Numerical simulation on thermal stress and magnetic forces of current leads in BEPCⅡ

Zhang X.B.[1], Jia L.X.[2]

[1]Institute of Cryogenics and Superconductivity Technology, Harbin Institute of Technology, Harbin 150001, CHINA
[2]Brookhaven National Laboratory, Upton, New York 11973, USA

Six pairs of low current leads are used for the superconducting interaction quadruple magnets (SCQ) in the Beijing Electron Positron Collider Upgrade (BEPCII). This paper presents analyses on the magnetic field induced by the current lead bundle as well as the magnetic forces on the leads. The thermal stress of the single lead is investigated. The stress of interference fitting for a novel insulator used for the current leads at various operating temperatures is analyzed.

INTRODUCTION

One pair of current leads with nominal current 1600A, two pairs with nominal current 630A and three pairs with nominal current 150A have been designed for the SCQ magnet in BEPCII. Figure 1 shows the schematic diagram of the current lead bundle. A novel cryogenic electrical isolator has also been designed for the leads. With the FEM software package ANSYS, this paper presents numerical simulation on the magnetic field of the current lead bundle induced by the operating current. The thermal stress of the 1600A current lead is investigated in detail. The stress of interference fitting for the insulator at various operating temperatures is analyzed to avoid the failure of the involved material.

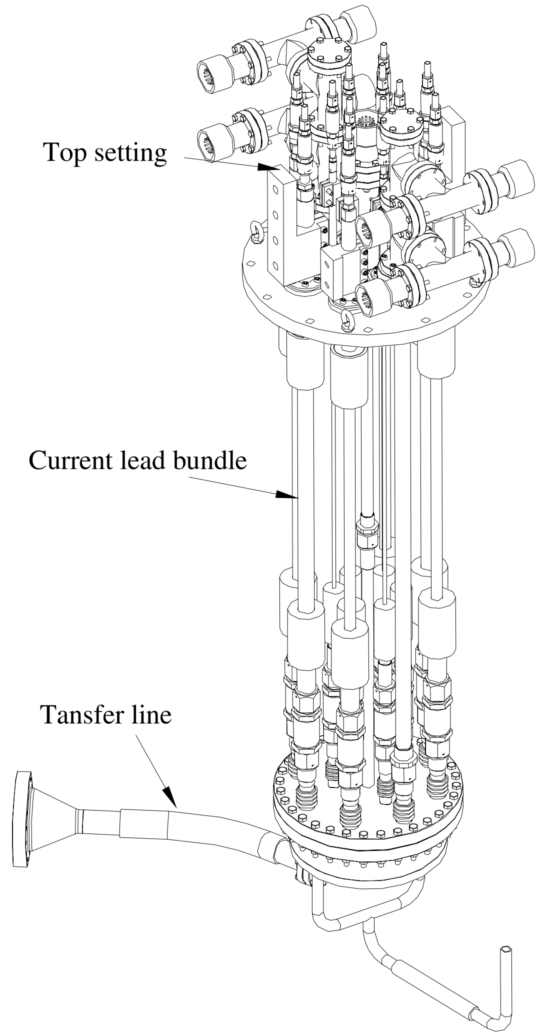

Figure 1 Current lead bundle for the SCQ magnet in BEPCⅡ.

MAGNETIC FIELD OF CURRENT LEAD BUNDLE

The numerical model of the current lead bundle for the magnetic field simulation is shown in Figure 2. The relative location of the current leads carrying different current flux is indicated. The symbols “+” and “-” indicate the current direction. The equivalent inner diameter d_e is introduced to simplify the multi-pipe structure [1] of the current leads based on the same cross section area. Both the copper and vacuum have the same relative magnetic permeability of 1, and no external magnetic field is applied. The vacuum shield and other transfer tubes are neglected for their little effects on the magnetic field. The far field is used to explain the infinite field beyond the interesting zone of the current lead bundle. Figure 3 shows the magnetic intensity and the isochronous magnetic force applied to the left

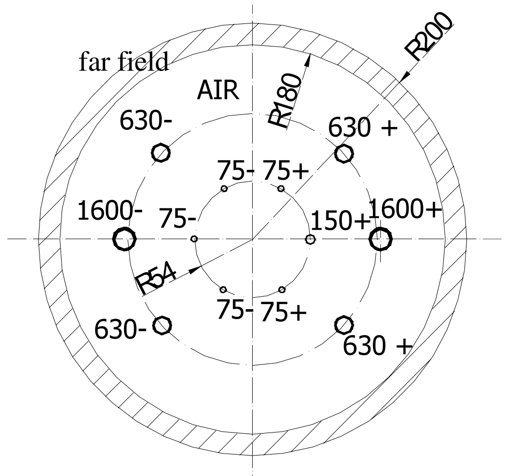

Figure 2 Model of magnetic field simulation of the current lead bundle.

