ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-MOPB099

DESIGN OF C-ADS INJECTOR-I CRYOMODULE FOR 325MHz CAVITIES

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Abstract

The Chinese Accelerator Driven Sub-critical system (C-ADS) uses a high energy proton beam to bombard the metal target and generate neutrons to deal with the nuclear waste. The Chinese ADS proton linear has two 0~10 MeV injectors and one 10~1500 MeV superconducting linac. Injector-I is studied by the Institute of High Energy Physics (IHEP) under construction in the Beijing, China. The linear accelerator consists of two accelerating cryomodules operating at the temperature of 2 Kelvin. This paper describes the structure and thermal performances analysis of the cryomodule. The analysis takes into account all the main contributors (support posts, multilayer insulation, current leads, power couplers, and cavities) to the static and dynamic heat load at various cryogenic temperature levels. The thermal simulation analysis of the cryomodule is important theory foundation of optimization and commissioning.

INTRODUCTION

The Chinese Accelerator Driven Sub-critical system (C-ADS) project is based on a proton Linac that provides a10mA, 1.5 GeV CW proton beam for nuclear waste transmutation. The C-ADS linac includes two major sections: the injector section and the main linac section. [1]. The general layout of the linac is shown in Fig. 1. To satisfy the restricted stability and reliability command of the C-ADS driver linac in the lower energy part, there will be two identical Injectors operating in parallel, backing each other up. One of them, Injector I is under design and construction at Institute of High Energy Physics (IHEP), Chinese Academy of Sciences(CAS) [2]. The injector I consists of two accelerating cryomodules (CM1 and CM2), which accelerates proton beam up to 10MeV. One C-ADS cryomodule houses 7 325 MHz Spoke（β =0.12）superconducting cavities, 7 high power couplers, 7 superconducting solenoids, 7Beam Position Monitors(BPM), et al, and the cavities and solenoids will be immersed in a 2K liquid helium bath .

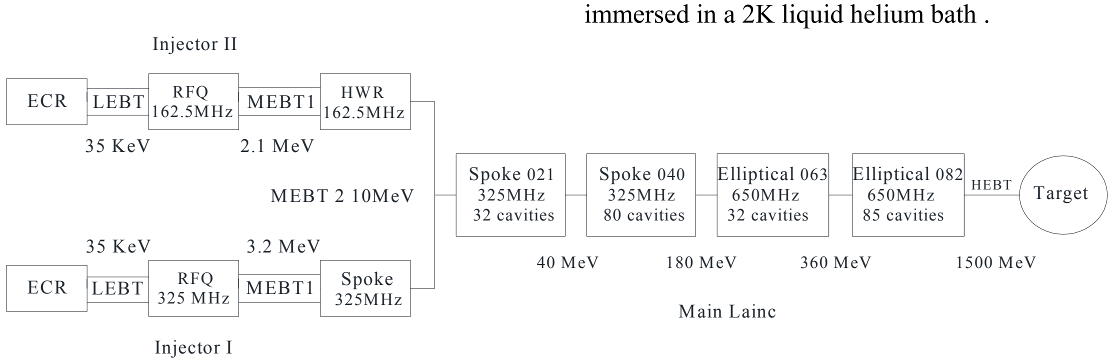

Figure 1: Schematic layout of the C-ADS driver linac.

STRUCTURE OF THE C-ADS INJECTOR-I CRYOMODULE

The C-ADS Injector-I system includes two cyomodules: CM1 cyomodule and CM2 cyomodule. The C-ADS Injector-I cryomodules are based on a modular bottom-supported, the cavities string and cold mass are supported by composite posts, and put them on a strongback at room temperature.

The cryomodule can be separated into three parts, the outer vacuum vessel; the cavities string assembly which comprises of the seven spoke cavities and their associated auxiliary components (high-power input coupler, helium tank, mechanical tuner etc.), the seven superconducting solenoids package including their current leads; the so-called cold-mass of the cryostat, which includes the cryogenic pips, support fixtures (for the cavity string), thermal shields, etc. Transverse and Longitudinal section of the cryomodule are shown in Figs. 2-3.

The design of the accelerator module described as following. A stainless steel vacuum vessel with a

standard diameter about 1400 mm, strongback at the room temperature acting as a support structure, together with 14 posts on top of the strongback, a 2 K two phase pipe connected to the cavity Helium vessels, a 5K forward and return line, a 80 K forward and return line, and a warm-up/cool-down line with capillaries to the bottom of each cavity and solenoid helium vessel. Two Aluminum thermal shields that 5 K helium shield and 80 K nitrogen shield attached to the support structure, and 10 layers of upper insulation (MLI) for 5 K and 30 layers for 80 K.

