Design of a helium-liquid hydrogen based indirect cooling system for an HTS coil cooling

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1 Introduction

This paper deals with the design of a helium-liquid hydrogen indirect cooling system(HLHICS) for an high-temperature superconducting (HTS) coil cooling. The HLHICS consists of a hydrogen liquefaction system, a helium-liquid hydrogen heat exchanger and a 2G HTS coil. The hydrogen liquefaction system liquefies gaseous hydrogen precooled by liquid nitrogen using a cryo-cooler. The heat exchanger was located in the inner tank of a hydrogen cooling system filled with liquid hydrogen, and gaseous helium exchanges heat through the contact surface of a copper tube cooled with liquid hydrogen. The temperature distribution and heat load of the hydrogen liquefaction system and HTS coil were analyzed by a 3D finite element method program. The helium-liquid hydrogen heat exchanger was designed based on the outlet temperature of the hydrogen liquefaction system and the heat load of the HTS coil. As a result, the temperature of the HTS coil was maintained at a target of 30 K, and the heat load of the HTS coil was minimized to 5 W. These study results can be effectively used in the design of a liquid hydrogen-based cooling system.

2 Design of a HTS coil

A. Specifications of the HTS coil

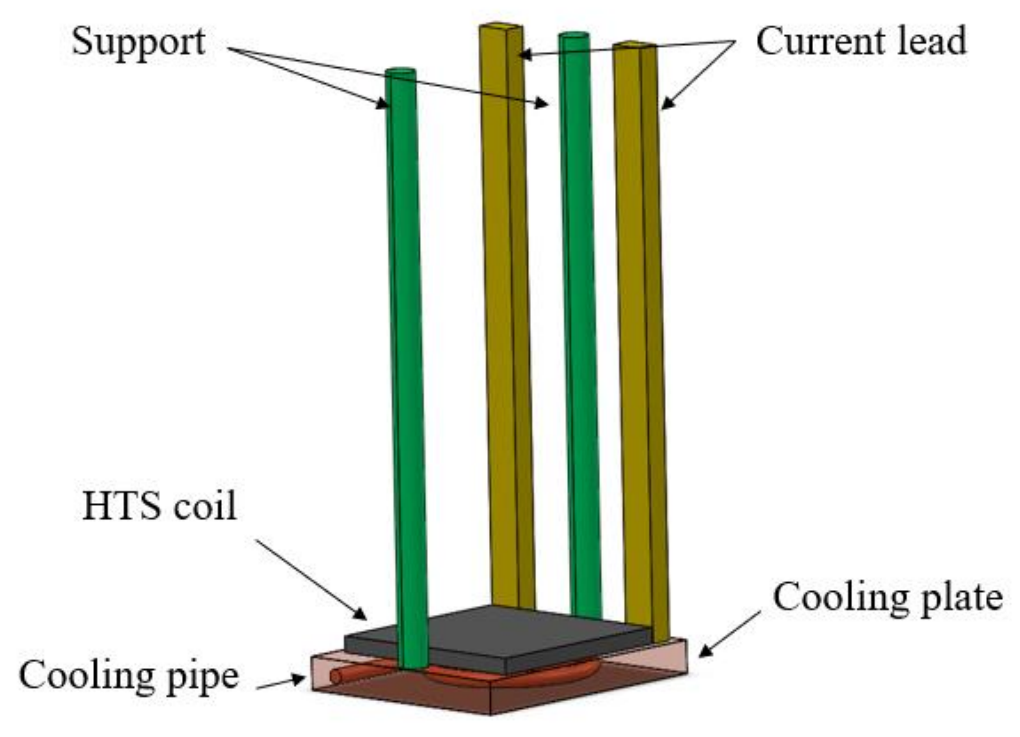
A prototype HTS coil was designed to simulate a superconducting application with a HLHICS. The shape of the HTS coil was O shape, and two HTS coils were stacked together. The design specifications of the HTS coil are summarized in Table I.

