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Design of 650MHz 2-cell Cavity Cryomodule for the CEPC Accelerator

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Abstract. The Circular Electron Positron Collider (CEPC) is a long-term collider project. The 650MHz 2-cell SRF cavity cryomodules will be used for CEPC accelerator. All the cryomodules will be operating at 2 Kelvin of superfluid helium. A CEPC cryomodule houses six 2-cell 650 MHz superconducting cavities, six high power couplers, six mechanical tuners, twelve HOM couplers and two HOM absorbers, et. al. The diameter of vacuum vessel is about 1.4m, and the length from flange to flange about 8 m. The technology of Fast Cool-down and magnetic hygiene are introduced. The static heat load of the whole cryomodule is about 5 watt at 2K. Up to September 2018, the conceptual design of the CEPC cryomodule and the mechanical design of the test cryomodule have been completed.

1. Introduction

The CEPC accelerator will use 650 MHz RF system with 336 cavities for the Collider and 1.3 GHz RF system with 96 cavities for the Booster. The CEPC accelerator has two RF sections locating at the long straight section LSS3 and LSS7 respectively. Each RF section contains two Collider RF stations and one Booster RF station between the Collider RF stations. One Collider RF station contains fourteen 650 MHz cryomodules, and one Booster RF station contains six 1.3 GHz cryomodules. Each of the 8 m-long Collider cryomodule contains six 650 MHz 2-cell cavities, and each of the 12 m-long Booster cryomodule contains eight 1.3 GHz 9-cell cavities [1].

2. Overview of CEPC Cryogenic System

There are 4 cryogenic stations lied beside the RF stations around the 100 km circumference, and each cryogenic station supplied from a common cryogenic plant which provides helium for the collider ring and the booster ring. Figure 1 was shown the layout of CEPC double ring.

All the cavities in the Booster and Collider rings will be cooled and immersed in the 2 K superfluid helium to achieve a good quality factor. The cooling benefits from helium II properties of large effective



thermal conductivity and heat capacity as well as low viscosity. The 2 K cryostat will be protected against heat radiation by means of two thermal shields cooled with 5-8 K helium as well as 40-80K helium from a refrigerator.

During operation, one-phase helium of 2.2 K and 1.2 bar is provided by the refrigerator to all cryomodules. Each cryomodule match one valve box, and the J-T valve that used to expand helium to a liquid helium separator. A two-phase line (liquid-helium supply and concurrent vapor return) connects each helium vessel and connects to the major gas return header once per-module. A small diameter warm-up/cool-down line connects the bottom of the helium vessels at both ends. The cavities are immersed in baths of saturated superfluid helium, gravity filled from a 2 K two-phase header. Saturated superfluid helium flows along the two-phase header which is connected to the pumping return line and then to the refrigerator [1,2]. Figure 2 was shown simplified flow scheme of CEPC cryogenic system.

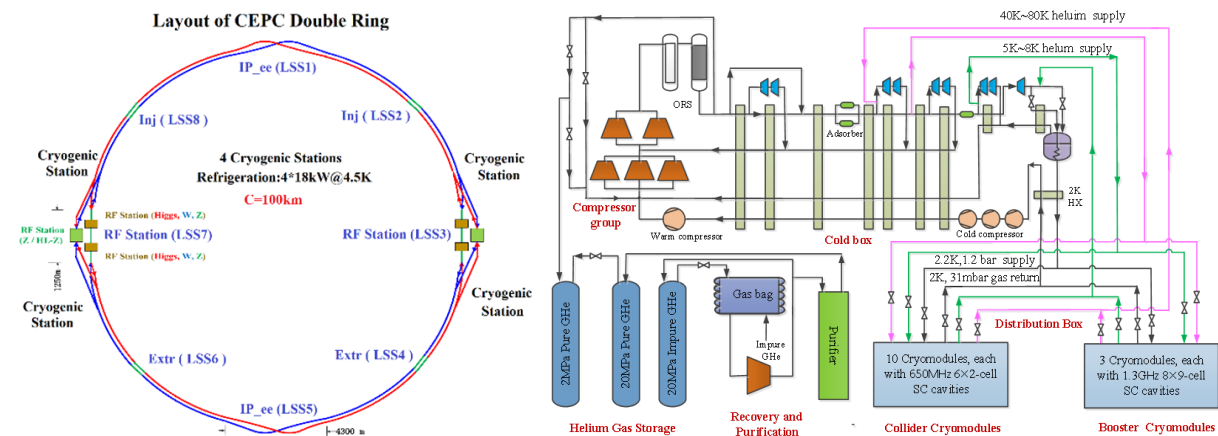
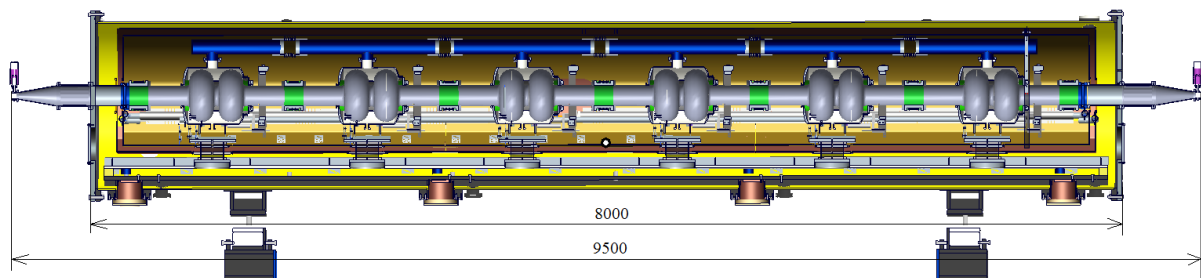


