Cryogenic facility design in BEPCII superconducting upgrade

Jia L.X.*,Wang L., Yang G.D., Liu X.K., Zhang X.B., Tang H.M., Du H.P., Xing Z.H., Liu C.S., Han G., Xu F.Y., Wang T.H., Yang C.Z., Xiao H., Liu D., Shi L.H., Huang M.X., Gai X.Y., Xu F.Y., Ji Z.M, Jiang W., Yao Z.L., Chen A.B.,

*Brookhaven National Laboratory, Upton, New York 11973, USA
Institute of Cryogenics and Superconductivity Technology, Harbin Institute of Technology, Harbin 150001, China

Three kinds of superconducting device are to be constructed at interaction regions in the upgrade of Beijing Electron-Positron Collider (BEPCII). Two sets of refrigerators with each capacity of 500W at 4.5K are adopted to provide the refrigeration for them. The cryogenic systems to support the operation of the superconducting facilities are under design by Harbin Institute of Technology in China. This paper presents the current design of main cryogenic facilities.

INTRODUCTION

In order to support the operation of three superconducting devices in BEPCII upgrade, a cryo-plant with the cooling capacity of 1.0 kW at 4.5K is under design [1, 2]. It is composed of two refrigerator systems with each capacity of 500W at 4.5K. One is to cool a pair of superconducting quadrupole magnets (SCQ) together with a superconducting solenoid magnet (SSM) located at the first interaction region, and the other is to cool a pair of SRF cavities at the second interaction region.

The main tasks of the cryogenic system involve production of refrigeration power, preparation and distribution of cryogens, cooling of cryomodules, handling of different modes of operation, recovery, purification and storage of cryogens as liquid or gas, process control and monitoring, and cryogenic safety. Correspondingly, the cryogenic system is made of various cryogenic facilities such as refrigerators, control dewar, control valve boxes, subcoolers, transfer lines, storage tanks and purifiers. The engineering design of the BEPCII cryogenic system has been carrying out by the Institute of Cryogenics and Superconductivity Technology at Harbin Institute of Technology since March, 2003, and almost completed. This paper presents the current design of the main cryogenic components in detail.

CRYOGENIC FACILITIES DESIGN FOR SUPERCONDUCTING MAGNETS

The refrigerator systems can be divided into three parts, which are the helium compressor and refrigerator system, LN2 system, and cryogen production and distribution system. The three parts are connected by low temperature supply and return transfer lines and 300K supply and return lines. The cooling system for the magnets shares the helium purification, recovery and storage system with that for the SRF cavities [4]. Two LN2 tank with each volume of 30m3 serves to supply the liquid nitrogen for precooling of the refrigerator and cooling of heat shields inside the cryomodule, which are respectively located close to the first and second colliding hall.

The SCQ magnets are to be cooled by single-phase helium in order to eliminate the flow instability in constraint cooling channel [3], and the SSM magnet is to be cooled by forced two-phase flow. The cryogen production and distribution system for the magnets mainly includes a control dewar with a built-in heat exchanger acting as a thermal subcooler, a distribution valve box, service cryostats for magnets, and cryogenic transfer lines.

Control dewar and subcooler

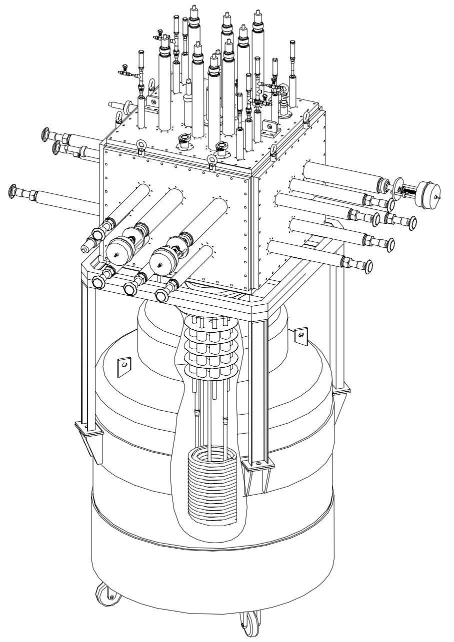

Figure 1 Control dewar, subcooler and distribution valve box

The subcooler is a coil-shaped heat exchanger residing in the control dewar with the volume of 1000 liter (see Figure 1). The neck of the control dewar is modified to allow the installation of the heat exchanger and connected with the distribution valve box. The heat loads through the neck to the dewar have to be minimized. The subcooler is used to further cool the supercritical helium or two-phase helium flow from the J-T circuit of the refrigerator before it goes into the magnet cooling circuit. The liquid pressure in the control dewar is lower than that in the heat exchanger and while the outgoing helium temperature in the heat exchanger can reach to the saturation temperature at control dewar pressure. It produces low temperature helium with high pressure. The control dewar can server as an oscillation dumper for helium supply to the magnets and a phase separator for the helium returning from the cryostats. It can also act as a buffer vessel that can provide additional cooling by using the liquid stored in the dewar during times when the thermal load exceeds the capacity of the refrigerator, or withdraw the LHe when needed.

