

## Cryogenics In BEPCII Upgrade

Jia, L.\*<sup>1</sup>, Wang, L.\*<sup>1</sup> and Li, S.\*<sup>2</sup>

\*<sup>1</sup>Brookhaven National Laboratory, Upton, New York 11973, USA

\*<sup>2</sup>Institute of High Energy Physics, Beijing 100039, CHINA

This paper presents cryogenic design for upgrading the Beijing Electron-Positron Collider (BEPC) at the Institute of High Energy Physics (IHEP) in Beijing. The upgrade involves three new superconducting facilities, the interaction region quadrupole magnets, the detector solenoid magnets, and the SRF cavities. For cooling of these devices, a new cryoplant with a total capacity of 1.0 kW at 4.5K is to be built at IHEP. An integrated cryogenic design to fit the BEPCII cryogenic loads with high efficiency is carried out using computational process analysis software with the emphases on economics and safety in both construction and operation of the plant. This paper describes the cryogenic characteristics of each superconducting devices, their cooling schemes, and the overall cryoplant.

## INTRODUCTION

In BEPCII upgrade, to realize the goal of two orders of magnitude higher luminosity, three superconducting hardware systems need to be developed, including a pair of superconducting interaction region (SIR) quadrupole magnets, a pair of superconducting radio frequency (SRF) cavities, and the superconducting detector (SCD) solenoid magnet. To increase the luminosity the amplitude of the beta function at the interaction point needs to be decreased. This can be achieved by local focusing using powerful superconducting quadrupole magnets. In the case of the BEPCII, two quadrupole magnets for the interaction region are used. To minimize the loss of solid angle for particle detection, the transverse dimension must be kept as small as possible. Therefore, the superconducting magnets and their cryogenic system must be designed in close coordination. Two superconducting RF cavities are also used in the BEPCII to achieve higher stored beam current, shorter bunch length, and thus higher collision luminosity for the Beijing Spectrometer (BESIII) detector as well as for the synchrotron light source. The 500 MHz single-cell superconducting niobium cavity is proposed for the BEPCII. The BESIII superconducting solenoid magnet is designed to produce axial steady magnetic field of 1.0 Tesla over the tracking volume and to meet the requirement of particle momentum resolution to particle detectors. [1,2]

This paper intends to provide a base for the engineering design of the BEPCII cryogenic system. It describes the cryogenic characteristics of each superconducting cryomodule and their cooling methods as well. It also provides the system parameters of the BEPCII cryogenic system and the configuration of the overall cryoplant.

## SUPERCONDUCTING CRYOMODULES

### SIR Magnets

Two identical iron-free and non-collared coils with active shielding are proposed for the BEPCII SIR magnets. Figures 1 and 2 show the layer arrangement and the axial structure of the magnet cryostat. Each

magnet consist of one dipole coil, one anti-solenoid, one shielding solenoid, one quadrupole coil, one horizontal dipole correction coil, one vertical dipole correction coil, and one skew quadrupole coil. They are all wound in layer-by-layer manner on a common support cylinder. The magnet has an overall effective length of 0.96 m and provides a good field aperture of 130 mm in diameter. The total length of the cryostat is 1332 mm. The inner diameter is 132 mm and the outer diameter is 332 mm. The outer diameter of the endcan is 635 mm. The magnet cryostat is designed as an assembly of four individual units, the coils and its support cylinder, the liquid helium vessel, the liquid nitrogen shield, and the vacuum chamber. The vacuum chamber has an endcan with an enlarged diameter containing the power cable box, the LHe supply and return pipes, and the LN2 supply and return pipes. From the endcan, a cryo chimney is used to link the magnet cryostat and the service cryostat. The service cryostat contains the power leads with different currents, the LHe and LN2 bayonet ports, the control valves, and the instrumentation ports.