Table I
Specifications of the HTS wire and test coil

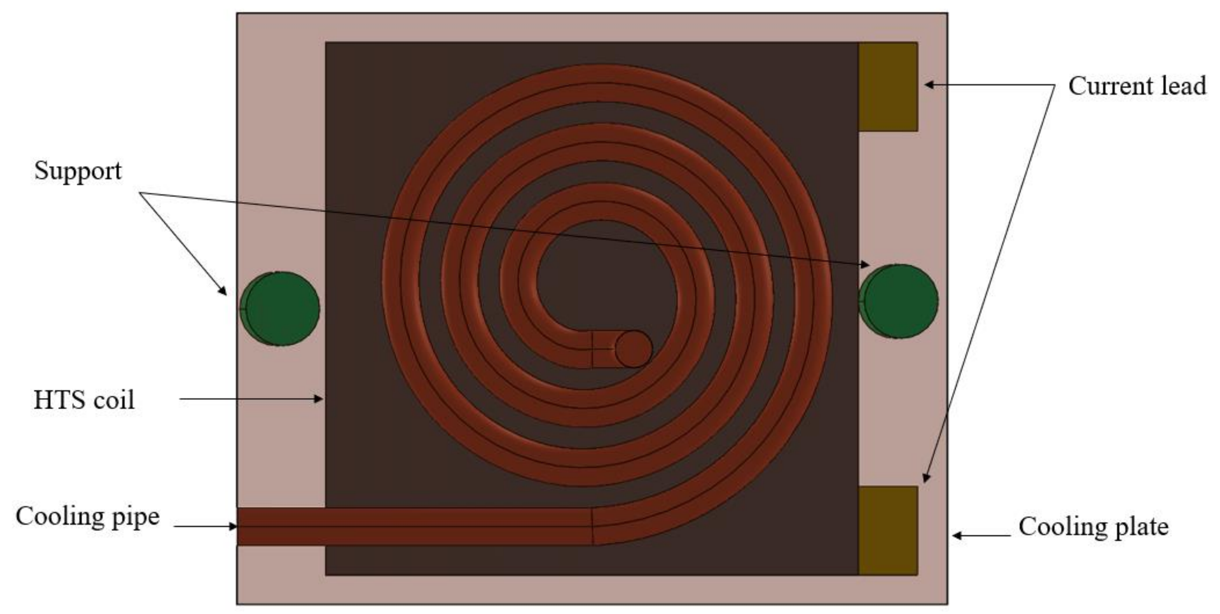
Items	Value
Thickness of HTS wire	4 mm
Critical current of HTS wire	250 A @ 77 K
Outer diameter of HTS coil	147 mm
Inner diameter of HTS coil	90 mm
Number of turns	100
Number of layers	2
Insulation type	Metal insulation
Critical current of HTS coil	234 A @ 30 K 80 A @ 77 K
Operating current of HTS coil	234 A
Operating temperature of HTS coil	30 K

B. Structure design of the HTS coil

Figure 1 and Table II show the composition and material of the HTS coil. The HTS coil consists of a copper block for supplying current and a bobbin for fixing.



(a)



(b)

Fig. 1 Configuration of the HTS coil (a) front view and (b) bottom view

Table II
The material of each component of HTS coil

Items	Material
Copper block	OFHC
Bobbin	Aluminum 6061 (anodized)
Supporter	GFRP
Current lead	Brass
Cooling pipe	OFHC
Cooling plate	OFHC

3 Design of a HLHICS

A. Configuration of a helium-liquid hydrogen indirect cooling system

Figure 2 show the configuration of the HLHICS The HLHICS consists of a hydrogen liquefaction system, a helium-liquid hydrogen heat exchanger and a 2G HTS coil. Figure 3 shows the HLHICS design process.