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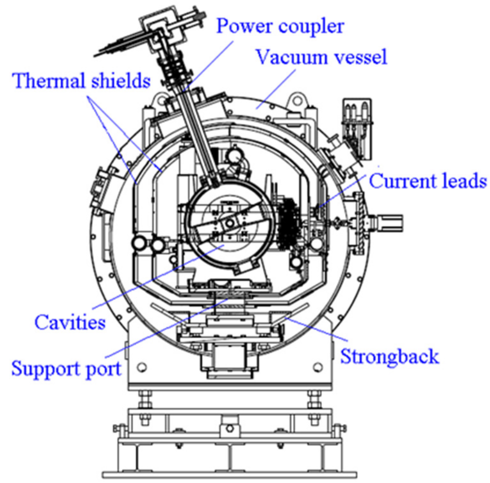

Figure 2: Transverse section of the cryomodule.

Figure 4 depicts an image for 3D model of CM1 and CM2, the total length is 10773mm (flange to flange).

Seven completed cavities and seven solenoids attached to the strongback, the cavities and solenoids can be aligned individually. In addition, the cavity and solenoid helium vessels and 2 K two phase pipe are wrapped with 10 layers MLI to reduce the heat transfer in the event of vacuum failure. Four C-shaped stainless steel elements clamp a Titanium pad welded to the Helium tank, lateral and vertical position are defined by reference screws, and the longitudinal position should be a very small. In order to minimize particulate contamination of beam vacuum, there are two manually operated valves to terminate the beam tube at both ends. An overview of a cryomodule is shown in Fig. 5.

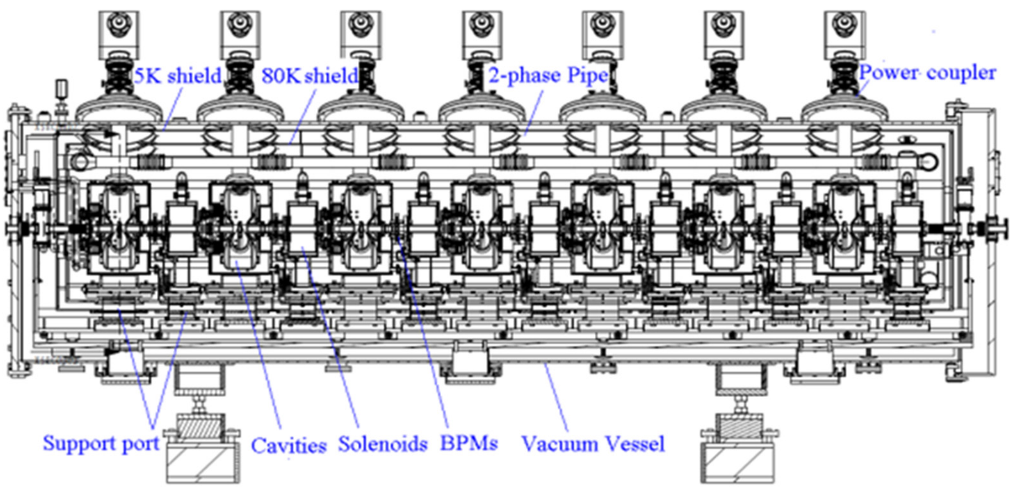

Figure 3: Longitudinal section of the cryomodule.

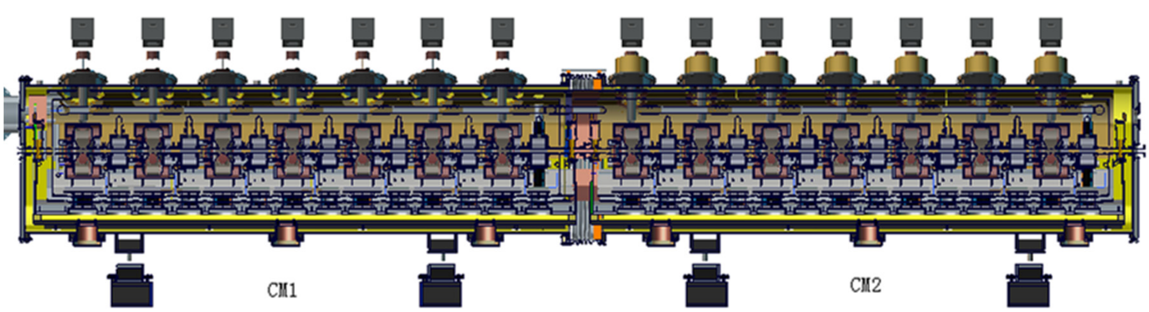

Figure 4: Overview of the connection of CM1 and CM2 cryomodule.

