THE PRELIMINARY CONCEPTUAL DESIGN OF A 2K CRYOGNEIC SYSTEM FOR CIRCULAR ELECTRON POSITRON COLLIDER (CEPC)

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Abstract

The Circular Electron Positron Collider (CEPC) is a long-term collider project, which will serve as a Higgs Factory and offer a unique opportunity for direct searches for New Physics in the high-energy range far beyond LHC reach [1]. In the frame of this project, a large 2K cryogenic system will be built to provide coolant for superconducting cavities used in booster ring and collider ring. All the superconducting cavities will be working under 2K. This paper will give a brief introduction to the preliminary considerations of this large cryogenic system, including the general layout, heat load estimation, helium refrigerator, schematic flow diagram as well as the main parameters and working process.

INTRODUCTION

CEPC-SPPC is the most ambitious accelerator project ever proposed in China and even in the world as a Higgs factory for further fine measurement of the new particle after LHC [2]. The circumference will be more than 50 km (current baseline; 100 km as alternative) and tremendous studies and financial supports are demanded.

Figure 1 is a layout of the CEPC. The circumference is about 54km. There are 8 arcs and 8 straight sections. Four straight sections are for the interaction regions and RF; another four are for the RF, injection, beam dump, etc. Among the four IPs, IP1 and IP3 will be used for e+e– collisions, whereas IP2 and IP4 are reserved for pp collisions. The cryogenic system is always following the rf station. Where there are the superconducting cavity strings, there located the cryogenic station.

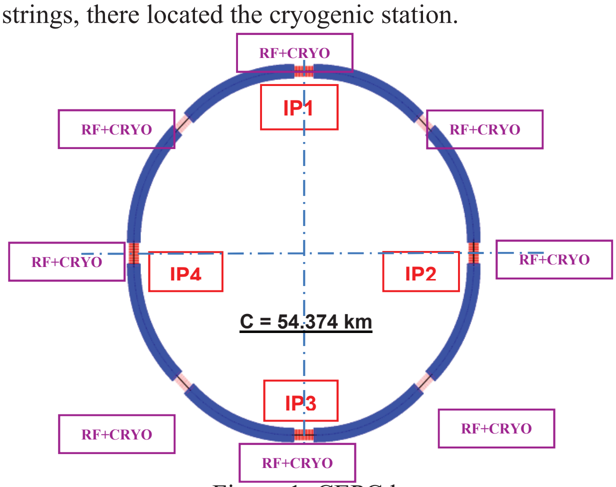

Figure 1: CEPC layout.

The CEPC tunnel will accommodate two ring accelerators: the collider and a full energy Booster. As the baseline consideration, the CEPC will use 640 superconducting cavities. In the Booster, there are 256 ILC type 1.3 GHz 9-cell superconducting cavities; eight of them will be packaged in one 12-m-long module. There are 32 such modules. In the collider ring, there are 384 650 MHz 5-cell cavities; four of them will be packaged into one 10-m long module. There are 96 of them.

All the cavities will be cooled in a liquid-helium bath at a temperature of 2 K to achieve a good cavity quality factor. The cooling benefits from the helium II thermophysical properties of large effective thermal conductivity and heat capacity as well as low viscosity. It is a technically safe and economically reasonable choice.

HEAT LOAD ESTIMATION

For CEPC, the heat load is mainly from the superconducting cavities. As mentioned, two types of superconducting cavities provide the energy for the Booster and collider. The quality factor is more than $2*10^{10}$ @19.3 MV/m for Booster cavities and $4*10^{10}$ @15.5 MV/m for collider cavities [3]. Table 1 shows the detailed parameters for the two types of cavities and the total dynamic heat load from the cavity wall.

Table1: Parameters of the Cavities

	Unit	Booster	Collider
Frequency	MHz	1300	650
Voltage	MV	20	17.9
duty factor		20%	CW
cells number per cavity		9	5
Cavity number		256	384
module number		32	96
R/Q		1036	514
Q		2.00E+10	4.00E+10
Operation temperature	K	2	2
dynamic heat load	W	3.86	15.6
Total dynamic heat load	KW	0.99	5.99

From the table we can see that of the total 128 SCRF cryomodules in the CEPC, the 96 Main Ring 5-cell 650 MHz SCRF cryomodules comprise the largest cryogenic cooling load and therefore dominate the design of the cryogenic system. The Q value here is very high, and it is the key parameter for the cryogenic system which will highly influence the dynamic load. Cavities people need make more effort on it.

Table 2 summarizes the static and dynamic heat loads of CEPC Booster and Collider cryomodules at the nominal operating conditions at different temperature levels. The total equivalent entropic capacity is 78.6 kW at 4.5 K.

