DEVELOPMENT OF TWO ADDITIONAL CRYOMODULES FOR SUPERCONDUCTING LINAC AT IUAC, DELHI

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Abstract

Superconducting Linac was partly commissioned with one linac cryomodule housing eight quarter wave bulk niobium cavities along with superbuncher and rebuncher cryomodule. Two more linac cryomodules to accommodate another 16 cavities have been designed, developed and installed in the beam line and integrated with the cryo distribution line recently. The design of these two modules have been modified based on the feedback from the performance of the earlier module. Present paper highlights the modified design to overcome the shortcomings of the earlier module along with preliminary thermal and vacuum performance.

INTRODUCTION

To augment the energy of heavy ion beam from the 15 UD Pelletron and to also attain the domain of higher atomic number up to 80, a Superconducting Linear Accelerator [1] with one cryomodule consisting of eight quarter wave bulk niobium cavities is under operation at the IUAC, New Delhi. These cavities are being operated at a radio frequency of 97 MHz at 4.5 K. Two more cryomodules with some novel features are being added such that now a total of 24 cavities will be accelerating the beam. The schematic of LINAC accelerator along with quarter wave cavity is shown in Figure 1.

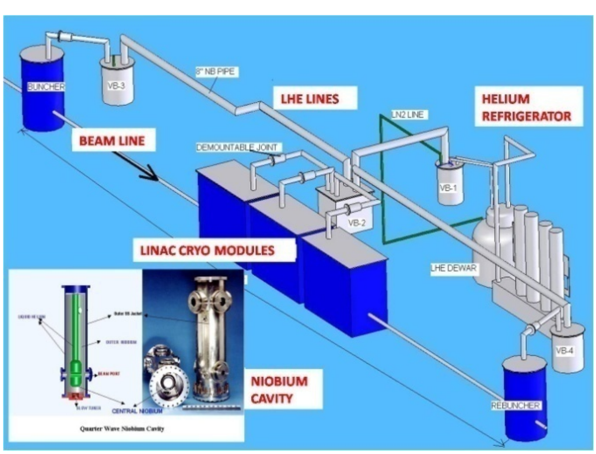

Figure1: Schemetic of IUAC LINAC and Cavity

The beam from the Pelletron travels through a superbuncher cryostat containing one Nb cavity, then through an array of three cryomodules each consisting of eight quarter wave cavities of bulk Nb and a superconducting magnet and finally through a rebuncher having two cavities. The beam then enters the experimental enclosure. The expected energy gain will be a factor of two with an average accelerating field of 3-4 MV/m. The first LINAC cryomodule along with the superbuncher and the rebuncher cryostats were installed in the beam line and are presently under operation after a series of trial experiments. These indigenously developed cryostats are integrated with helium and nitrogen refrigerators through locally developed liquid helium and liquid nitrogen distribution lines [2]. With this partly established linac, the energy of silicon beam with charge state of +11 has been enhanced from 130 MeV to 167 MeV and delivered to users. Several other beams have also been delivered successfully [3]. The development of 2^{nd} and 3^{rd} linac cryomodules was taken up late as (1) the required no of indigenous cavities were not available, (2) to get feedback from the performance of first module and improve it in subsequent modules. The design of the two new linac cryomodules have been modified and developed accordingly. At present all the cryomodules are installed in the beam line and integrated with the cryo network system. Present paper will be highlighting the modified design to overcome shortcomings of the earlier module.

DESCRIPTION OF CRYO MODULE

These are rectangular cryostats [4] of dimension 3.0 m x 1.2 m x 1. 9 m, each housing 8 cavities and one solenoid magnet along with helium and nitrogen vessel. Considering rectangular and long shape, the vacuum jacket is welded with cross stiffening plate to overcome buckling under vacuum. In the earlier module, the cavities were rested on two aluminium bars with a total weight of 160 kg. As the beam line vacuum and cryostat vacuum is common, no MLI is used in these modules considering stringent requirement of a clean environment around cavities and to have better vacuum in the beam line. A rectangular shaped copper sheet cooled by liquid nitrogen is used as thermal shield to reduce the radiation load. The sheet is cooled by forced flow of liquid nitrogen through a 3/8 inches dia. SS pipe, which is anchored to the copper sheet by using a number of copper clamps. Liquid nitrogen vessel is used as a phase separator for shield cooling as well as cooling of the RF cable. The cavities along with the rest of the other cold mass are shown in figure.2.

