DESIGN OF A TEST CRYOMODULE FOR IMP ADS-INJECTOR II

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Abstract

Two cryomodules are to be applied for the Injector II of the Accelerator Driven Sub-critical System (ADS). Each of them will contain 8 superconducting HWR cavities and 9 superconducting solenoids. In order to test the performance of the HWR cavities and validate the related technique for cooling the cavities and the solenoids together, a test cryomodule (TCM1) including one HWR cavity followed by one cold BPM and two superconducting solenoids was developed. The design of the TCM1 cryostat was carried out by the Shanghai Institute of Applied Physics (SINAP), CAS. The vacuum of the cryostat is independent from that of the beam line. Both the cavity and the solenoids will work at 4.4 K by bath cooling. The fast cooling down for the cavity from around 100 K to 120 K is required to avoid degrading of the cavity performance. After cool down and before energization, the solenoids can be warmed up to above 10 K and re-cooled down for the purpose of degaussing. The TCM1 can not only be cooled by using the dewar-filling system, but also operated by the refrigerator system. The main components of the cryostat were designed including vacuum chamber, thermal shields, magnet current leads, cooling circuit, and cold mass support assembly. This paper presents the detailed design of the TCM1 cryostat.

INTRODUCTION

The Accelerator Driven Sub-critical System (ADS) to be built by Chinese Academy of Sciences in China consists of two injectors and one main linac. The Institute of Modern Physics in Lan Zhou undertakes construction of the Injector II, which includes two cryomodules. Each of the two cryomodules will consist of 8 superconducting half-wave resonance (HWR) cavities and 9 superconducting solenoid magnets, and each cavity is followed by one cold BPM, as shown in Fig. 1. A test cryomodule (TCM1) has been developed for the purpose of performance test of the HWR cavities as well as validating the relevant technique for cooling the cavity and the solenoids together under the collaboration between IMP and SINAP. The TCM1 comprises a 4 K cold mass assembly and a cryostat. The 4 K cold mass assembly includes one HWR cavity, one cold BPM and two SC solenoids. The development of the SC device was carried out by IMP, and the design of the TCM1 cryostat was implemented by SINAP as shown in Figure 2 [1].

4 K COLD MASS ASSEMBLY

The cold mass assembly to work at liquid helium temperature includes one HWR cavity, one BPM and two solenoids, as shown in Fig. 2. The HWR cavity horizontally positioned is made of pure niobium and immersed in a liquid helium vessel made of titanium (TA2). Its coupler made of copper is vertically positioned and to be cooled by cold helium gas. Its tuner made of Ti alloy is put at one side of the cavity. The SC magnet is composed of three solenoids, one main coil operated at a current of 100 A and two correctors at 50 A. The coils are wound by using copper stabilized NbTi conductors. The liquid helium vessel containing the solenoids, the cold BPM next to the cavity and the beam ducts connecting them are all made of non-magnetic stainless steel. Table 1 and Table 2 list some parameters of the HWR cavity and the solenoid, respectively.

Table 1: Main Parameters of HWR Cavity

f (MHz)	162.5
Gb	0.09
Ra/Qo (Ohm)	148
Qo	1.40E9 at 4.4K
Epeak (MV/m)	25
Uacc (MV)	0.78
Operating temp. (K)	4.4-4.5
Operating pressure (bara)	1.20-1.25
Volume of Lhe container (Liter)	18.3
Static heat load (W)	~0.9
Dynamic heat load (W)	12
Coupler cooling flow (W)	Ghe cooled,12L/min under standard condition

Table 2: Main Parameters of SC Solenoids

SC conductors: 1 main coil：rectangular 1.25×0.8 mm NbTi/Cu (1:4) wires；correctors：0.8mm round wires	
Operation currents (A)	100,50,50
Max. central magnetic field (T)	4
Max. Storage energy (kJ)	27
Operating temp. (K)	4.4-4.5
Operating pressure (bara)	1.20-1.25
Heat load at 4 K（W）	0.25
Volume of Lhe container（L）	8
Cooling flow for leads (W)	0.02g/s Ghe cooled

