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CFD ANALYSES ON LHE COOLING FOR SCQ MAGNETS IN BEPCII UPGRADE

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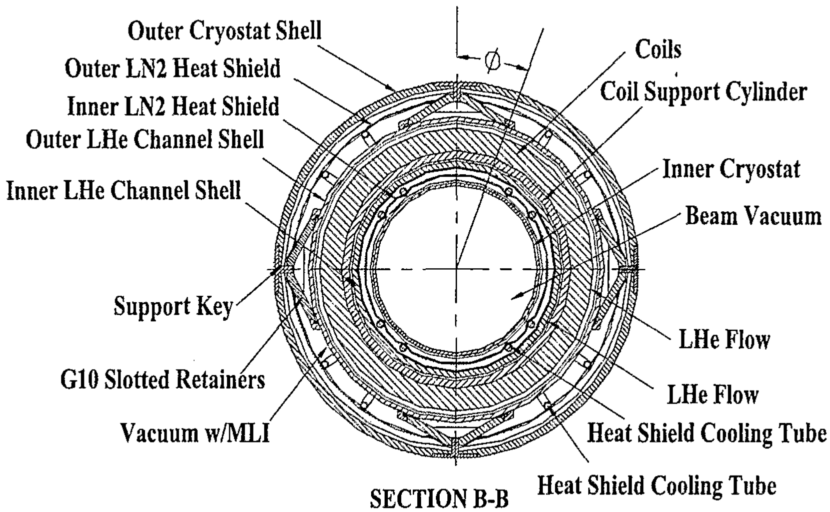
ABSTRACT

A pair of superconducting interaction region quadrupole magnets in Beijing Electron-Positron Collider Upgrade (BEPCII) are to be cooled by supercritical helium in order to eliminate the flow instabilities in the constrained cooling channels. The fluid flow is simulated by the commercial computational dynamics fluid software. The heat loads to the superconducting quadrupole (SCQ) magnets from the radiation shields at 80 K and from the thermal conduction of mechanical supports are considered. The temperature distribution of the fluid in the liquid helium cooling channels, and the heat transfer in the SCQ magnet and by its supports are presented. The influence of mass flow rate on pressure drop in the cooling passage is analyzed.

INTRODUCTION

In BEPCII upgrade, two quadrupole magnets with high focusing strength are applied to decrease the amplitude of the beta function at the interaction region. They are inserted in the BESIII detector symmetrically with respect to the interaction point. In principle, the small size and the low field leakage are the two basic requirements for the magnets. The superconducting magnet and its cryostat must be as compact as possible. Two identical iron-free and non-collared coils with active shielding are proposed for the BEPCII. Each magnet consists of seven coils wound in a common stainless steel cylinder, which include one independent quadrupole, one horizontal dipoles, one vertical dipole, one skew-quadrupole and three part anti-solenoids [1-2]. The magnet's cryostat with the Endcan and the transfer-line ports is shown in FIGURE 1. The main components include, from inner to outer, the cryostat inner warm shell, the inner heat shield with liquid nitrogen cooling tubes, the inner annular cooling channel for liquid helium, the coil support cylinder, the coils, the outer annular cooling channel for liquid helium, the outer heat shield with liquid nitrogen cooling tubes and the cryostat outer warm shell [3].

The heat loads at 4K are calculated first since they are critical for the design of the SCQ magnet cryogenic system. Based on the calculated heat loads, study on the supercritical helium cooling for the magnet is carried out by using the commercial CFD software package, FLUENT 6.0.