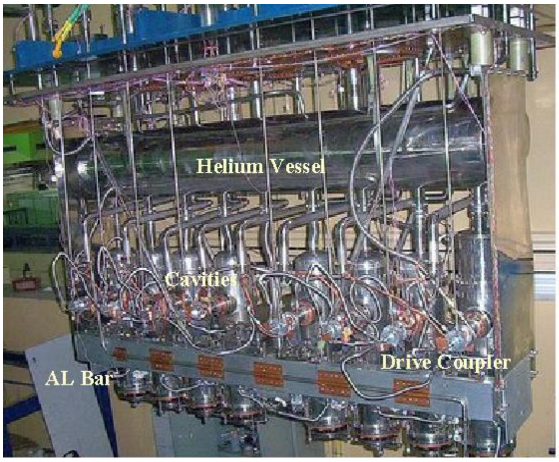

Figure 2: Cavity assembly in first module

Shortcoming of First Cryomodule

- Static heat load is higher than the design load. A detailed thermal analysis was carried out based on measured temperature profile and results are presented in Table 1
- Fine tuning of in-situ alignment facility of the cavity assembly was not available. This led to frequent opening of cryostat by disturbing vacuum and warming up the system to room temperature
- Cool down rate was only 12- 15 K/hr in the zone between 150 K and 60 K. Better cool down rate is preferable to avoid any Q disease
- Problems of inadequate flow of liquid helium during cool down and possibility on trapped cold helium gas

All these problems have been addressed in the present cryomodule and design was modified accordingly.

Table 1: Analysed Heat Load on First Cryo Module

Load	Design (W)	Measured/ Analysed
Conduction	4.9	< 5.0
Radiation	2.67	5-6
Al Bar	2.0	10- 12
Drive Coupler		5-10

Modification in Present Cryomodules

Measured heat load through drive coupler was high because of the long length of vacuum exposed RF cable. Joule heating load in the cable was shared by liquid helium and nitrogen. In the present design, exposed cable length is reduced by changing the position of nitrogen vessels with extended leg. In this case most of joule heating will be absorbed by LN2. To reduce the shield temperature from average 115 K to 85 K, the dimension and volume of liquid nitrogen vessels is also increased to have higher flow rate through SS pipe attached to copper thermal shield. An immersion heater has been installed in the LN2 vessel to maintain the liquid nitrogen level. Cross view of new module is shown in figure 3.

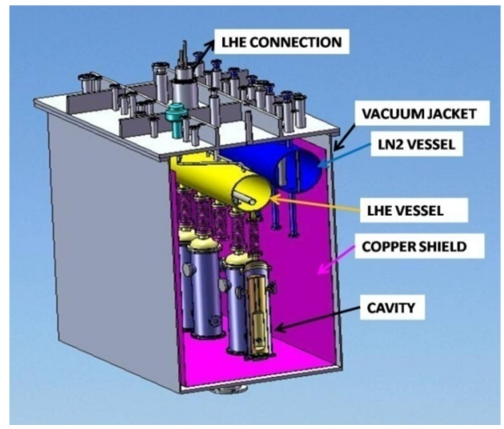

Figure 3: New cryomodule cross-section

In the earlier module, cavities are rested on two aluminium bars of approx. weight of 160 Kg. Precooling of Aluminium support bar was not effective considering the high mass and specific heat of the support bar. A variable conduction heat load at 4.2 K through the support collars to each individual cavity was evident on measurement of the cool down rate (5- 10 K/ day) of Al bar. Stored enthalpy in the bar is now reduced by replacing Al bar with light weight SS channel. Conduction load is minimized by introducing contact resistance through additional G-10 spacers in between support collars.

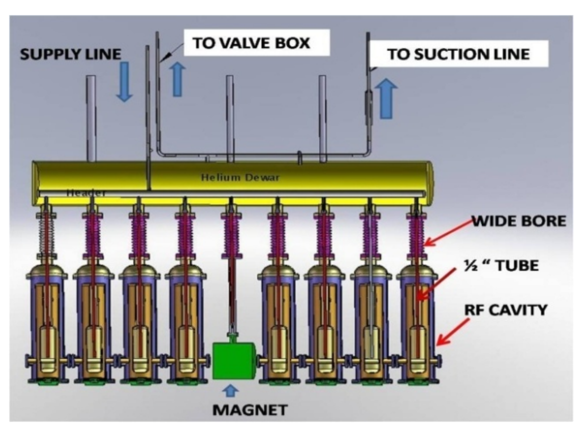

Figure 4: Cool down schematic of new module

The most important modification in the cryostat has been carried out on liquid helium cooling scheme. An additional header with eight tubes extended to the bottom of cavities has been incorporated to achieve a higher cool down rate of the cavities. Return cold gas will have two optional paths either to the suction line of compressor during cool down time or directly to the valve box in steady state. In the first module, precooling by liquid nitrogen was necessary as liquid helium supply line ends at the helium vessel. Helium cool down pattern is shown schematically in figure 4