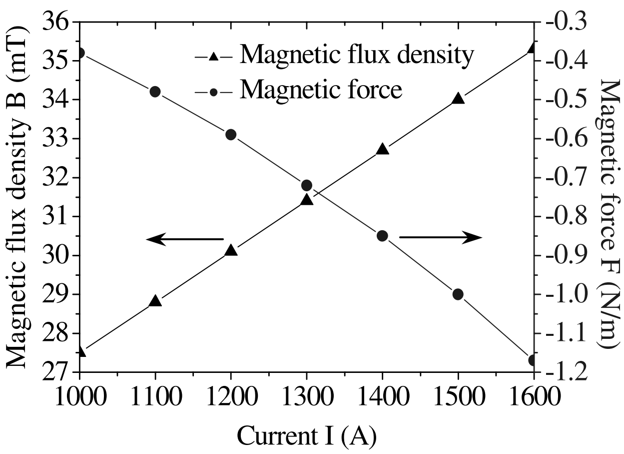

Figure 3 Variation of magnetic force F and magnetic flux density B as function of maximum current I .

1600A current lead at different current I . The maximum magnetic flux density of 0.035T is found in the vicinity of the 1600A current leads for the normal operation. This value reveals that the effect on the accuracy of the silicon diode thermometers is inappreciable [2]. The symbol minus for the magnetic force means that the lead is pushed back from the right 1600A lead. When $I = 1600A$, the maximum magnetic force -1.17N/m is applied to the 1600A current leads. This corresponds to the stress of 52.7pa with its outer diameter of 22.22mm.

THERMAL STRESS OF 1600A CURRENT LEAD

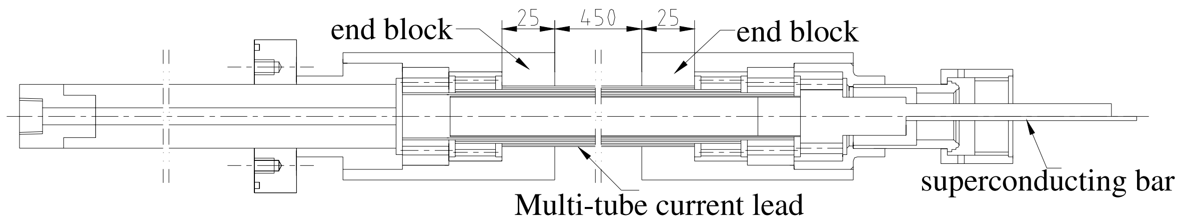

Figure 4 Schematic diagram of the 1600A current lead for the SCQ magnet

The thermal stress of the leads cooled down from room temperature to the operating temperature has great effluence on the lead performance. The temperature distribution along the gas-cooled current lead by the numerical analysis on thermal process has been studied [3]. For the multi-tube current lead of 1600A (see Figure 4), axisymmetric condition is adopted for simplifying the simulation model. Considering their similar temperature distribution and connecting fashion, only outer tube of the multiple tubes is modeled. The length of the lead is 0.45m excluding the 25mm soldering length with the end copper block (see Figure 4). The tube has the outer diameter of 22.22mm with the wall thickness of 1.5mm. The temperature of the hot end block is set at 300K and is considered stable along the soldering length for all degrees of freedom. A ripple tube is added below the cold end block to allow thermally shrinking and for convenient assembling of the leads, thus no constraint of degree of freedom is set at cold end block. The Young's modulus and coefficient of thermal expansion of copper are the function of temperature and the Poison ratio of copper is set to 0.3 here [4]. Figure 5 shows the Von Mises stress profile along the outer wall of the tube. It reveals clearly that the stress has almost no effect on the majority of the length of the lead. However, the stress goes up to about 10MPa just at the beginning of the soldering surface at hot end. Fortunately, this value of thermal stress is very small comparing with the soldering strength we usually acquired.

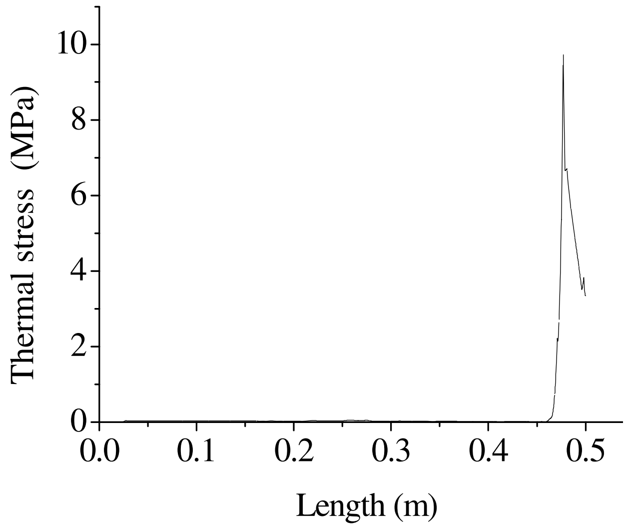

Figure 5 Von Mises stress profile of outer wall along the 1600A current lead for the SCQ magnet.

TRESS OF INSULATOR

The leads must be electrically insulated at both ends while the cooling gas can go through them. One type of insulator has been designed to meet this requirement. The insulator is consisted of two coaxial tubes. The inner tube is made of g-10 with its outer diameter greater than the inner diameter of the outer aluminum casing at room temperature. The function of aluminum casing is to strengthen the insulator. The helium transfer pipes are connected to the inner tube through the fittings. A quarter of model is appropriate to simulate the contact because of the symmetry of the insulator. Axis-direction displacement of one end of the inner tube is set at zero and no other constraint of degree of freedom is applied.

