32nd Linear Accelerator Conference (LINAC2024),Chicago, IL, USA JACoW Publishing
ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-MOPB077

PROGRESS IN THE DEVELOPMENT OF THE CRYOMODULES FOR CSNS-II SUPERCONDUCTING LINAC

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Abstract

The China Spallation Neutron Source phase II (CSNS-II) upgrade design will increase the total beam power from 100 kW to 500 kW and boost the beam energy from 80 MeV to 300 MeV in the linac by adding a superconducting linear accelerator to the existing accelerator complex. Its proton linac will include 18 superconducting cavity cryomodules. It is composed of one string of Spoke cavity cryomodule and another string of elliptical cavity cryomodule. The nominal operating temperature for the cavities is 2 K, with 50~60 K thermal shielding. This paper introduces the thermo-mechanical design and expected operation of the CSNS-II spoke cavity cryomodule and elliptical cavity cryomodule, it also include the horizontal test results about the prototype of Spoke cavity cryomodule with two cavities.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is the first pulsed neutron source facility in developing countries. CSNS locates at Dalang Town of Dongguan City, the heart of the Guangdong-Hong Kong- Macao Greater Bay Area. The China Spallation Neutron Source phase II (CSNS-II) upgrade design will increase the total beam power from 100 kW to 500 kW and boost the beam energy from 80 MeV to 300 MeV in the linac by adding a superconducting linear accelerator to the existing accelerator complex. Based on superconducting radiofrequency technologies, the superconductign linear accelerator will operate for the first time a 90 meter long section of niobium cavities.

It is composed of 10 Spoke cavity cryomodules and 8 elliptical cavity cryomodules. Paired in 18 cryomodules, each cavity will generate an accelerating pulsed field of 9MV/m. The cryogenic system is the specialised techical systems and can be further divided into two subsysytems: the linac cryoplant and the test stand and instruments cryoplant. The linac cryoplant will provide all the cooling to the 18 cryomodules containing the superconducting RF cavities. The PID design of the linac cryoplant is finished. The test stand and instruments cryoplant have been finished commissioning and under nomal operation for more than 3 years.

A prototype of double Spoke cavity cryomodule housing two superconducting Spoke cavities and their RF power couplers is now being fabricated and assembled. It provides the cryogenic environment for their normal operation in a 2K saturated superfluid helium bath: a 60 K thermal shield, a cold magnetic shield enclosed cavities, and integrates all the interfaces necessary to be operational within the linac machine. This prototype has finished the cryogenic horizontal test at Platform of Advanced Photon Source Technology R&D (PAPS) site and then it is prepaired to transport to CSNS site.

LINAC CRYOPLANT

The linac cryoplant provides cooling at three nominal temperature levels : 45 K to 60 K for the thermal shields of the cryomodules, valve boxes, 60 K thermal intercepts of the power coupler and beam pipe and distribution system; 5 K for the power coupler thermal intercepts and 2 K for the SRF cavities. The linace consists of 18 cryomodules operating at 324 MHz for the Spoke cavities and 648 MHz for the elliptical cavities. The CSNS-II cryomodules are individual cryogenic units and are cooled in parallel by the cryogenic distribution system. Figure 1 is a flow schematic fo the helium distribution system of superconducting linac. Figure 2 shows the layout of the superconducting linac.

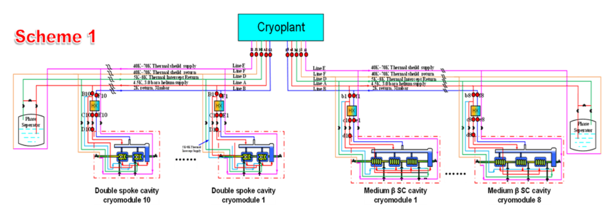

Figure 1: Flow schematic fo the helium distribution system of CSNS-II superconducting linac.

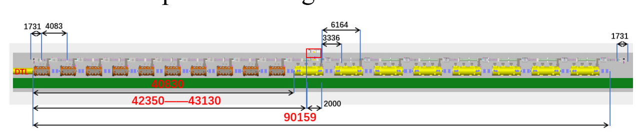

Figure 2: The layout of the superconducting linac.

MECHANICAL DESIGN

The superconducting linac of CSNS-II includes two type of cyomodules, one is Spoke cavity cryomodule and another is elliptical cavity cryomodule. A cut view of the Spoke cavity cryomodule is shown on Fig. 3. The two double Spoke cavities are installed along the axis of the vacuum vessel. Cold tuning systems are vertical mounted at the side of helium bath of cavity, which face toward the end head assembly of the vacuum house to facilitate the maintenance operations. Cold magnetic shields cover the helium bath of cavity. The RF power couplers are horizontal installed and its thermal anchors are connected to the corresponding cold source by copper braided tapes. The bi-phase pipe is positioned horizontally on the top of the cavities. The cold mass is surrounded by the thermal shield.