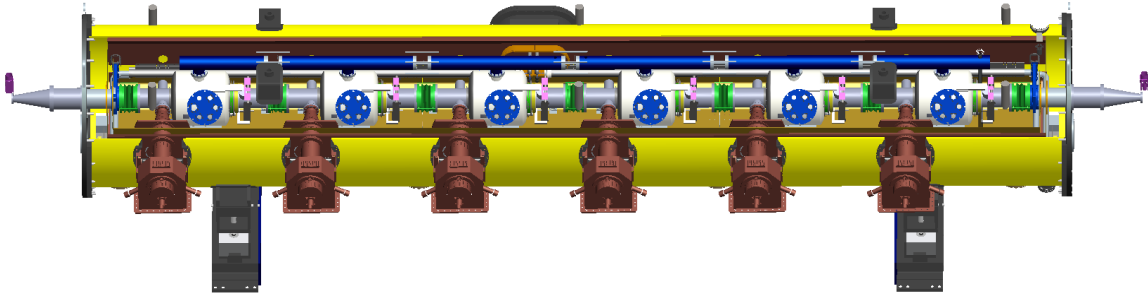
Figure 1. Layout of CEPC double ring **Figure 2.** Simplified flow scheme of CEPC cryogenic system

3. The Conceptual Design of the CEPC Cryomodule

The CEPC cryomodule is operating at 2 K in superfluid helium. It houses six 2-cell 650 MHz superconducting cavities, six high power couplers, six mechanical tuners and two HOM absorbers. The 650MHz Cavities will be capable of operating at >9 MV/m CW mode with a $Q_0 = 2E10$ at 2 K. High Q_0 requirements drive some of the new design features. The technology of fast cool-down is introduced. “Fast” means 2–3 K/minute below the niobium 9.2 K critical temperature. The static heat load of the whole cryomodule is 5 watts at 2 K. Figure 3 were shown the Conceptual structure of the CEPC cryomodule.



a) Cross-section view of the CEPC cryomodule



b) Part-section view of the CEPC cryomodule

Figure 3. Conceptual structure of the CEPC cryomodule

3.1 Cryomodule Design

The basic structural framework of the CEPC cryomodule is that cavities string bottom support by the room temperature strongback, and six completed cavities are attached to the support post (low thermal conduction structural supports). The stainless steel vacuum vessel with a standard diameter about 1400 mm, and the overall length is 9500mm. A 2 K two-phase pipe and a warm-up/cool-down connected to the cavity Helium vessels. The 5K and 8K aluminium thermal shields dress respectively with 10 and 30 layers of super-insulation (MLI), and both of them attached to the support of POST. In addition, the cavity Helium vessels and 2 K two-phase pipe are wrapped with 10 layers of MLI to reduce the heat transfer. Manually operated valves terminate the beam tube at both ends. The cavities can be aligned individually by four C-shaped stainless steel adjustment elements clamp, and lateral and vertical position are defined by reference screws[3]. The position error of X or Y direction should be below $\pm 0.5\text{mm}$, and Z direction should be below 2mm. One of the important reasons for using stainless steel 316L is for minimizing the ambient magnetic field for the cavity high Q_0 performance.