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Table 2: CEPC Heat Load

	Unit	BOOSTER			COLLIDER		
		40-80K	5-8K	2K	40-80K	5-8K	2K
Module static heat load	W	140	20	3	200	40	8
Module dynamic heat load	W	140	10	30.88	200	40	62.4
HOM loss per module[1]	W	52.8	3.2	7.2	390	39	13
Connection boxes	W	50	10	10	50	10	10
Total heat load	KW	11.45	1.22	1.47	78.2	11.9	8.48
Overall net cryogenic capacity multiplier		1.54	1.54	1.54	1.54	1.54	1.54
4.5K equiv. heat load with multiplier	KW	1.34	1.74	7.3	9.12	16.97	42.13
Total 4.5K equiv heat load with multiplier	KW		10.38			68.22	
Total heat load of booster and collider	KW	78.6					

REFRIGERATOR

The CEPC heat loads shown in Table 2 require the helium refrigerator plants to have a total capacity over 78.6 kW at 4.5 K. Eight individual refrigerators will be employed for the CEPC cryogenic system. The cryogenic plant capacities are equivalent to 12 kW at 4.5 K for each cryogenic station.

Many aspects must be taken into account during refrigerator design, mainly including reliability, efficiency, maintenance, flexibility, convenience of operation and the cost. The construction costs as well as the operation costs of the cryogenic system occupy a significant fraction of the total project budget, so reducing these costs is the primary focus of our study. The refrigerator main components include oil lubricated screw compressors, oil removal equipment, and the cold box which is vacuum insulated and houses the aluminum plate-fin heat exchangers, adsorbers and several stages of turbo-expanders.

Helium is compressed at ambient temperature by a two-stage screw compressor group to a pressure in the 20 bar range. After re-cooling to ambient temperature, careful oil removal and drying from residual water vapor, the high pressure helium is cooled in a cascade of counter-flow heat exchangers and expansion turbines. At the 40-K and 5-K temperature levels helium flows are directed to the thermal shields of the cryomodules. The corresponding return flows are fed back to the refrigerator at suitable temperature levels. Inside the refrigerator cold-box the helium is purified from residual air, neon and hydrogen by switchable adsorbers at the 80-K and 20-K temperature levels, respectively [4].

The cryoplant will supply 4.5 K helium to the cryomodules. At each cryomodule the helium goes through a phase separator and a counter-flow heat exchanger to recover the cooling power, then expanded to 31 mbar via a JT-valve, resulting in helium II liquid at 2 K. The low pressure helium vapor from the 2 K saturated baths surrounding the cavities returns to the refrigerator through the gas return tube. The vapor is pumped away and returned to the cryoplant.

There are two options for such a pumping system. One relies solely on cold compressors; the other employs a set of cold compressors followed by a final stage of warm compression. After superheating in the counter flow heat exchanger, the gas is compressed in the multiple-stage cold compressors to a pressure in the 0.5 to 0.9 bar range. This stream is separately warmed up to ambient temperature in exchangers and goes back to the warm compressors. The choice of a warm vacuum compressor makes it easier to adjust for the heat load variations. This approach, which CERN uses in the LHC plants [5], also allows for an easier restart of the 2-K system after a system stoppage.

The cold box will be divided into two parts. Those parts whose temperature higher than 80K will be installed on the ground and called UPPER cold box, and those parts whose temperature lower than 80K will be installed in the tunnel to reduce heat load which is called LOWER cold box. The UPPER cold box and LOWER cold box are connected by multi-layer insulation pipes.

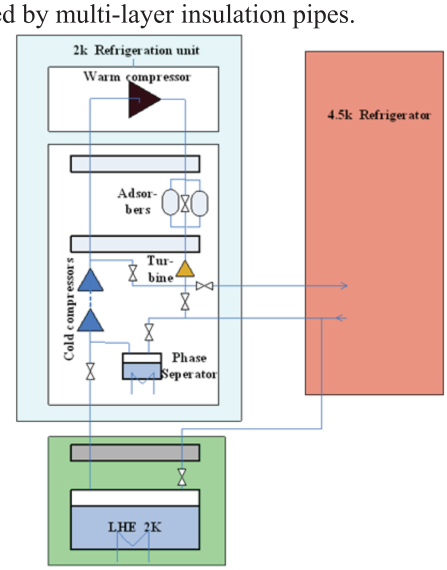

Figure 2: 2 K refrigerator flow diagram.

LAYOUT AND INFRASTRUCTURE

The 2-K cryogenic system consists of oil lubricated screw compressors, 2 K refrigerator cold box, liquid-helium storage vessel, cryomodules, helium-gas pumping system and high-performance transfer lines, etc (see Fig. 2). The cryogenic station is situated alongside the RF station. The cooling power required at each RF station will be produced by a 12 kW@4.5 K refrigerator. These are installed at eight cryogenic stations, and distribute to the adjacent superconducting cavities as Fig. 1 show.

