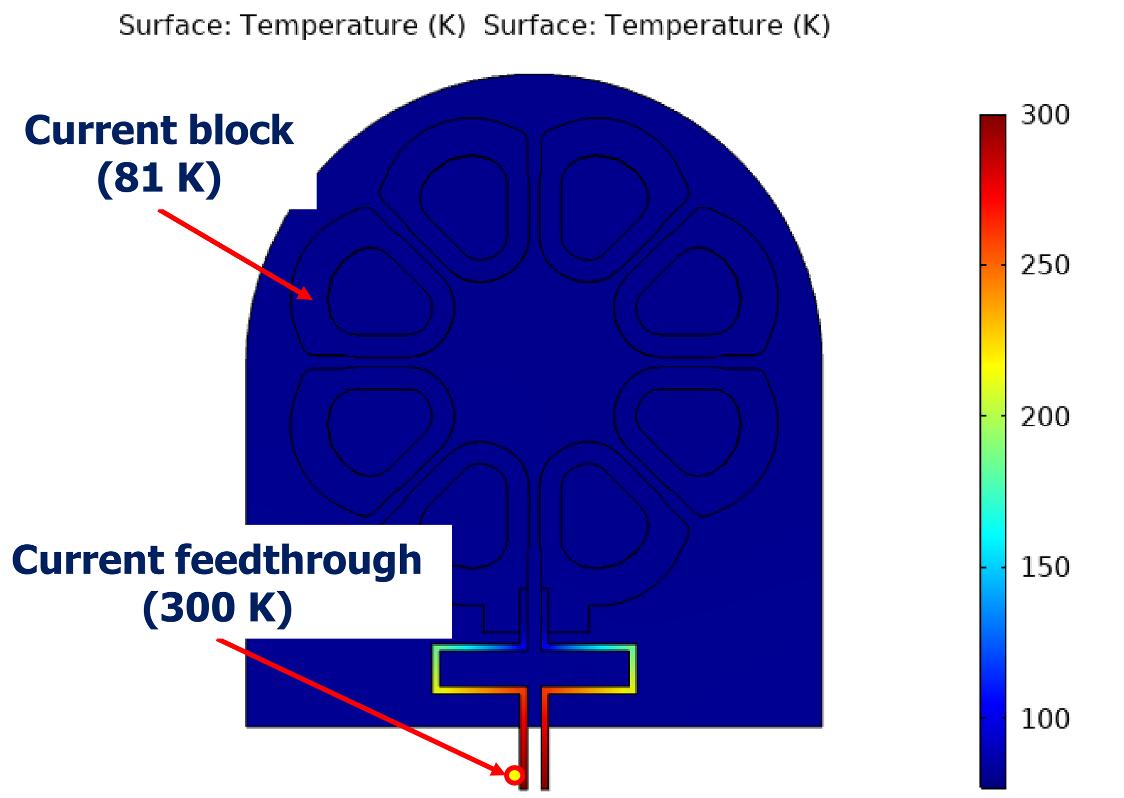

Fig. 6. The temperature distribution of current lead

4 Conclusions

This paper discusses the design and analysis of a revolving armature type axial flux HTS motor. This axial flux HTS motor, rotating armature was chosen because a solid vacuum must be maintained for reliable cooling of the HTS field coil. The field superconducting coil was designed in consideration of the maximum radius of curvature of YBCO wire, temperature, magnetic field, and magnetic field incident angle, which affects the critical current. The minimum heat load and the optimal length of the current lead were calculated by equations. Electromagnetic and thermal properties were analyzed using a 3D FEM program.

As a results, the maximum magnetic fields and the perpendicular magnetic fields were 0.67 T and 0.54 T, respectively. The total thermal load of the stator part was 19.79 W. The results of this study can be effectively used to design various types of HTS axial flux motors in the future.

Acknowledgement

This research is financially supported by Changwon National University in 2021.