3.2 Fast Cool-down

The technology of fast cool-down is introduced, where “fast” means 2-3 K/minute below the niobium 9.2 K critical temperature. During fast cool-down, whole cryomodule is cooled at a time. A close-ended warm-up/cool-down manifold will be created for the cryomodule by providing a cool-down/warm-up valve on each cryomodule. Cooling must be slow from 300 K until most thermal contraction is complete (around 80 K). Cool-down rates (dT/dy and dT/dt) are based on the measurements and analysis at other laboratories. “Fast” means 2–3 K/minute (“slow” < 0.5 K/minute). Since thermal shield is $\sim 35\text{ K}–55\text{ K}$, we use 40 K delta-T at 3 K/minute. This gives us several minutes for transition from thermal shield temperature to below the niobium 9.2 K critical temperature [4].

4. Heat Load of the CEPC Cryomodule

The static and dynamic heat loads are used to evaluate the thermal performances of the cryomodule. The static heat loads arise from the overall cryomodule design and are present during cold operation of the accelerator. There are two main contributors: thermal radiation between the 5K shield to the 2K bath and the direct thermal conduction through the cold mass support system. The latter is the conduction of the outer pipe of RF power couplers that bring signals and RF power from the room temperature environment to 2K. The dynamic heat loads originate during RF and beam operations from specific

components: the cavities the RF power couplers and the High Order Mode (HOM) coupler. The static heat load of the whole cryomodule will be 5 watts at 2 K.

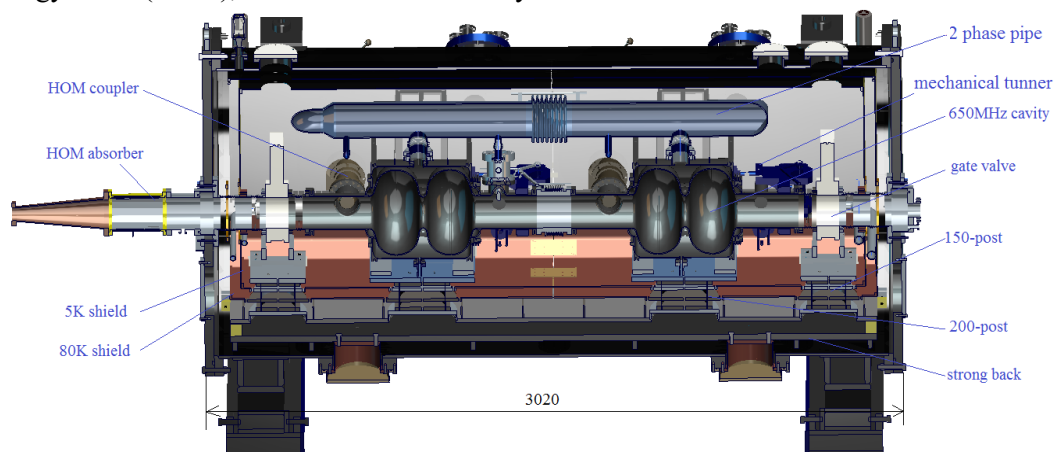
The cryomodule contains six support posts that the diameter of G10-tube is 200mm which are the support for the cold mass. The cryomodule contains 6 single coaxial type input coupler with fixed coupling. The input coupler must deliver RF power in CW mode up to 6 kW. The outer conductor is made of stainless steel with 10 μm thick copper electro-plated on the surface carrying the RF currents, the location of the two copper thermal intercepts and the total length of the coaxial line are optimized to reduce the static heat load to 2 K and 5 K. Multi-Layer Insulation (MLI) is the most thermally efficient insulation system used in the cryomodule reduce the heat load due to radiation between components at different temperatures. Conduction in residual gas can be neglected at low residual gas pressure ($<10^{-3}$ Pa). The heat load of CEPC cryomodule is shown in Table 1.