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The total length of the Spoke cavity cryomodul is 2.823 m, from one UHV gate valve to another one. The internal diameter of the vacuum vessel is 1.35 m. The vacuum vessel is thus a rigid cylinder with 12 mm thickness, and withstanding the static and buckling loading from the ambient pressure. The design pressure range is from 1.2 bara to 0 bara. During the vacuum-pressure cycles, small deformations will induce the cold mass expecting small misalignment.

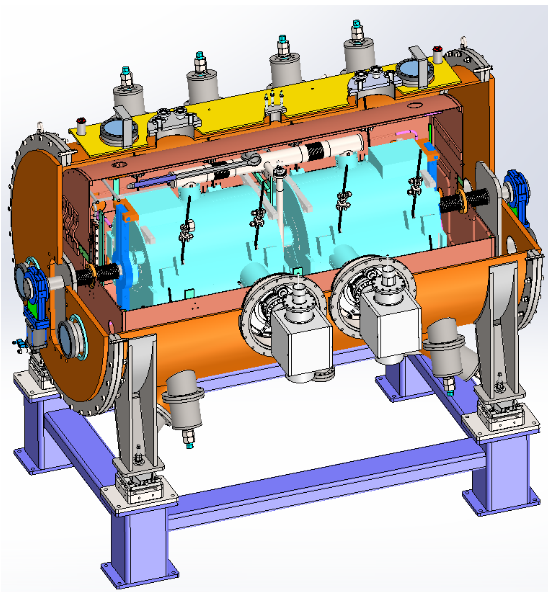

Figure 3: The Spoke cavity cryomodule.

The design highlights of Spoke cavity cryomodule is the supports of helium bath. Antagonist rods are designed as the supports which fixed on the helium bath of the cavity, and its material is carbon fiber with low thermal conductivity. Figure 4 shows the supporting and positioning system of spoke cavities. Rods antagonism increases the length of the conductive thermal path and reduces the stress generated by the helium bath thermal contraction by converting the tensile force into a deflexion moment. 6 radial rods are positioned in two vertical planes at both ends of each cavity, 4 diagonal rods link the helium bath to the vacuum vessel and two invar rods connect them mutually. These two invar rods enable the positioning of the two equipped Spoke cavities one from each other. The 6 radial rods are designed in an assembly of two parts, a spherical connection structure (see Fig. 5) is provided to avoid shear forces during installation and adjustment. Connections of this outer threaded rod to the vacuum vessel is carried out by use of a bolt supporting on cylinder, which with side seal construction and blocks the rotational degree of freedom. This experienced connection [1-4] allows the correction of the positioning of the cold mass at any time: under room temperature and at cryogenic conditions.

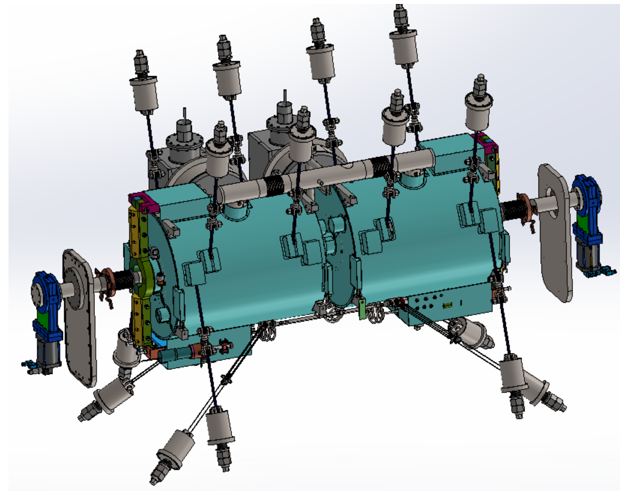

Figure 4: The supporting and positioning system of Spoke cavities.

Figure 5: The spherical connection structure.

The copper thermal shield (see Fig. 6) is made of a elliptical cross section with a 2.142 m long and all coverd with 30 layers of MLI.

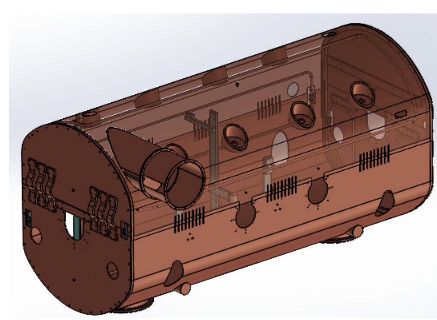

Figure 6: The copper thermal shield.