The supercritical helium at 2.7bar and around 5.2K with the mass flow rate of 35.25g/s from the refrigerator cold box flows through the subcooler and can be cooled to about 4.6K. The heat exchanger is made of copper tubing with the inner diameter of 17mm and the outer diameter of 19mm. The copper tubing with 40m in length is currently wound as three layers with the diameters of 200mm, 245mm, and 290mm, respectively. The height of the heat exchanger is about 350mm. The size and structure of the subcooler is largely restricted by the neck size and inner space of the liquid helium dewar. The numerical optimization for the subcooler is being carried out, and the design will be further updated later.

Distribution valve boxes

The distribution valve box is one of substantial facilities in the BEPCII cryogenic system through which the supercritical or two-phase helium from the refrigerator is sub-cooled and distributed to the two SCQ magnets and SSM magnet. It is deigned as a vacuum-insulated cuboid vessel in order to reduce the radiation heat load from room temperature (Fig.1). The vessel is composed of a support frame and six demountable stainless steel plates. The bottom plate is located on the top of the 1000L dewar, and the other five plates are easy to disassemble. The valve box is 1m wide, 1m long and 0.8m high. There are totally thirteen cryogenic valves for control of helium flow, two valves for LN_2 delivery respectively to the SCQ and SSM, nine safety valves, one vacuum relief valve, several pressure transducers and temperature sensors as well as relevant electric feedthroughs and service ports arranged tightly and compactly in or on the valve box. Thirteen cryogenic bayonets are applied to connect the low temperature transfer lines among the refrigerator cold box, the valve box and the magnets' cryostats, which allow the disconnection of the transfer lines without destroying the vacuums inside the valve box and transfer lines themselves. To decrease the conductive heat leak induced by the parts fixed or supported on the chamber walls, the valves and bayonets with long stems are employed. The piping for the safety valves and pressure transducers is made as long as possible.

Besides the heat leak, thermal stress is another concern for the design of the valve box. The displacement caused by the thermal stress for the piping must be considered when the temperature changes during cool down and warm up process in order to avoid the mechanical failure. For the six vessel plates, incase of cracking of the piping in the box, the low temperature helium or liquid nitrogen would spill into the vacuum vessel, and then the plates would deform or even to be broken due to the thermal stress. The numerical simulations and analyses on the thermal stress and strain for the piping and the plates at the above scenario were performed by ICST. The thickness of the plates is finally chosen as 30mm, and five flexible lines are used to compensate the piping contraction during the cool-down process.

Service Cryostats for magnets

The service cryostat is designed to provide a connection between the warm electrical power cable and the superconductor wires from the coils. Gas cooled current leads for SC coils are installed inside the cryostat. The current leads are made of copper tubes with the insulators at each end. The electrical power cables are attached to the bus bars of the current lead at the top and run to the power supply box.

The cryostat also serves as a cryogenic distribution box that controls the cooling flows for the superconducting magnets, thermal shields, and current leads by cryogenic valves at various operating modes including magnet quench. It is connected to the magnet cryostat through a cryogenic chimney. The heat leak and thermal stress are also two of major concerns during their design similar to the distribution box. There are totally three service cryostats in the first colliding hall, of which two are for SCQ magnets (see Figure 2), and one is for SSM magnet (see Figure 3). The cylindrical vacuum-insulated vessel made of stainless steel is 800mm in diameter and 1040mm in height for SCQ, and 1000mm in diameter and 1400mm in height for SSM. The SCQ service container can be easily assembled or disassembled from the flange at its lower portion, while the SSM service cryostat can be disassembled from the bottom flange for easy maintenance. The vacuum ports are set at the lower portion of the vacuum chamber. On the top flanges are tightly arranged the cryogenic valves and bayonets to control and connect the supply and return of helium and nitrogen, and helium back to quench line, as well as safety valves, pressure transducers and electric feedthroughs. The SC cables and various transfer lines can be disconnected at the bottom of the cryostat.

