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DESIGN OF THE 2×4-CELL SUPERCONDUCTING CRYOMODULE FOR THE FREE-ELECTRON LASER *

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Abstract

A 2×4-cell superconducting linac module for the THz-FEL facility has been developed at the China Academy of Engineering Physics, which is expected to provide 6~8 MeV quasi-CW electron beams with an average current of 1~5 mA. The design of the cryomodule is presented in this paper. The dynamic and static heat load have been evaluated to reasonable level. The temperature distribution inside the cryomodule has been optimized by simulation, as well as mechanical structure and the magnetic shielding.

INTRODUCTION

A high average power THz free-electron laser facility developed by the China Academy of Engineering Physics (CAEP) [1] is under construction at Chengdu, China. Figure 1 shows the simplified layout of the THz-FEL facility. The designed frequency of the THz radiation is 1-3 THz with the average output power beyond 10 W. Owing to the advantages of SRF technology in CW mode operation, a 2×4-cell superconducting linac module has been adopted to accelerate 300 keV, 1~5 mA electron beams from a DC-Gun up to an energy of 6~8 MeV.

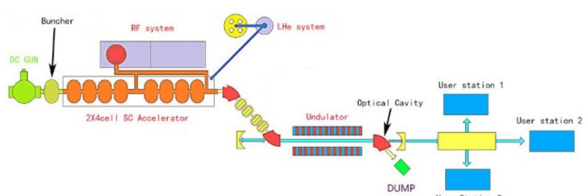

Figure 1: Layout of the CAEP THz-FEL facility.

CRYOMODULE DESIGN

In order to guarantee the SRF cavities have a good performance, the cryomodule must provide stable cryogenic temperatures, extremely low ambient magnetic fields and a stable mechanical support. The 2×4-cell cryomodule is designed to minimize thermal loss and fabrication cost. As shown in Fig. 2, the 2×4-cell cryomodule is consist of 2 K liquid helium layer, 80 K liquid nitrogen layer, vacuum vessel, magnetic shielding and cavity support structure.

THERMAL OPTIMIZATION

A simplified model (see Fig. 3) in ANSYS Workbench

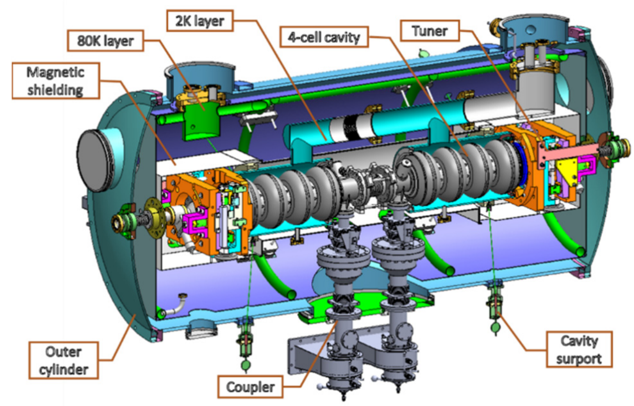

Figure 2: Schematic of the 2×4-cell module.

was used for thermal analysis of the cryomodule. Different thermal conditions were considered by this simulation, such as thermal radiation flux, HOM coupler power dissipation and coupler power dissipation. Figure 4 shows the simulated temperature distribution inside the cryomodule, including (a) the copper 80 K layer, (b) the connecting beam pipe, (c) the outer beam pipe and (d) the HOM couplers. Appropriate thermal insulations or insertions are used to cool down beam pipes and HOM couplers effectively.

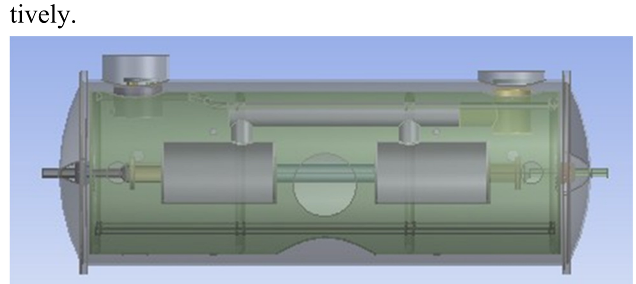

Figure 3: The simplified model in ANSYS Workbench.

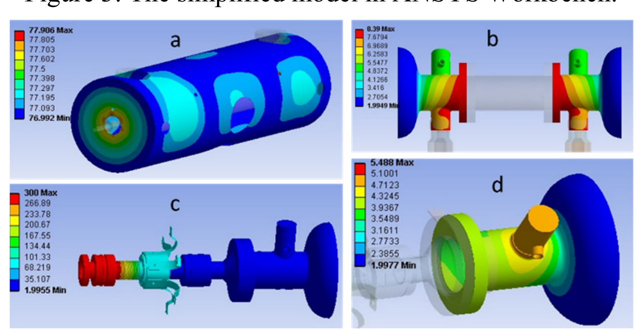

Figure 4: Simulated temperature distribution inside the cryostat.

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THERMAL LOSS

The static loads at the different temperatures originate from two contributions: thermal radiation from the "hotter" environment and direct thermal conduction through the cold mass supports and the feedthroughs bringing components from the room temperature environment [2]. The heat flux density due to radiation transport between two surfaces at different temperatures can be written as:

$$\dot{q} = \sigma_{sb}\varepsilon_{12}\left(T_2^4 - T_1^4\right) \quad (1)$$

And the heat flux density due to thermal conduction can be written as:

$$\dot{q} = -\frac{S}{L}\int_{T_1}^{T_2} k(T)dT \quad (2)$$

Long and thin connect structures (bellows for example) are adopted to increase conduction length and decrease conduction area. More than 20 layers cryogenic insulation are used to decrease the radiation flux to lower than 1 W/m. The 2 K thermal loss are estimated in Table 1.