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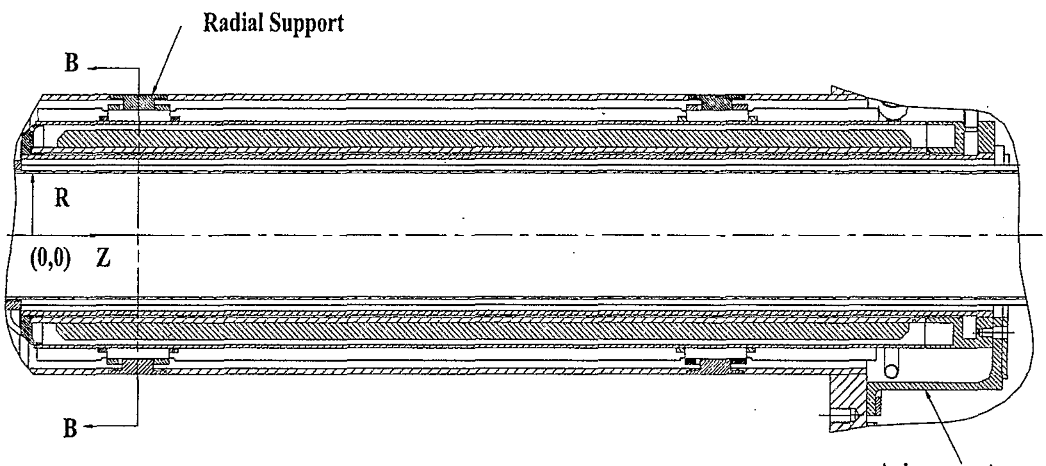

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FIGURE 1. The cryostat of SCQ magnet in BEPCII. a. cross section, b. longitudinal section.

HEAT LOADS AT 4K

Each magnet is fixed by eight radial supports and one axial support as shown in FIGURE 1. The heat loads at 4 K for the SCQ magnet are mainly due to the thermal conductions of the radial key supports and the axial support, the thermal conduction and radiation through multi-layer insulation (MLI). The conduction and radiation through the MLI are treated as the radiation boundary condition when simulating the heat conduction through the supports. The equivalent conduction coefficient of $1\text{x}10^{-4}$ W/m-K for the MLI is used.

Computation of Heat Conduction through Radial Supports

The conductive heat load to the magnet coils is minimized by the use of stainless steel support keys, aligned with and welded to the outer vacuum vessel. These keys engage slots in G-10 retainers, arranged in a 90° pattern around the circumference of the outer helium channel, in two axial locations. Besides being optimized for minimum heat flux, while retaining structural integrity, these G-10 retainers are also mechanically and thermally stationed to the 80K heat shield[1]. The physical model of the radial support involves the outer cryostat shell, the support key, the G-10 retainer, the outer 80 K thermal shield, and the outer LHe channel shell. The two sides of the support key contacts with the G-10 retainer. The material of the most components is stainless steel except for the retainers. The thermal conductivities of stainless steel and G-10 are adopted, which are the functions of temperature and given in FIGURE 2. The convection heat transfer in the liquid helium channel, in the liquid nitrogen tubes and on the outer cryostat wall is considered. The convective coefficients are calculated using the empirical relations.

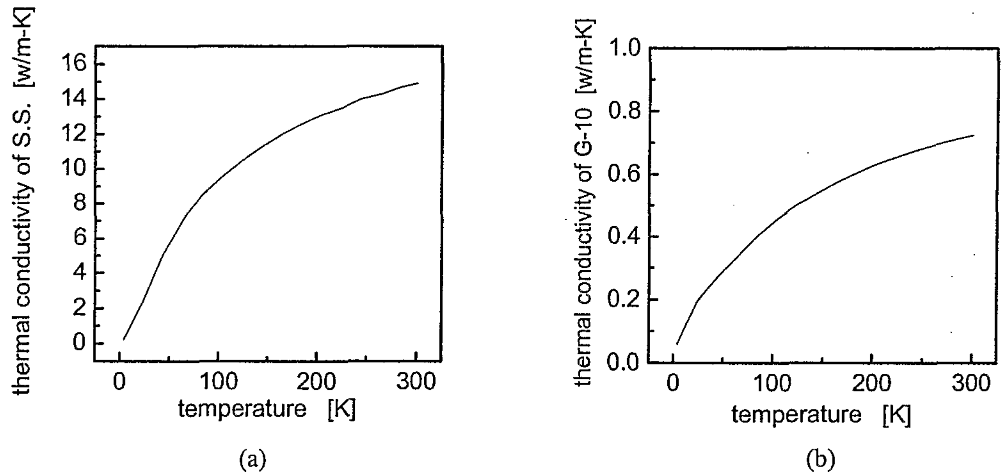


FIGURE 2. Thermal conductivity vs. temperature. a. stainless steel, b. G-10.