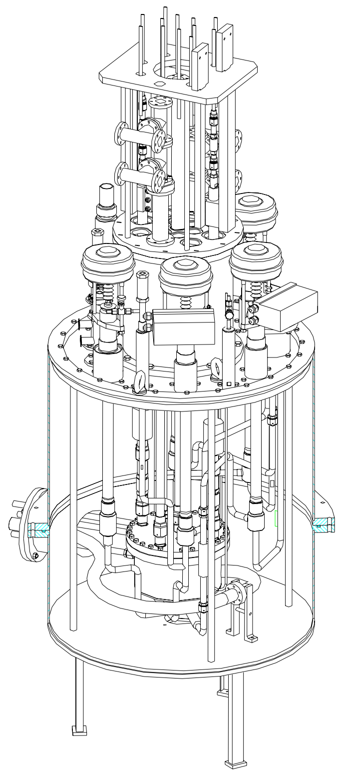

Figure 2 SCQ service cryostat

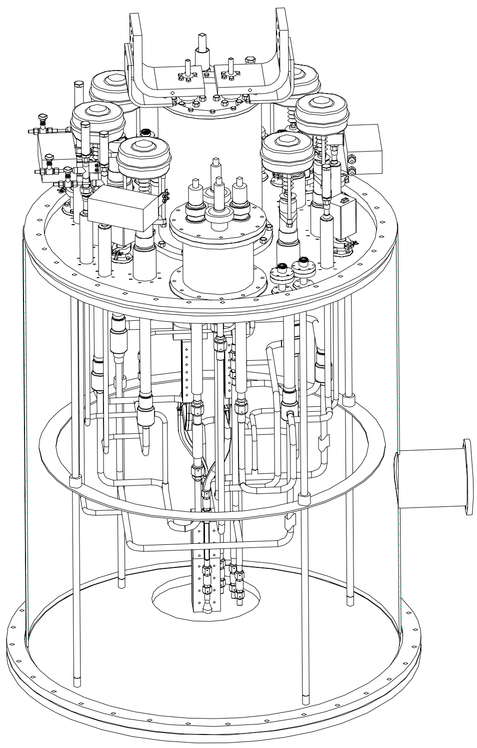

Figure 3 SSM service cryostat

CRYOGENIC FACILITIES DESIGN FOR SUPERCONDUCTING CAVITIES

The cryogen production and distribution system for the magnets mainly includes a control dewar of 2000 liter, a distribution valve box, and cryogenic transfer lines, which all are placed at the second interaction region. The control dewar performed the same function as that of the 1000L control dewar at the first interaction region.

2000L control dewar

The modified control dewar can server as both an oscillation dumper and a phase separator for the helium supply and return to and from the cavities. It can also act as a buffer vessel that can provide additional cooling by using the liquid stored in the dewar during times when the thermal load exceeds the capacity of the refrigerator, or withdraw the LHe when needed.

SRF distribution valve box

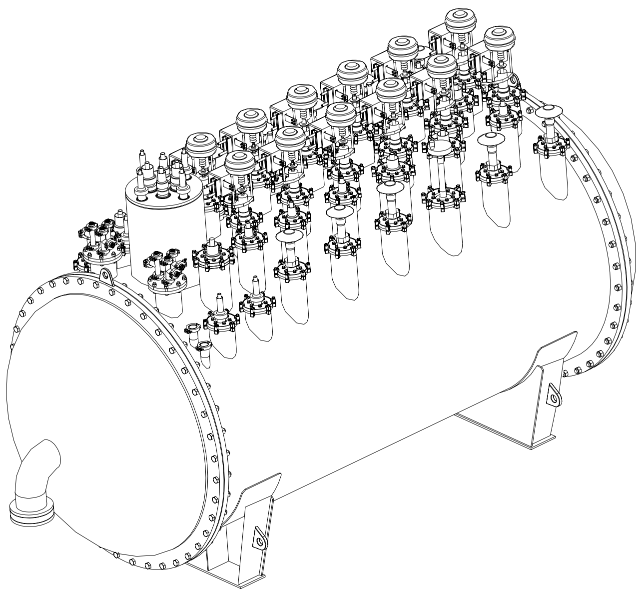

Figure 4 SRF valve box

The SRF valve box is to distribute and control the helium and nitrogen flows to the helium vessels and thermal shields of two SFR cavities at on-line or test spots (see Figure 4). It consists of a horizontal cylindrical vacuum vessel with two ellipse end caps and supports, twenty-four cryogenic valves, twenty-two bayonets, twelve safety relief valves and various ports for instrumentation. All the components including the piping inside are vertically placed at its upper portion, which will be pre-assembled outside by customized tooling, and then inserted into the vessel. The valves are connected with the container by flanges to allow easy disassembly. The vacuum port is set at one end cap. The vessel is 1400mm in inner diameter, 10mm in thickness and 2794mm in length. The overall length of the facility is 3952mm. It is one of the most complicated designed facilities in BEPCII cryogenic system.

CONCLUSIONS

This paper presents the current design of main cryogenic components in BEPCII. They are designed based on the operation requirement and space limitation. The heat leaks induced from room temperature and thermal stress during cool-down, warm-up and failure modes are considered.

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