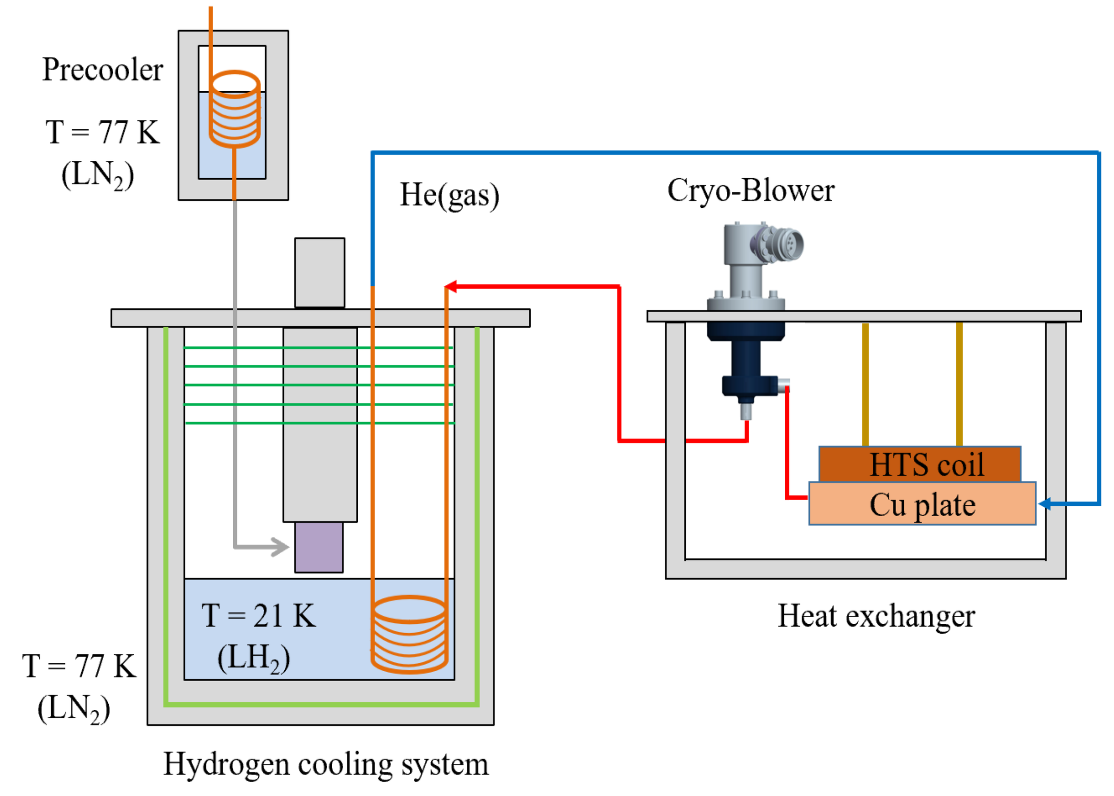


Fig. 2. Configuration of HLHICS

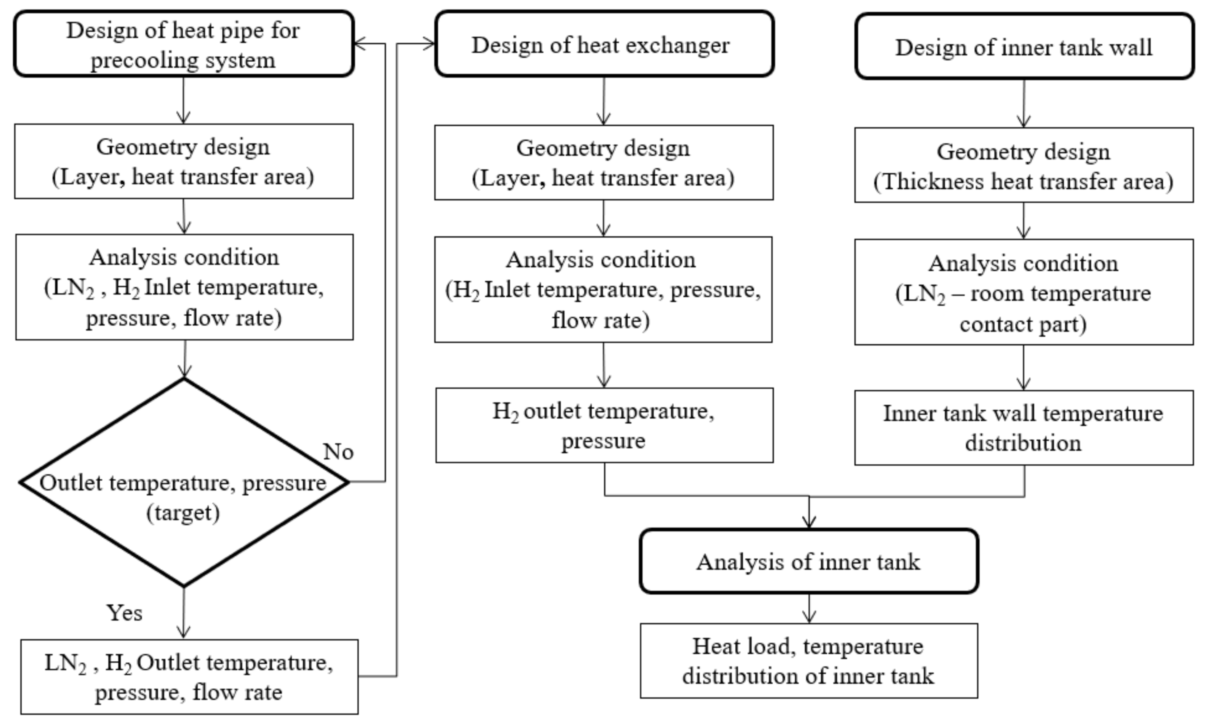


Fig. 3. Design process of HLHICS

B. Design of precooler

Table III show the design condition and specification of precooler. In order to minimize the heat load, hydrogen gas was injected into the liquefaction system at a temperature of 77 K by the precooling system.

Table III
Design condition and specification of precooler

Items	Material
Diameter of copper pipe	25.4 mm
Thickness of pipe	2 mm
Number of turn	17
Inlet temperature (H_2)	300 K
Inlet pressure (H_2)	1 bar
Inlet volume flow (H_2)	45 L/min

C. Design of heat exchanger for HLHICS

The heat exchanger was located in the inner tank of a hydrogen cooling system filled with liquid hydrogen, and gaseous helium exchanges heat through the contact surface of a copper tube cooled with liquid hydrogen.

Table IV
Design specification of heat exchanger for HLHICS

Items	Value
Winding diameter of heat exchanger	350 mm
Diameter of copper pipe	25.4 mm
Thickness of pipe	2 mm
Number of turn	3
Inlet temperature (H_2)	25 K
Inlet pressure (H_2)	1 bar
Inlet volume flow (H_2)	45 L/min

4 Simulation results of a HLHICS

A. Simulation results of the precooler

Figure 4 shows the temperature distribution of precooler. The hydrogen injected at a temperature of 300K was cooled by liquid hydrogen, and the temperature at the outlet of the precooling system was 80 K.