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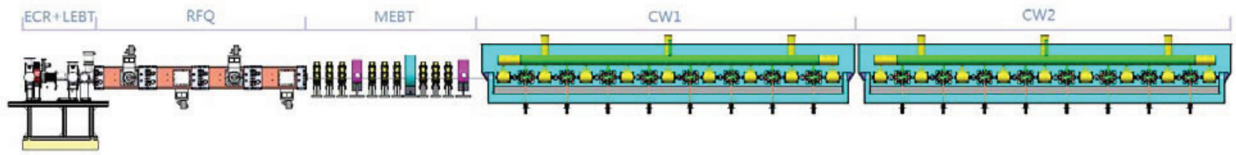

Figure 1: Layout of ADS injector-II

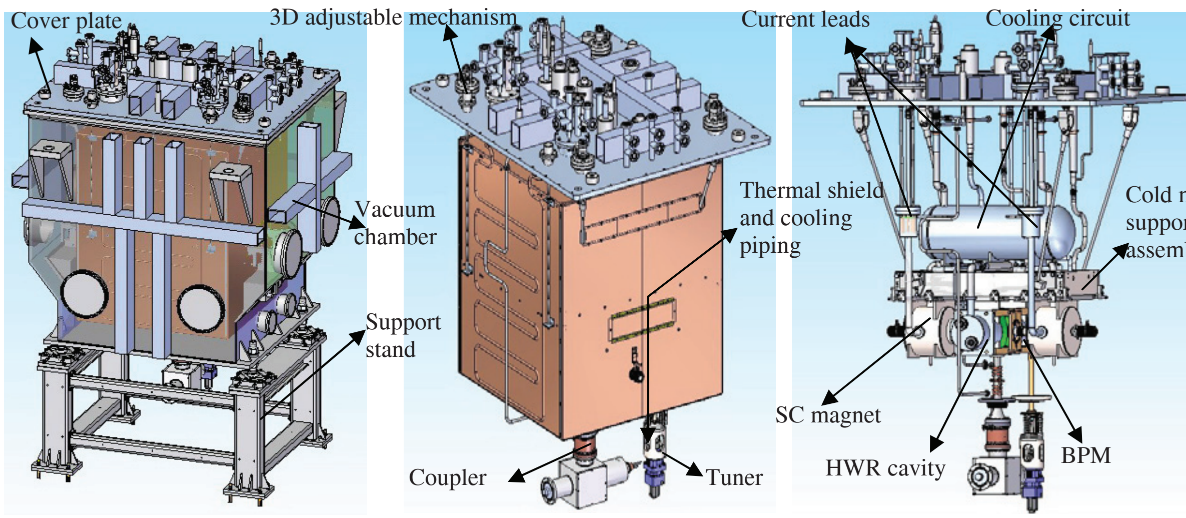

Figure 2: 3D design of TCM1.

DESIGN OF TCM1 CRYOSTAT

The TCM1 cryostat is composed of the cold mass support assembly, thermal shields, current leads for SC magnets, cooling circuit, vacuum chamber, instruments, and the TCM1 support stand, as shown in Fig. 2 [1]. The centre axis of the beam duct is positioned at 1.5 m above the ground. The overall size of the cryostat is 2.0 m in transverse direction, 1.97 m in longitudinal direction and 2.3 m high excluding its support stand. The SC devices are put at lower part inside it.

Vacuum Chamber

The vacuum of the cryostat is independent from that of the beam duct. The vacuum chamber is made of 316L stainless steel and composed of a top cover plate and a bottom plate of 30 mm in thickness, two end plates of 20 mm and two side plates of 30 mm. The reinforcement ribs are applied to control its deformation. All the parts and ports inside it are mounted onto its cover plate. A layer of u metal is attached onto its inner side for magnetic shielding.

Thermal Shields

In order to reduce the radiation heat from room temperature to the 4 K cold mass, the copper thermal shields cooled by liquid nitrogen are adopted between the cold mass assembly and the vacuum chamber. The thickness of the shields is 3 mm. The shields comprise two end plates and two side plates with the LN2 cooling piping soldering onto them. Each of the end plates is divided into two halves. The shields are designed easily assembled and disassembled for the purpose of changing the cavities and the solenoids inside.

