Thermal Stabilization of Cryogenic System in Superconducting Cyclotron

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1. Introduction

Radiology has some useful applications for medical purpose. For cancer therapy, the superconducting cyclotron should generate heavy ion beams. It radiates heavy ion beams to cancer patients. In order to make cyclotron system stable, the cryogenic system which makes superconducting state should work constantly. However, radiation heat transfer of cryogenic system should be considered because liquid helium's boiling point is extremely low and there is huge temperature difference between the cryogenic system and ambient temperature [1]. Accordingly, thermal analysis should be carried out. In this paper, the numerical analysis of the cryogenic system in practical superconducting cyclotron show temperature distribution and suggest the number of coolers using ANSYS Workbench program.

2. Methods and Results

2.1 Numerical Calculation

As the cyclotron has cryogenic system using liquid helium (LHe), the cryogenic system is composed of outmost SUS shell, copper thermal shield, LHe reservoir, and multilayer insulation (MLI) to decrease penetrating heat flow (Fig. 1) [2]. If LHe boils off because of some disturbances, the temperature and pressure of the system increase dramatically and then superconducting state will break down. This phenomenon is called quenching [3]. To prevent quenching in the reservoir, the system is required to have vacuum environment and MLI. Each part is connected with Kevlar bands under vacuum environment. Copper thermal shield is covered with 30 layers of MLI to block radiation heat between outmost SUS shell and thermal shield. Also LHe reservoir which contacts directly with LHe is covered with 10 layers of MLI.

The cryogenic system consists of several different parts, and radiation heat transfer is difficult to evaluate exactly. In order to simplify the model, because the cryogenic system has big cylindrical shape, it was calculated under one dimensional assumption.

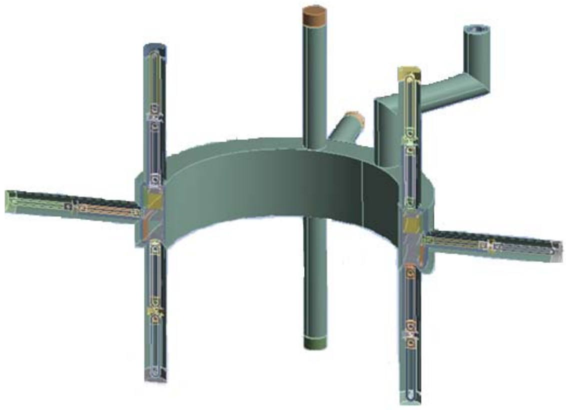

Fig. 1. The full description and cross section view of cryogenic system.

The radiation heat comes from the ambient air, 300 K. It goes through SUS shell, 30 layers of MLI, thermal shield, 10 layers of MLI, and then reaches SUS LHe reservoir. From this calculation, we estimated that 30 layers of MLI wrapping thermal shield have effective thermal conductivity (1.62×10^{-5} W/m· K) [4,5]. Also 10 layers of MLI, covering LHE reservoir have an alternative property which is called effective thermal conductivity as 2.36×10^{-5} W/m· K.

2.2 Thermal analysis of thermal shield

First, to determine the number of shield coolers, we should evaluate the temperature distribution because thermal shield should maintain the temperature below 77 K.

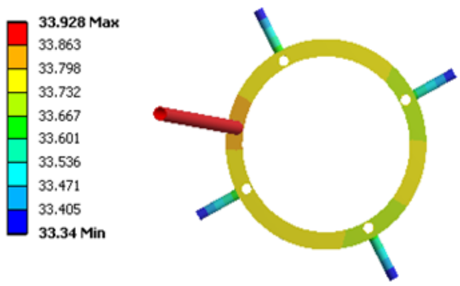

Fig. 2. The temperature distribution of thermal shield when four cryocoolers contact with copper thermal shield.

As shown in Fig. 2, when external heat flow from ambient air radiates to thermal shield and four shield coolers contact with thermal shield, the maximum temperature would be about 34 K. Also if there is only one shield cooler, the maximum temperature would not exceed the limit.

2.3 Thermal analysis of LHe reservoir

The very inside part is LHe reservoir of the cryogenic system and it is filled with liquid helium. The heat flow comes into LHe reservoir is critical to liquid helium boiling.

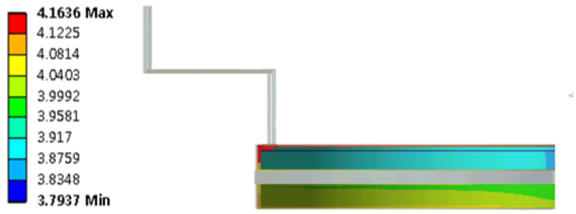

Fig. 3. The temperature distribution of LHe reservoir when four cryocoolers are working.

In Fig. 3, the temperature distribution of LHe reservoir shows that if four cryocoolers worked, the highest temperature of LHe reservoir is below LHe boiling point(4.2 K).

3. Conclusions

Superconducting cyclotron is required to stable cryogenic system to make superconducting state. It means that liquid helium which is working fluid maintaining system should not boil off. In order to prevent this problem, thermal analysis is a fundamental process to build up the system. Based on the numerical analysis results, if all insulation materials worked effectively, this cryogenic system needs at least one shield cooler and four cryocoolers for keeping each temperature below the limit.

ACKNOWLEDGEMENT
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