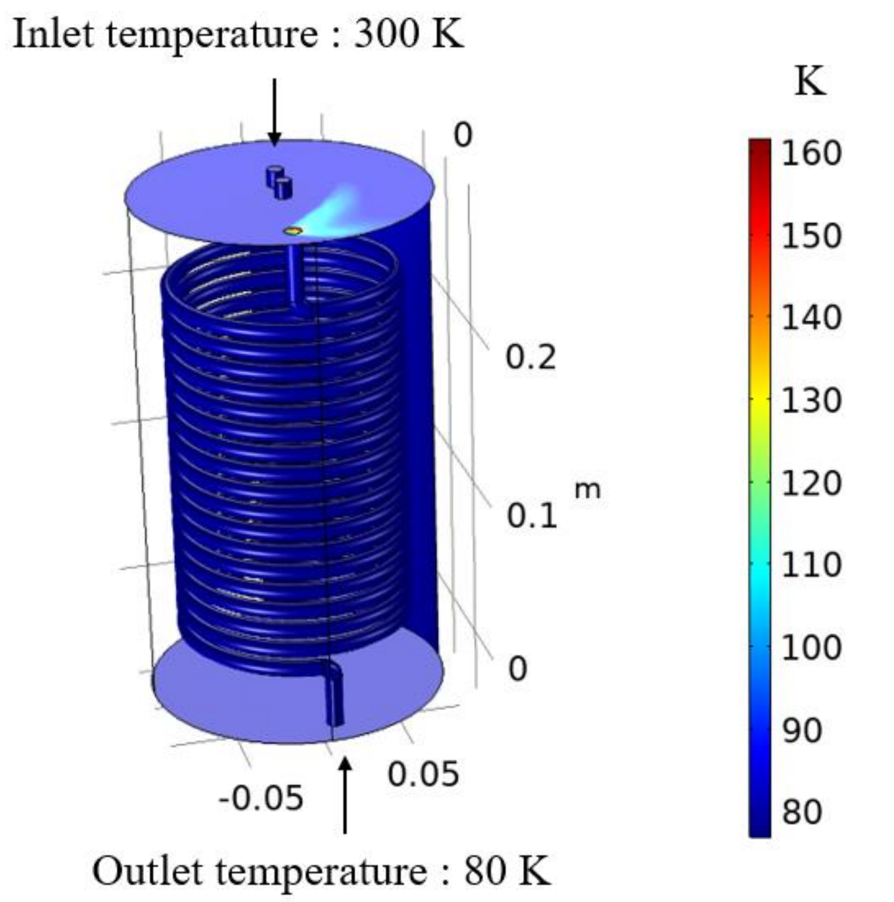


Fig. 4. Temperature distribution of precooler

B. Simulation results of HTS coil

Figure 5 shows the temperature distribution of HTS coil. The heat load of the HTS coil was minimized to 6 W and the operating temperature was maintained below 30 K

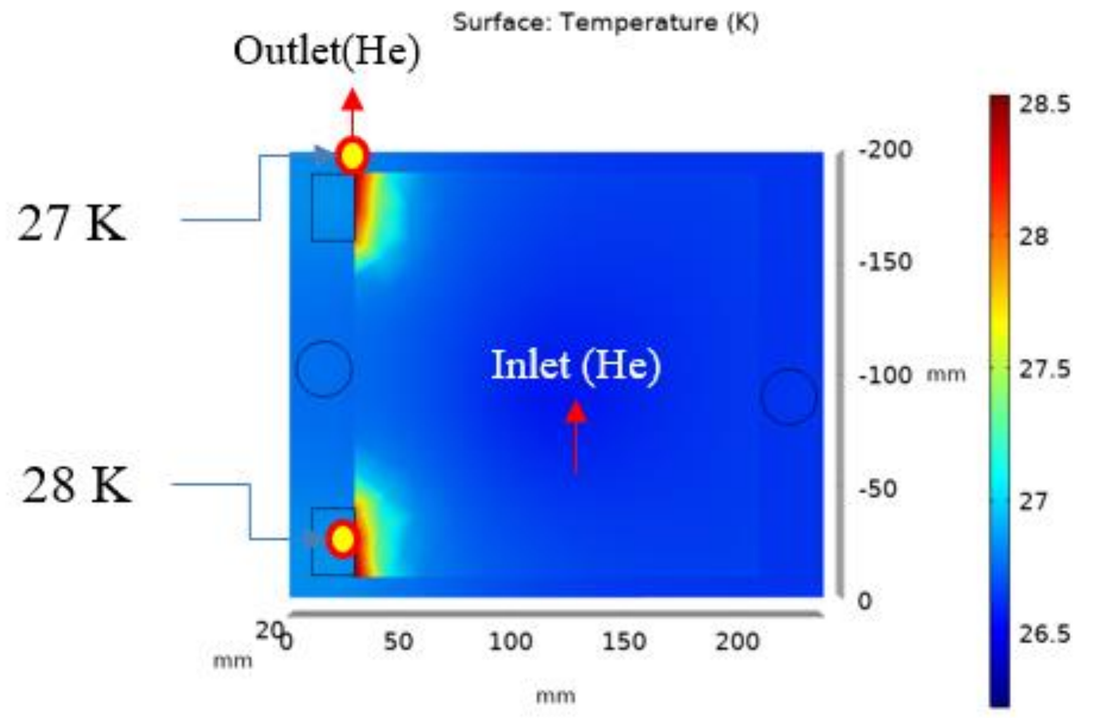


Fig. 5. Temperature distribution of HTS coil

5 Conclusions

In this paper, a helium-liquid hydrogen indirect cooling system (HLHICS) for a high-temperature superconducting (HTS) coil was designed and its performance was analyzed. The structure of the HTS coil and the cooling device was designed in detail. Critical current prediction of the HTS coil, the temperature distribution and the heat load of precooling system, the hydrogen liquefaction system, and the HTS coil were analyzed using a 3D finite element method program. As a result, the heat load of the HTS coil was minimized to 5 W and the operating temperature was maintained below 30 K. The inner wall temperature of the hydrogen liquefaction system was 86 K, and it was cooled by the liquid nitrogen shielding layer. The outlet temperatures of the precooling system and the hydrogen liquefaction system were 80 K and 25 K, respectively.

These results can be effectively utilized in the design of a cooling system using liquid hydrogen as a refrigerant. In addition, by adding a hydrogen fuel cell to this, it is possible to implement a system that includes an energy conversion process.

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