The calculation results are given in FIGURE 3. FIGURE 3a shows the temperature contour of the radial support. FIGURE 3b-3d present the temperature distributions of the G-10 retainer, the heat shield and the cryostat shell. In FIGURE 3b, for the G-10 retainer, the temperature distributions at the sides touching the support key are apparently different from that at the other sides. The former is higher than the latter. In FIGURE 3c, for the heat shield, the temperature adjacent to the touching sides of the G-10 retainer with the support key rises up to about 100 K due to the heat leak from the room temperature. However, most of the heat shield can keeps at 80 K. In FIGURE 3d, the minimum temperature of the outer vacuum shell is about 278 K. The calculated heat flux is listed in TABLE 1.

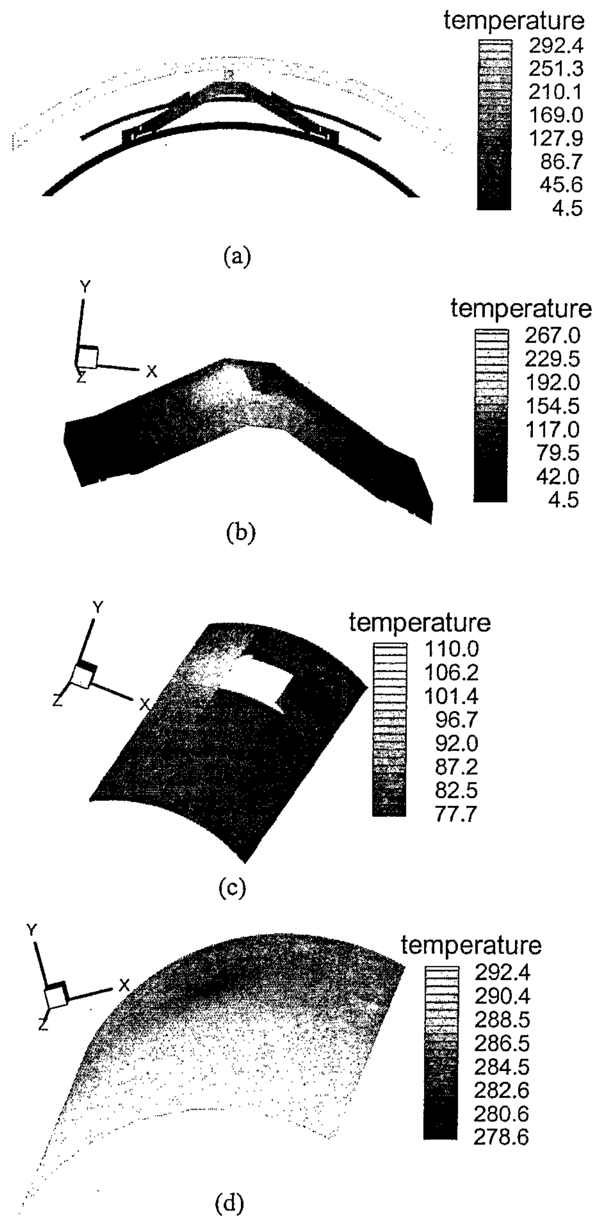


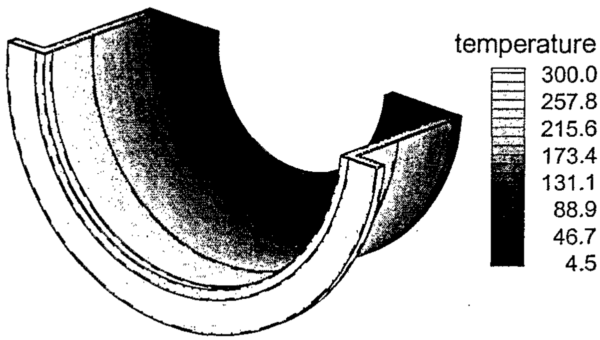
FIGURE 3. Temperature distribution of radial support. a. radial support, b. G-10 retainer, c. 80K shield, d. outer cryostat shell.