HEAT LOAD ANALYSIS OF THE C-ADS INJECTOR-I CRYOMODULE

Key components of the The ADS Injector-I cryomodule were studied by thermal simulation and numerical analysis. The source of heat load of the cryomodule were analyzed, such as the heat conduction of POST, current leads and high power coupler, the heat radiation of 80 K shield, and the dynamic heat load of superconducting cavity and high power coupler. The results show that the CM4 cryomodule satisfy the needs of low heat load [3-7]. The preliminary summary of the heat load of the cryomodule is shown in Table 1.

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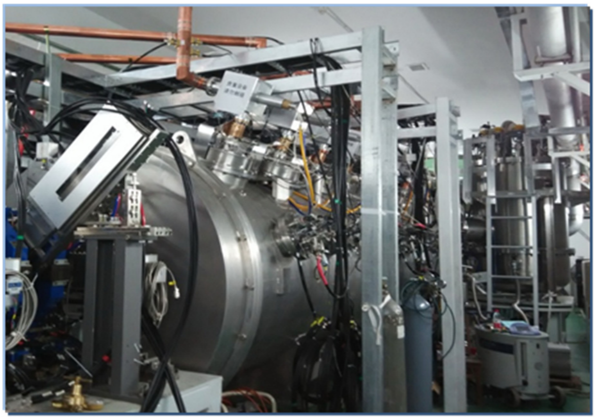

Figure 5: Overview of the cryomodule in the tunnel.

Table 1: Heat Load Summary of the ADS Injector-I Cryomodule

Heat source	*N*	*Static*/W			*Dynamic*/W		
		80K	5K	2K	80K	5K	2K
150-POSTs	7	36.77	5.68	1.75	/	/	/
180-POSTs	7	44.37	6.81	2.10	/	/	/
Current leads	7	53.76	32.48	9.66	246.19	67.97	23.52
Couplers	7	82.60	18.20	5.88	87.23	21.77	2.17
BPM cables	28	/	/	1.00	/	/	/
Other cables	/	/	/	0.54	/	/	/
Cavities	7	/	/	/	/	/	4.20
Radiation	/	25.49	1.43	0.01222	/	/	/
Sum		242.99	64.60	20.94	333.42	89.74	29.89

EXPERIMENTAL DATA OF STATIC HEAT LOAD

Two typical heat load measurement at 2 K is mass flow rate measurement and level measurement. The value of the mass flow rate used to evaluate the heat loads is the average value integrated over a certain period after reached stability. The static heat loads are summarized in Table 2. and Fig. 6. These are calculated from the average heat flux and the latent heat value of 23.06 J/g for the saturated helium at 31 mbar.

Table 2: 2K Heat Load of the ADS Injector-I Cryomodule

	Level measurement	Mass flow rate measurement
2K/W	31.2	30.4

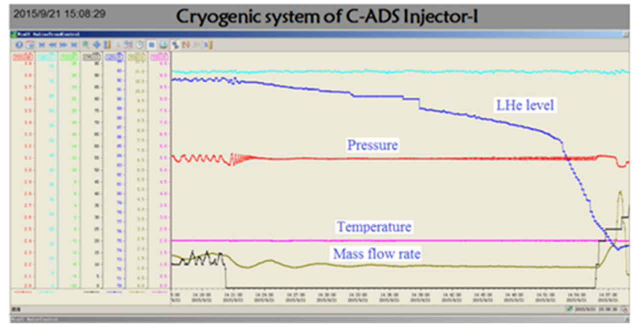

Figure 6: 2 K heat load measurement.

CONCLUSION

The structure of CM1 is similar to CM2 cryomodule, and they operated at 4.2K liquid helium temperature. Each cryomodule houses 7 325MHz Spoke（β=0.12） superconducting cavities,7 high power couplers, 7 superconducting solenoids, 7Beam Position Monitors(BPM), et al. In order to optimize the structure of cryomodule, the sources of heat load of the cryomodule were analyse. The static and dynamic heat load of cryomodule were studied by thermal simulation and numerical analysis, and the experimental heat load of cryomodule at 2K is measured in this paper. The ADS Injector-I cryomodule(CM1 and CM2) are operating at 2K liquid helium temperature for beam commissioning. On 2TH July 2016, the proton beam reached a final energy of 10.5 MeV with a beam current of 10.11mA in pulse mode.

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