Because the severe constrain in the radial dimension of the magnet cryostat, the annular channels for LHe and LN2 flows are slim. To eliminate vapor bubble in the helium flow around the coils, the magnets are cooled by sub-cooled single-phase helium. Heat is absorbed by the sensible heat of helium mass flow rate of 9 g/s with a corresponding increase in temperature, 0.7 W/(g/s) at  $\Delta T=0.1K$ . The flow instabilities like those in two-phase flow conditions are excluded. The maximum allowed temperature rise is about 0.1 to 0.2 K. The outer surface and inner surface along the length of the magnet are cooled in series. The corresponding T-S diagram is given in Figure 5. The 4.5 K heatload in each magnet cryostat is 7 W. Of other heatloads, there are the 15 W in each service cryostat, the 25 W in the control dewar with electrical heater, the 10 W in the transfer line of 25 m, and the 0.12 g/s helium mass flow for the power leads. The total mass flow rate of 24.5 g/s at 4.42 K and 0.14 MPa from the subcooler control dewar is required. The total cryo load in a pair SIR magnets to the BEPCII helium refrigerator is 95W without contingency.

**SRF Cavity**

To illustrate the SRF cryomodule for the BEPCII, one proposed design is shown in Figure 3. The 500 MHz single-cell superconducting niobium cavity resides inside a liquid helium vessel. It is surrounded by insulation vacuum, LN2 thermal shield, layer of magnetic shielding  $\mu$  metal, layers of MLI superinsulation, and room temperature vacuum enclosure. All cryogenic service ports including those for LHe, LN2, pressure relieves, and vacuum pumping are mounted on the vacuum chamber end plates.

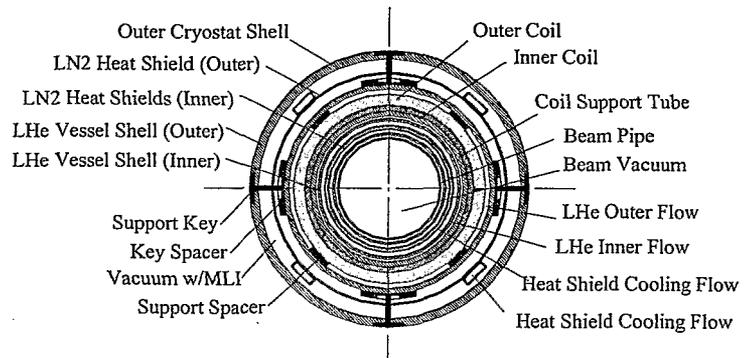


Figure 1 Cross section of BEPCII SIR magnet

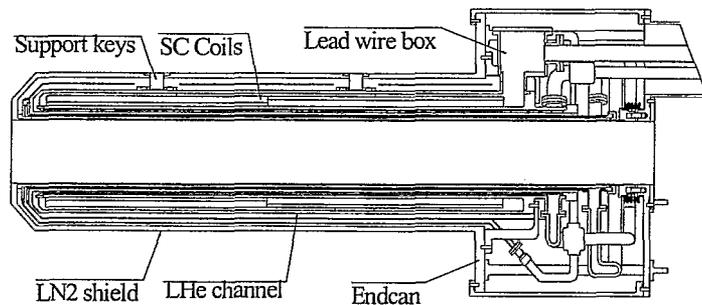


Figure 2 BEPCII SIR magnet cryostat

The static heat loads in the SRF cryomodule include the beampipe heat conduction at each side of the cavity cell, the wave coupler thermal transition, the heat conduction in suspension of LHe vessel, and the thermal radiation from LN2 shield. The dynamic loads include the heat dissipation in the SRF cell and couplers. The static load on each cryomodule is estimated 31 W. The dynamic load on each cryomodule is estimated 51 W which is due to the RF dissipation assuming the unload Q of  $5 \times 10^8$  at 1.5 MV per cavity. The mass flow rate of 0.15g/s is used to cool the waveguide. The heat load in the LHe storage dewar, the control valve box, and the local transfer line is estimated 74 W. The total thermal load to the cryoplant for the two cavities at operation will be 287 W. Saturated helium at slightly above atmospheric pressure and a temperature of 4.4 K is used for bath cooling of the SRF cavity. Heat flux of 19.7 W/g/s of helium flow is absorbed by the latent heat of helium. The LHe mass flow rate of 7.5 g/s is used for each SRF cryomodule during the normal operation. Figure 5 shows the T-S diagram for the saturated helium cooling of the SRF cryomodules comparing with those for the SIR magnets and the SCD solenoid. There is 380 liters of LHe in each SRF cryomodule. To supply and recover the LHe in a control manner, the 2000 L storage dewar with an electrical heater is used. The cooling of the SRF cryomodule and the helium flows are controlled by a service cryostat containing the control valves and bayonet ports.