The another kind cryomodule of CSNS-II project is elliptical cavity cryomodule which is currently heading into the schematic design phase. The most highlights of elliptical cavity cryomodule is the cold mass of 2K temperature zone such as superconducting cavity string and helium bath is supported by Low thermal conduction structural supports (POST) [5-7], and it also have only one layer of thermal shields with 60 K average working

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temperature. The total length of the elliptical cavity cryomodul (see Fig. 7) is 4.786 m, from one UHV gate valve to another one. The internal diameter of the vacuum vessel is 1.35 m.

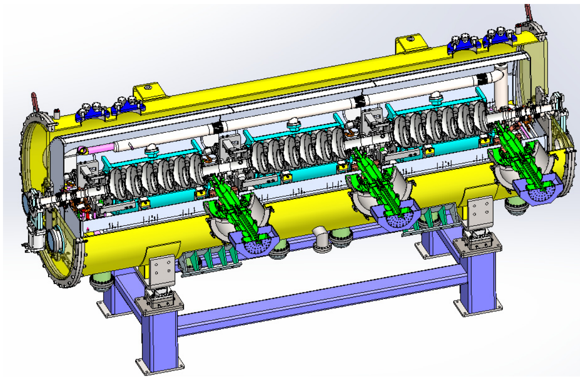

Figure 7: The elliptical cavity cryomodule.

CRYOMODULE ASSEMBLY AND CRYOGENIC HORIZONTAL TEST

The string of 2 K cold mass include two Spoke cavities, RF power coupleers and two cold to warm transitions are mounted and the beam tube is closed by the two UHV gate valves inside the clean room of PAPS. At the exit of clean room, the cavities are equipped with 10 layers of MLI firstly and then equipped with their magnetic shield. The cooper thermal shield is all coverd with 30 layers of MLI (see Fig. 8) and positioned onto the cryostating tooling with 2 K cold mass together. At the same time, we should finish other necessary mounting procedures in this process, such as cold tuning systems, instrumentation(including alignment or the heat intercept blocks) and cryogenic distribution.

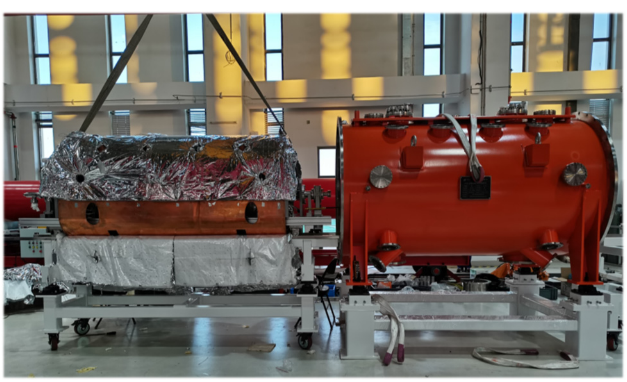

Figure 8: The assembly and tooling of prototype.

The cryogenic horizontal test have been finished in August. The test results show that the prototype of Spoke cavity cryomodule can normal work stably at 2 K temperature (see Fig. 9), The average accelerating gradient of Spoke cavities is more than 9 MV/m, especially the 2# Spoke cavity's accelerating gradient can reach to 15MV/m. The static heat load of prototype is 25.838 ±0.959 W, but the total uncertainty of dynamic heat load is high (flow rate is measured from liquid level 93% to 84%).

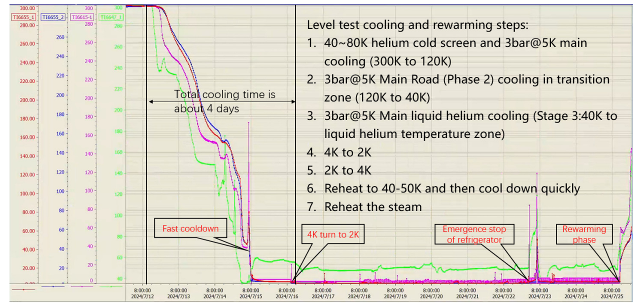

Figure 9: The cooling curves and cooling strategy

SUMMARY AND OUTLOOK

The design of the elliptical cavity cryomodule section of the CSNS-II is still under progress, but the prototype of a Spoke cavity cryomodule and valve box have sucesseful finished the horizontal test in August at PAPS site. the transportation test of full scale test model, which means the same weight and size, will be caaried out in October. If validated, the prototype of Spoke cavity cryomodule will be transported to CSNS site to perform the experiences about cryomodule long-distance transportation. On the other hand, the vertical test of elliptical cavity have been finished in August at PAPS site. and the mass production of prototype of elliptical cavity cryomodule will begin in November.

ACKNOWLEDGEMENT

This work was supported by the Platform of Advanced Photon Source (PAPS) fundings.

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