Cooling Circuit

The HWR cavity and SC solenoids are cooled by bath cooling. The cooling circuit is composed of helium piping and one helium header. During cool down process, the cryogen to be supplied from outer dewar or refrigerator system goes to cool the Ti support frame first through the cooling passages in it. The cryogen flow from the support frame is then divided into three branches and sent to the cavity and solenoids, respectively. The cryogen enters the helium containers of the SC devices from their bottoms, and flows out from their tops and then goes into the helium header. The cryogen goes out of the cryostat from the top of the He header. At the end of the cool down process, the header is fed to be 70% full of liquid helium. During normal operation, the liquid helium will be filled directly into the header to compensate the loss of the helium due to absorbing the heat load. A small branch of liquid helium from the bottom of the He head will be delivered to cool the cavity coupler. The Ti support frame will be kept cold by heat conduction. The materials of all the piping and the He header are made of 316L stainless steel. All the design of pressure piping and pressure vessel conform to Chinese relevant codes. The cooling circuit is designed to avoid any potential thermal oscillation.

Cold Mass Support Assembly

The cold mass support assembly is to support the 4 K cold mass assembly and the He head [1][2]. It's mainly composed of one Ti support frame, four 316LSS rods, and

LHe cooling passages slotted in the long inner sides of the frame. The HWR cavity and two magnets are hanged up onto the support frame. The frame is made of the same material as the LHe vessel of the cavity in order to avoid any force to be imposed on the cavity resulting from different cold shrinkage between different materials. There are 2D adjustable mechanisms mounted on the frame for alignment of the cavity and the magnets. The support rod assembly consists of a 3D adjustable mechanism at room temperature end, a tension rod and a cold end block screwed to the frame. The spherical rod end bearing and the spherical gasket are applied to both ends of the tension rod. The 3D adjustable mechanism can be used to adjust the position of the cold mass assembly.

Current leads

The current leads are used to connect the electric power at room temperature with the superconducting solenoids at 4.5 K. There are 3 pairs of conventional copper leads for each magnet, one pair of 100 A and two pairs of 50 A. The leads are designed to be cooled by boil-off helium gas [3]. Table 3 provides their design parameters. As shown in Fig.2, two pairs of 50 A leads and one pair of 100 A leads are placed in two stainless steel tubes separately. The two tubes are connected to a helium container. The cold ends of leads in the tubes are immersed in the liquid helium in the container. The container is connected to the helium vessel of the SC magnet. The evaporated helium gas due to absorbing the heat generated by the leads flows inside the tubes to cool the leads.

Table 3: Design Parameters of Current Leads

Material: Phosphor bronze RRR=20		
Design current I (A)	50	100
Shape factor IL/A(10^6A/m)	12.5	
Length L (m)	0.83	
Qopt/I（mW/A）	1.04	
Area A(mm^2)	4	10
GHe flow rate m (g/s)	0.0025	0.01
Heat Leak Q (W)	0.052	0.208
Cooling Tube Size (mm)	Φ14×1 (4×50A)	Φ14×1 (2×100A)

Estimation of Heat Loads

Table 4 summarizes the heat loads to 4 K region in the cryostat with considering the thermal intercepts at 77 K for piping, bayonets and support rods. The total heat load at 4.4 K is about 28 W. Without the thermal intercepts at 77 K, it is about 40 W.

Table 4: Estimation of Heat Loads to 4 K

HWR cavity	Radiation heat	0.173
	Dynamic heat	12.000
	Tuner conduction heat	0.235
	Coupler heat load	0.478
SC Solenoids	Radiation heat	0.173
	Current leads	1.112
Cryostat	Radiation heat	1.267
	Cold mass supports	0.181
	Bayonets and piping	2.313
Others	Heat through instrument wires, beam ducts, etc.	0.5
Total	w/ 50% contingence	27.485

Instruments

Temperature sensors such as Cernox at 4 K and Pt at 77 K will be used to monitor the temperature status and changes of HWR cavity, SC solenoids, coupler, current leads, cold mass support assembly, thermal shields, and cooling circuit during normal operation, and also to control the cool down speed. Pressure transducers will be applied to monitor the pressure status and change of He flow in cooling circuit. He lever meters will be installed in the helium header to monitor and control the liquid helium level. Voltage taps will be attached to both ends of current leads to monitor the voltage drop along the leads. Mass flow rate meters will be used for monitoring and controlling the cooling of current leads and coupler.

CONCLUSIONS

The cryostat of the test cryomodule for the IMP ADS Injector-II project was designed by SINAP, CAS. Currently, fabrication of the cryostat has almost been done. The cryostat will be assembled and under commissioning at IMP soon.

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