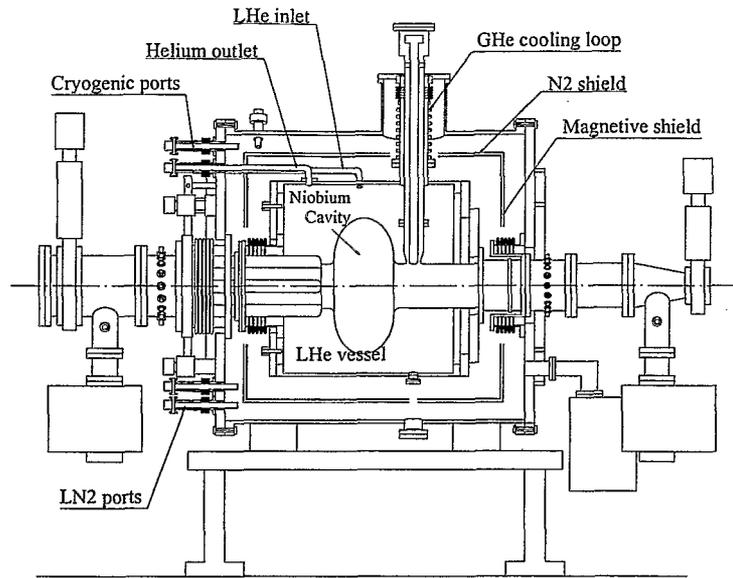


Figure 3 Illustration of the SRF cryomodule

SCD Solenoid Magnet

BESIII SCD solenoid magnet can be categorized as the bobbin-less and thin-wall superconducting solenoid magnet. The S.C. coil radius is 1.47 m and the length is 3.5 m. The nominal magnet field is 1.0 T at the nominal operating current of 3000 A. The stored energy is 7.4 MJ and the cold mass is 997 kg, which yield the cold mass design ratio of 7.4 kJ/kg at the maximum quench temperature of 74 K.

Having two successful techniques used in cooling the thin-wall S.C. solenoid magnets in existing running systems around the world as the options, the thermosyphon cooling and the forced two-phase flow cooling, the current design has adopted the later method. Figure 4 shows the cooling loop arrangement on the support cylinder. Same as the saturated liquid, heat flux of 20 W/(g/s) of helium flow is absorbed by the