Computation of Heat Conduction through Axial Support

In addition to the sliding radial supports, the coil assembly is supported axially by a separate saddle-backed support at the magnet lead end, which is made of G-10. Two cases are simulated. One is to consider the heat conductivity as the function of the temperature, and the other is to keep the heat conductivity constant at 0.22 W/m-K. During the numerical simulation, the temperature of the side connected with the Endcan is set at 300 K, and the other side connected to the LHe vessel at 4.5 K. The temperature contour along the axial support is given in FIGURE 4. The heat conductions through the axial support using the variable thermal conductivity and constant conductivity are 3.3 watts and 1.45 watts, respectively. The radiation heat loads are separately 0.022 watts and 0.016 watts. The heat loads at 4 K for the SCQ magnet are summarized in TABLE 1.

TABLE 1. Estimated heat loads at 4 K for the SCQ magnet

Heat load [W]	Radial support	Axial support using variable conductivity	Axial support using constant conductivity
Heat conduction of support	10.4	3.3	1.45
Radiation and conduction through MLI	2.6	0.022	0.016
Total	13	3.322	1.465



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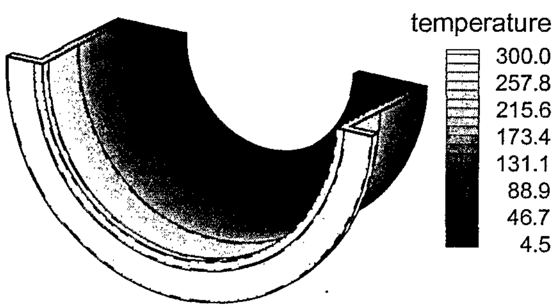

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FIGURE 4. Temperature distribution of axial support. a. variable thermal conductivity, b. constant thermal conductivity.

SIMULATION OF LHE COOLING FLOW

The simplified physical model for the LHe flow is shown in FIGURE 5. LHe flows in turn through the outer and the inner channel. The fluid adsorbs the heat along the passage induced by the heat conduction and radiation. The steady state, three-dimensional turbulent flow is modeled. The standard k- εmomentum equation and standard wall function were adopted for the simulation.

The magnet is cooled by the supercritical helium fluid at 2.7 bar and 4.5 K. FIGURE 1 defines the coordinates of the circumferential ϕ, radial r and axial z. The temperature distribution of the cooling fluid at the mass flow rate of 12 g/s is shown in FIGURE 6 and FIGURE 7. The highest temperature of the supercritical helium is about 6.7 K. It happens at eight spots where the radial G-10 retainers are held on the outer cooling channel wall. Most of the helium fluid inside the cooling channel keeps lower than 4.7 K. The temperature of the magnet is around 4.6K. The temperature difference between the inlet and the outlet is within 0.2 K. The pressure drops at different mass flow rates are shown in FIGURE 8.