Figure 3 shows the general architecture of the CEPC cryogenic system. Equipment at ground level includes the

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electrical substation, the warm compressor station, storage tanks (helium and liquid nitrogen), cooling towers, and upper cold-boxes with liquid nitrogen precooling. Underground are the lower cold-boxes, 2 K cryomodules, multiple transfer lines, and distribution valve boxes.

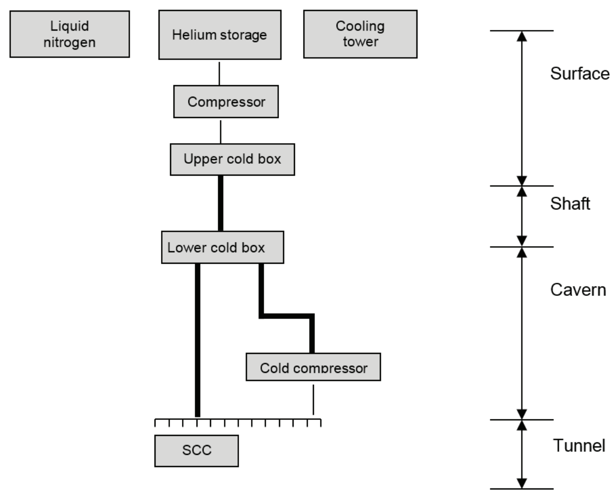

Figure 3: General architecture of the CEPC cryogenic system.

CRYOGENIC PLANT OPERATION

Saturated He II cools the RF cavities at 2 K. In view of the high thermodynamic cost of 2 K refrigeration, the thermal design of the CEPC cryogenic components aims at intercepting heat loads at as high a temperature as possible. Hence, helium gas-cooled shields intercept radiation and conduction at 40 -80 K and also at 5- 8 K. The 40 – 80 K thermal shield is the first major heat intercept, shielding the cold mass from the bulk of heat leaks from ambient temperature. This is followed by the 5- 8 K shield for lower temperature heat interception [6].

Every station we have two strings, 4 9-cell cavity cryomodules and 12 5-cell cavity cryomodules. We adopt similar flow diagram for the booster ring and collider ring cryomodules. A two-phase line (liquid-helium supply and 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 bottoms of the helium vessels. 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 has phase separators located at one or both ends; the two-phase header is connected to the pumping return line [7]. For the flow refer to Fig 4.

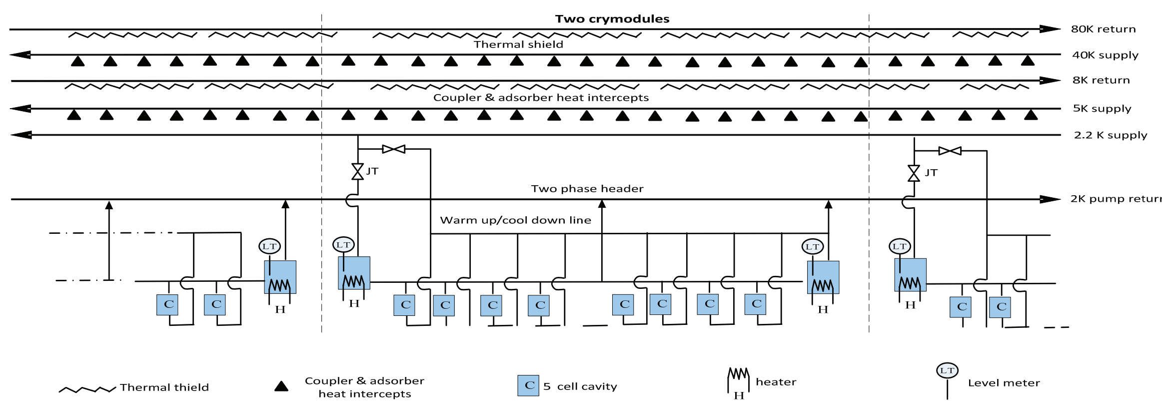

Figure 4: The flow scheme of CEPC collider ring.

SUMMARY AND OUTLOOK

The CEPC cryogenic system is a large 2K superfulid helium system, the total capacity of which at 4.5K will reach about 80KW and the total helium inventory is about 14,000Kg. We already have experience on design, construction, commissioning and operation of a 200W 2K system and work well, but not expert in large system, especially the large capacity refrigerators. Great efforts need be made to overcome all the obstacles beyond us.

The scale of the cryogenic system is highly depending on the superconducting cavity performance and working conditions. So the preliminary conceptual design of the cryogenic system may be modified with the update of the superconducting rf system.

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