Table 1. Heat load summary of the CEPC cryomodule

<i>Heat source</i>	<i>N</i>	<i>Static/W</i>			<i>Dynamic/W</i>		
		80K	5K	2K	80K	5K	2K
Cavities	6	/	/	/	/	/	120
Input Couplers	6	36.00	18.00	2.10	60.00	36.00	6.00
HOM couplers	12	/	/	/	/	/	6.00
200-POSTs	6	44.37	6.81	2.10	/	/	/
Instrumentation Cables	/	/	/	0.54	/	/	/
Radiation	/	32.50	1.28	/	/	/	/
Other	/	1.00	0.30	0.20			
Summary		113.87	26.49	4.94	60	36	132

5. CEPC Test Cryomodule and Distribution Valve Box

In order to verify the feasibility of the CEPC cryomodule design plan, a shorter 650MHz cryomodule will be fabricated firstly, and it called for the CEPC test cryomodule. The CEPC test cryomodule and the distribution valve box were subsidized by project of Platform of Advanced Photon Source Technology R&D (PAPS), and PAPS was officially launched in Feb. 2017.



a) Longitudinal section of the test cryomodule

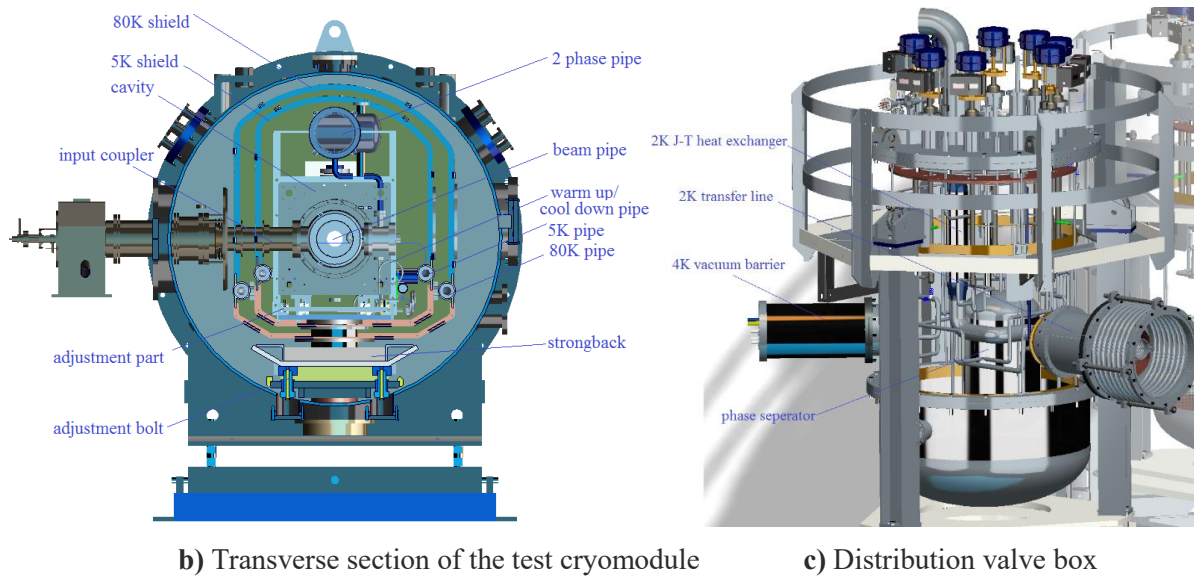


Figure 4. Structure of the test cryomodule and distribution valve box

The test cryomodule bases on a modular bottom-supported, and it houses two 2-cell 650 MHz cavities, two high power couplers, two mechanical tuner, three HOM couplers and one HOM absorber, et. al. A stainless steel vacuum vessel with a standard diameter about 1400 mm, and the overall length from flange to flange is 3020mm. Two completed cavities and two gate vacuum valve attached to the each post, the cavities and other equipment can be aligned individually. The structure of test cryomodule is similar to the formal CEPC cryomodule. Figure 4 were shown the structure of test cryomodule and distribution valve box.

6. Conclusion

The CEPC accelerator will be one of the largest and most powerful accelerator installations in the world. The conceptual design of the CEPC cryomodule and the mechanical design of the test cryomodule have been completed. The structure and specification of the CEPC cryomodule were introduced, and the detail design of the test cryomodule was shown. Nextly, the 650MHz elliptical cavities, the distribution valve box and the test cryomodule will be fabricated.

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