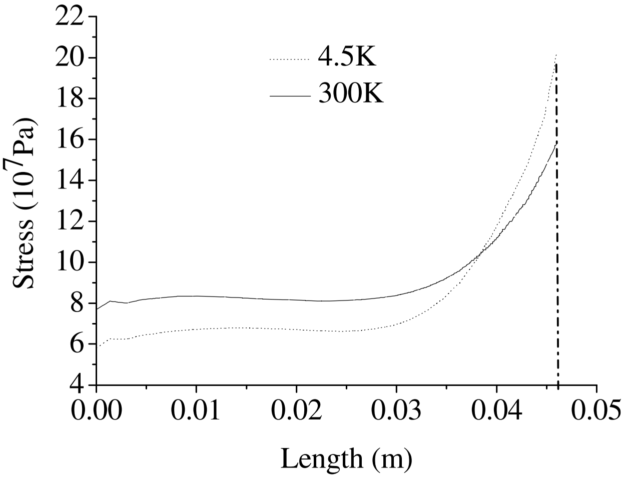

Figure 6 Von Mises stress along the length of the contact surface of the inner tube at 300K and 4.5K.

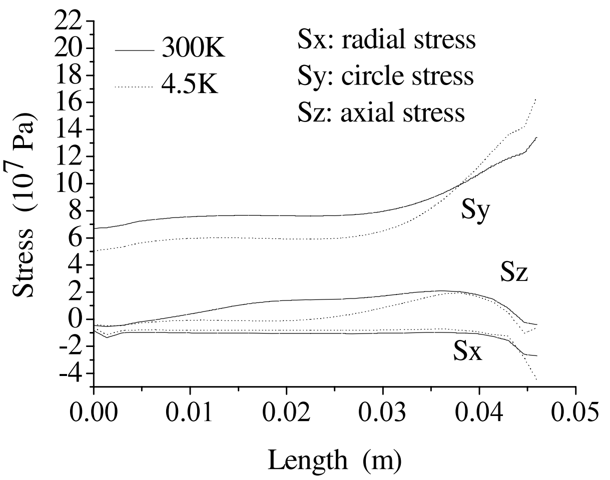

Figure 7 Stress components along the length of the contact surface of the inner tube at 300K and 4.5K.

During simulation two different load steps are defined: The objective of the first load step is to observe the interference fitting stress of the insulator at room temperature. The second load step is to observe the contact stress when the insulator is cooled down to 4.5K. Figure 6 shows the Von Mises stress profile along the length of the contact surface of the inner tube at 300K and 4.5K. The fixed end of the inner tube has the maximum stress value of 0.135GPa and 0.2Gpa at 300K and 4.5K, respectively. A strange phenomenon is found that the stress of the contact surface at 300K is larger than that at 4.5K when the length is less than about 40mm, but reversed at the rest part. The reason is that aluminum shrinks theoretically more than g-10 when they are simultaneously cooled down to 4.5K and the two will contact more tightly than that at 300K， while the Young's module of g-10 is decreased from 73.5GPa at 300K to 68.6GPa at 4.5K [4]. Besides the radial displacement, there also exits the axial frictional stress and the circle stress (see Figure 7). The circle stress component holds dominant position among these stress components. The constraint on the zero axial displacement at the right end of the inner tube also resists the radial displacements during cooling process, so the circle stress component increases greatly as it approaching to the fixed end, which offsets the reducing of the Young's module of g-10 and finally exceeds the stress at 300K.

CONCLUSION

The numerical simulation for the magnetic field induced by the current lead bundle of the SCQ magnet in BEPCII shows that the effect of the magnetic field intensity on the accuracy of silicon diode thermometers is inappreciable, and the magnetic force on each of current leads is negligible by comparing with the thermal stress. When the 1600A current lead is cooled down from room temperature to the normal operating temperature, the maximum stress of 10MPa is found at the soldering place of the warm end from the results of thermal stress simulation. For copper, this stress value is acceptable. The results of the numerical simulation for the novel cryogenic electrical insulator reveal that the maximum stress of the inner tube is 0.135GPa and 0.2GPa at 300K and 4.5K respectively. However, the maximum stress value may be overestimated for the boundary condition of no axial displacement at one end.

REFERENCE

1. Jia, L.X. et al, Design Parameters for Gas-cooled Electrical Leads of the g-2 Magnets, Cryogenics (1994) 34 631-634
2. Jia, L.X. and Wang, L., Cryogenic Engineering, Harbin Institute of Technology, 20 (interior material)
3. Zhang, X.B., Wang, L. and Jia, L.X., Numerical analyses on transient thermal processes of gas-cooled current leads in BEPCⅡ, to be published in Advances in Cryogenic Engineering (2004), 49
4. Ying X., Handbook of Mechanical design, Mechanical Industrial Press, Beijing, China (1991) 2-47