PRESENT STATUS

The 2nd and 3rd cryomodules with the above mentioned modifications were designed and developed. Each subcomponent underwent several thermal shocks between 300 and 77 K and was leak checked prior to final welding with top plate. After preliminary leak checking both the modules were installed in the beam line as shown in figure 5.

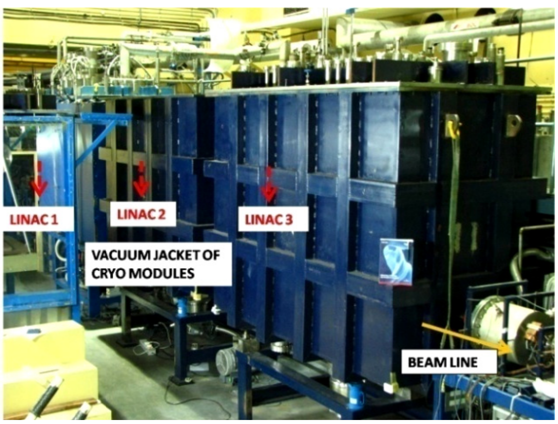

Figure 5 : Installed LINPAC cryomodule in beam line

With a view to automate the LN2 flow rate to control shield temperature as well as to maintain a minimum liquid nitrogen level in the vessel, it was planned to have thermo siphon cooling rather than forced flow cooling with a header on bottom surface of shield. Space constraints between the bottom of cavities and shield to accommodate header forced us to drop the thermo siphon cooling of shield. Proposed thermo siphon scheme is shown in figure 6.

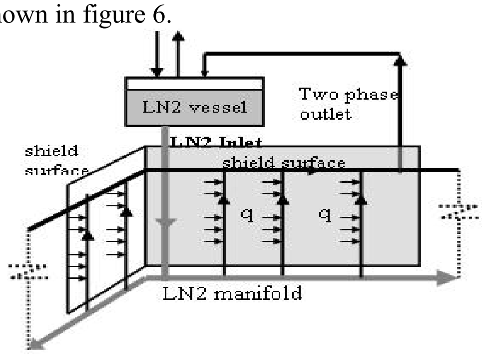

Figure 6: Schematic of thermo siphon cooling

After positioning and final alignment in the beam line, cryomodules have been integrated with existing liquid helium valve boxes through vacuum jacketed and MLI insulated lines with demountable joints. Top view of all cryomodules along with helium line is shown in figure 7.

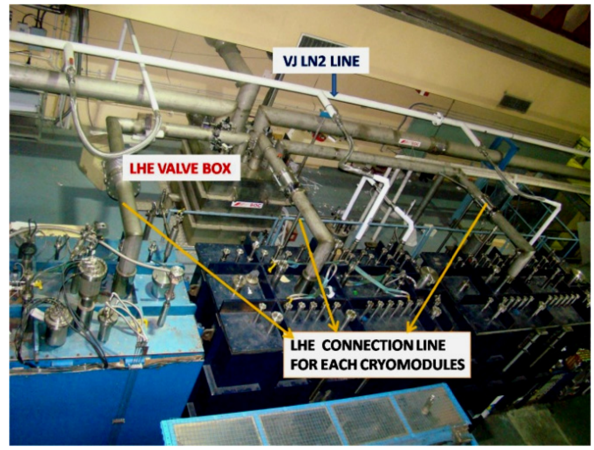

Figure 7 : Cryomodules with liquid helium line

Vacuum performance test has been done at room temperature and the vacuum level achieved without baking of copper shield is 5 x 10^{-7} mbar. We observed a central deflection of approximate 7 mm on top middle of rectangular ring flange, when module is evacuated without anchoring the bolts between top plate and ring flange. The stress calculation of vacuum jacket with stiffening ring was analysed using ANSYS which shows that strain is critically dependent on angular shape of cross-channels.

CONCLUSION

Fabrication of remaining sixteen cavities has been completed and off line performance testing is under way. Prior to acceleration of the beam through complete linac with 24 cavities, performance of additional cryomodules with respect to vacuum, heat load and cool down rate will be carried out shortly.

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