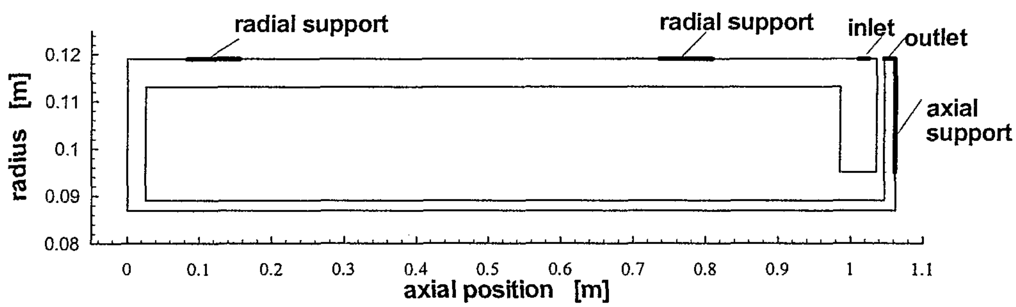


FIGURE 5. The model of LHe flow channel

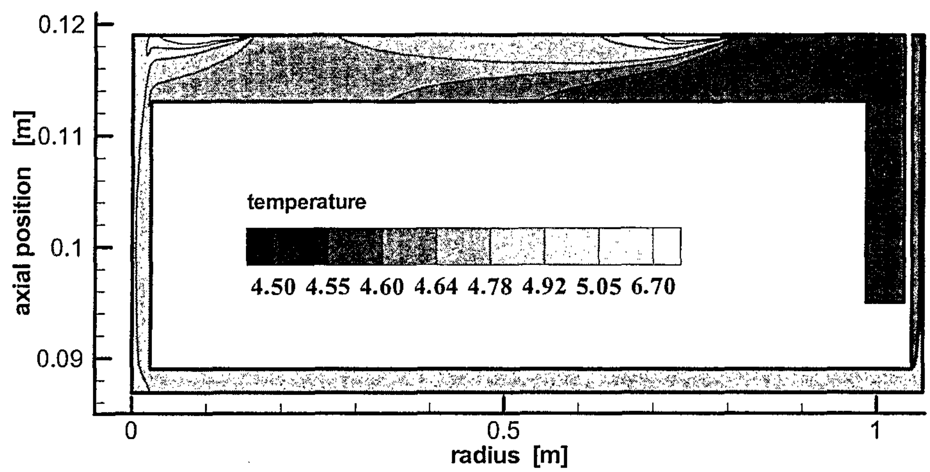
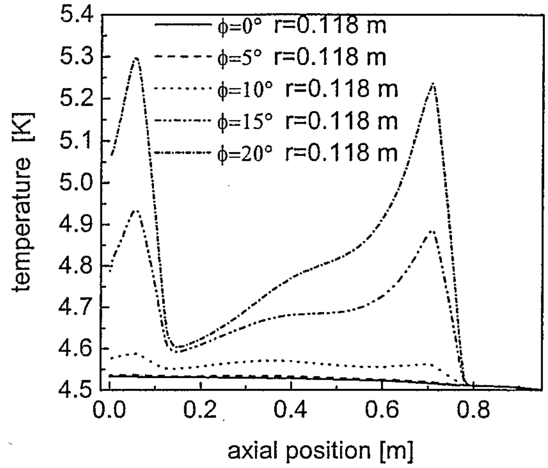


FIGURE 6. Temperature contour at $\phi = 20^{\circ}$ and 12 g/s



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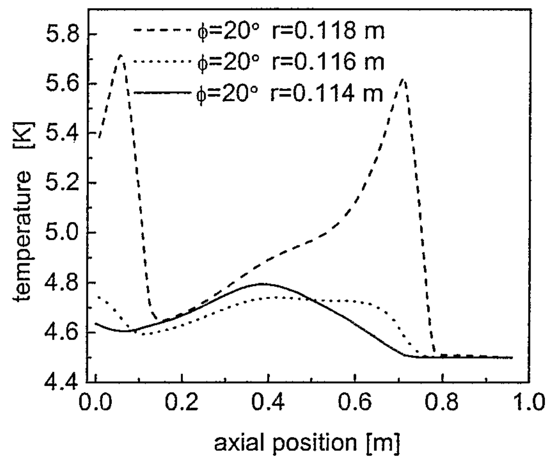

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FIGURE 7. Temperature vs. axial position. a. $r = 0.118m$, b. $\phi = 20^{\circ}$

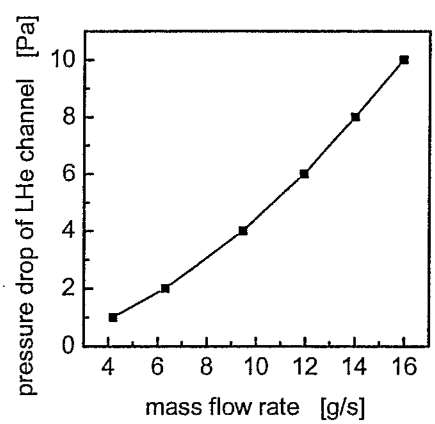

FIGURE 8. Mass flow rate vs. pressure drop

CONCLUSONS

The heat loads at 4K for the SCQ magnet are computed using the CFD software. The dominant part of the loads is from the heat conduction of the radial supports, which is 10.4W. The total heat loads is 16.3 W.

Based on the calculated heat loads, simulation on the supercritical helium cooling for the magnet is carried out. Most of the helium fluid inside the cooling channel keeps lower than 4.7 K. The temperature of the magnet is around 4.6 K. The pressure drop can be negligible.

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