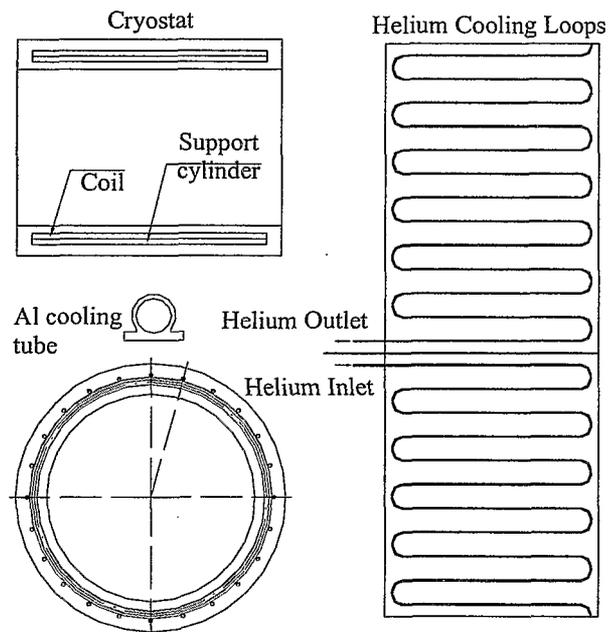


Figure 4 Coil support cylinder with cooling loops

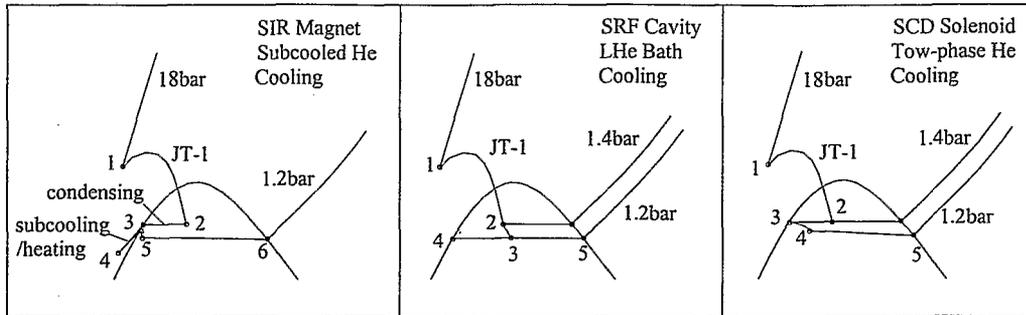


Figure 5 helium T-S diagrams for three cryomodules

latent heat of helium. The helium is boiling at nearly constant temperature, increasing fluid quality along the cooling path. The cooling pipe is made of extruded aluminum alloy with an inner diameter of 16 mm and is welded to the outer surface of the support cylinder. It has 24 serpentine passes in series with a total pipe length of 95 m. The serpentine shape is selected rather than the spiral shape to avoid severe pressure oscillation in the forced two-phase flow. The total heat loads in the SCD cryostat is 95 W at 4.5 K with additional 0.2 g/s helium mass flow rate for the currents leads. The heat leaks in the solenoid cryostat include the radiation heat flux of 15 W and the heat conduction in the coil mechanical support of 25 W. The cryo chimney and the service valve box present 10 W. The control dewar for two-phase flow with an installed electrical heater has 25 W. During the magnet charging/discharging, an eddy current loss of 5 W in the support cylinder will build up in a period of 30 minutes. In case of emergency fast ramping, the dynamic cryogenic load could increase up to 15 W.

#### OVERALL CRYOGENIC SYSTEM

BEPCII cryoplant with a total capacity of 1kW at 4.5 K was designed for the operation of all these superconducting facilities. The main challenge to the BEPCII cryogenic system is to accommodate the strong differences among the three types of superconducting devices as regard to their structures, locations, and cryogenic operating requirements. Three types of cooling methods are applied in the cryogenic system, the saturated liquid helium cooling for the SRF cavities, the subcooled liquid helium cooling for the SIR magnets, and the two-phase helium cooling for the SCD solenoid. In order to meet these requirements, the normal duty of the cryoplant is to supply a mix of liquefaction and refrigeration at 4.5K in varying proportions depending on the operating modes of each device. Table 1 gives the cryogenic characteristics of the each S.C. devices.

Table 1 Cryogenic characteristics of the superconducting devices

	SIR Magnets	SCD Solenoid	SRF Cavity
<b>Cold mass</b>	2 x 160 kg	2,720 kg	2x350 kg (est.)
<b>Cooling method</b>	Sub-cooled helium	Two-phase helium	Liquid helium bath
<b>Control dewar capacity</b>	1000L/25W	(1000L/25W)	2000L/74 W
<b>Mass flow rate</b>	18.5 g/s	5.56 g/s	14.7 g/s
<b>Refrigeration</b>	108W+0.12g/s	125W+0.2g/s	234 W+0.15g/s
<b>Operating temperature</b>	4.46 – 4.56 K	4.44 – 4.41 K	4.4 K
<b>Operating pressure</b>	1.4 bar	1.25 bar	1.2 bar

There are several options in configuration of the cryoplant. These options exist because of the site location of each cryomodule, the space availability, construction cost, equipment capital expenses, operation requirements, maintenance convenience, and safety regulations, etc. The SIR magnets and the SCD solenoid will be installed in the first interact region. The two SRF cavities will be installed in the RF straight-line section at the second interact region. The distance in cryogenic path between these two sites is about 100 m. Two refrigerators of 500 W on each have been configured for installation at each interact region with the remote operating controls.

## CONCLUSIONS

To support the three types of superconducting devices for BEPCII upgrade, substantial cryogenic facilities will be constructed around the BEPC site. The major cryogenic facilities in the overall cryogenic system include the middle and low pressure helium gas tanks, helium screw compressor skit, helium gas purification system, helium refrigerator cold box, liquid helium storage and control dewars, liquid nitrogen tower, liquid nitrogen circulation system, instrumentation air compressor and air buffer tanks, and transfer lines in various type and length. The layout of the BEPCII cryogenic system in BEPC site has been proposed for construction plan and the cryogenic engineering design is in progress.

## REFERENCES

1. BEPCII Groups, BEPCII Design Reports, Institute of High Energy Physics, (2002)
2. Zhang C., Overview on the BEPCII Accelerators, International Workshop on BESIII Detectors, (2001)