Table 1: The 2K Thermal Loss Estimate for 2×4-cell Cryomodule

Components	Thermal loss
2K static losses	**~5.6 W**
Thermal radiation	0.9 m^2 × 1 W/m^2 = 0.9 W
Coupler static loss	1 W × 2 = 2 W
2 end bellows (stainless steel)	0.3 W
6 suspension sticks (titanium)	1.1 W
Tuner rod (stainless steel)	0.3 W
Cables	1 W
2K dynamic loss	**~22 W**
Cavity dynamic loss	10 W × 2 = 20 W
Coupler dynamic loss	1 W × 2 = 2 W

MECHANICAL DESIGN

The cavity string is suspended by six titanium sticks which connected to the outer cylinder. The thicker sticks means more steady support but larger thermal conduction load. Besides, the tuners are placed at both ends of the cavity string. The tuners' weight (about 60 kg for each) may make the cavity string ends droop. The mechanical simulation (see Fig. 5) by ANSYS is made to make sure the suspend sticks and middle connection structure are strong enough to maintain cavities in straight line. And the suspend position should be close to the barycentre of each half string. The results indicated that 5×5 mm sticks are more appropriate rather than 3×3 mm.

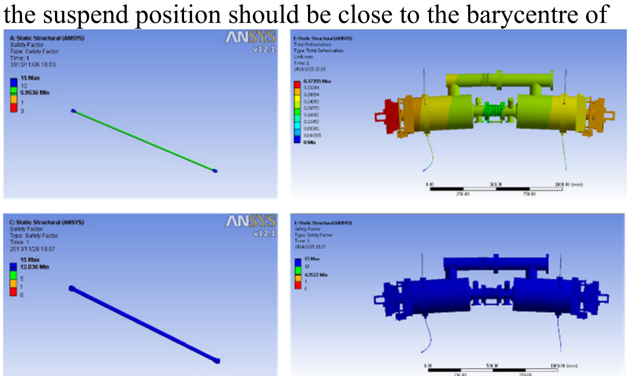

Figure 5: Simulated mechanical stress and deformation.

MAGNETIC SHIELDING

The magnetic shielding is consist of the vacuum vessel made of pure iron and the inner shielding layer made of permalloy, as shown in Fig. 6. The magnetic field distribution inside the double shielding has been simulated by CST EM Studio. The double shielding decreases the geomagnetic field (550 mG) to lower than 12 mG, as shown in Fig. 7.

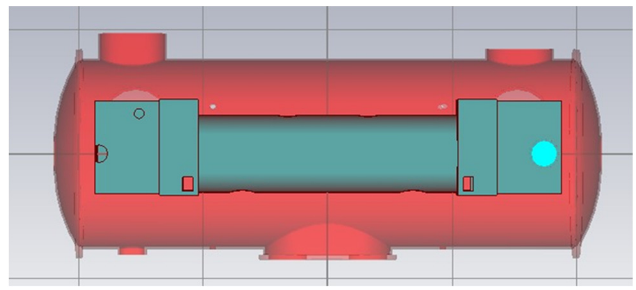

Figure 6: The double magnetic shielding.

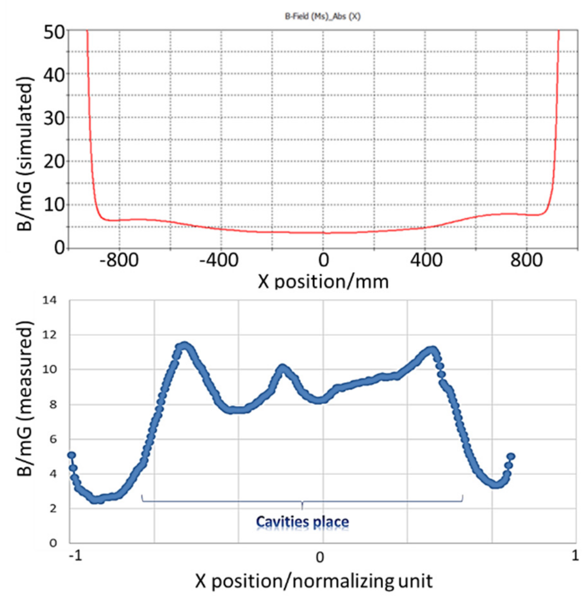

Figure 7: (top) Simulated and (bottom) measured magnetic field inside the double shielding.

STATUS

Table 2: Parameters of the 2×4-cell Cryomodule

Parameter	Design value
Temperature	2 ± 0.1 K
2 K static load (theoretical)	5.6 W
2 K dynamic @ CW	≤ 22 W
2 K system max load	70 W
80 K static load	68 W
80 K dynamic @ CW	140 W
Thermal insulation vaccum	< 5×10^{-4} Pa
Helium pressure	30 ± 0.1 mbar
Magnetic field at cavities position	< 12 mG

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The design parameters of the 2×4-cell cryomodule are listed in Table 2. The cryomodule has been assembled and horizontal tested at Chengdu, China [3]. The whole superconducting accelerator runs stably at 2 K state and the gradients of both cavities reach our target of 10 MV/m. Currently beam-loading commissioning is underway.

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