CORNELL'S MAIN LINAC CRYO-MODULE PROTOTYPE

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Abstract

In preparation for building an energy-recovery linac (ERL) based synchrotron-light facility at Cornell University which can provide greatly improved X-ray beams due to the high electron-beam quality that is available from a linac, a phase 1 R&D program was launched, addressing critical challenges in the design. One of them being a full linac cryo-module, housing 6 superconducting cavities operated at 1.8 K in continuous wave mode, 7 HOM absorbers and 1 magnet/ BPM section. The final design will be presented and a report on the fabrication status that started in late 2012 will be given.

INTRODUCTION

An NSF funded R&D program for the 5-GeV superconducting energy-recovery linac (ERL) [1] at Cornell University includes the design, build and thoroughly test all aspects of a complete cryomodule.

The almost 10 m long module (see Fig. 1) houses 6 superconducting cavities, operated in CW mode at 1.8 K. These 7-cells, 1.3 GHz cavities with an envisaged Q of $2*10^{10}$ will provide an energy gain of 16 MV/m. Each cavity is fed by a 5 kW power coupler. The Higher Order Modes (HOMs) absorbers are placed next to each cavity to obtain an efficient damping for the high beam current and short bunch operation. The series linac module will have a quadrupole/ steerer section which is omitted in the prototype as it technically does not present a challenge.

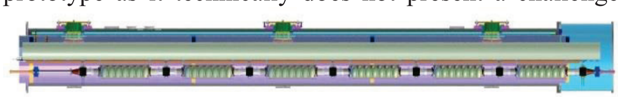

Figure 1: Cryomodule prototype.

COLD MASS SUPPORT SYSTEM

The beam-line string is suspended under the Helium Gas Return Pipe (HGRP) which acts as the beam-line backbone and is supported by three support posts to the vacuum vessel (see Fig. 2). The support system provides precision alignment and thermal insulation of the beamline string.

The HGRP is made of a Grade 2 Titanium pipe, with an outer diameter of 280 mm. With a 1 ton weight force of the beamline string, the maximum vertical displacement of the HGRP is estimated to be 0.1 mm and the natural frequency would be 88 Hz, indicating that a 3-posts support system is well suited to ensure an acceptable vertical displacement and vibration characteristics.

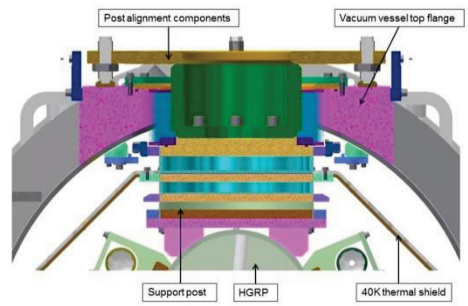

Figure 2: Cold mass support system.

The post has a same design as those used in the TTF cryomodule, which is an assembly of a low thermal conduction composite material pipe (G10 fiberglass pipe) and four stages of shrink-fit metal discs and rings. The two stainless steel disc/ring sets are connected respectively to the room temperature and to the 2 K cold mass environments. The two aluminum disc/ring sets provide thermal intercepts at 40 K and 5 K, with the 40 K set also providing structural support to the 40 K thermal shield. The heat load through conduction of each post (see Fig. 3) is estimated to be 8.58W to 40K, 0.54W to 5K and 0.05 W to 1.8K, respectively.

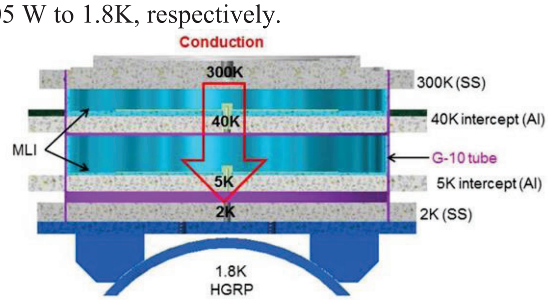

Figure 3: Support post.

The vacuum vessel is 965.2 mm in diameter, with a vessel cylinder made of carbon steel (A516 GR70) and stainless steel flanges that use O-ring seals. For the prototype the interior of the carbon steel portion will be painted with a low vapor pressure vacuum compatible epoxy, while the exterior will be painted with a marine paint product.

CYOGENIC PIPING SYSTEM

The cavities will be cooled by liquid helium sub-cooled to 1.8 K. Due to the fact that the half linac will be 350 m long, a big aperture (280 mm diameter) for the HGRP was chosen to provide the low flow impedance needed without excessive pressure drop. Connected to the HGRP at a single point in each module is a 100 mm diameter 2-phase helium manifold, show in Fig. 4. The purpose of this large 2-phase tube is to allow adequate surface area

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for evaporation and a sufficiently large cross-section for gas flow through it to the HGRP to avoid generation of waves on the liquid surface which could result in pressure fluctuations affecting frequency tuning of the cavities [2].

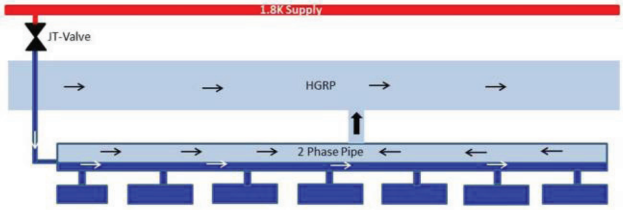


Figure 4: 1.8K flowchart.

A 5 K-6.5 K loop is used to cool the intercept all transitions to warmer temperatures in order to assure a minimal heat transfer to the 1.8 K system. A 40-80 K loop provides cooling for the coupler intercepts, cools the thermal radiation shield of the module and removes the heat generated in the Higher Order Mode (HOM) absorbers.

As show in Fig. 5, six lines of 50mm diameter run through the entire half-linac. In each module, local manifolds of smaller diameters deliver the cryogens via four valves (1.8 K, pre-cool, 4.5 K, and 40 K) which manage the flow division amongst the modules. The location and stiffness of piping supports were considered in the design to make sure the resonant frequencies are higher than 60 Hz (see Fig. 6 for details).

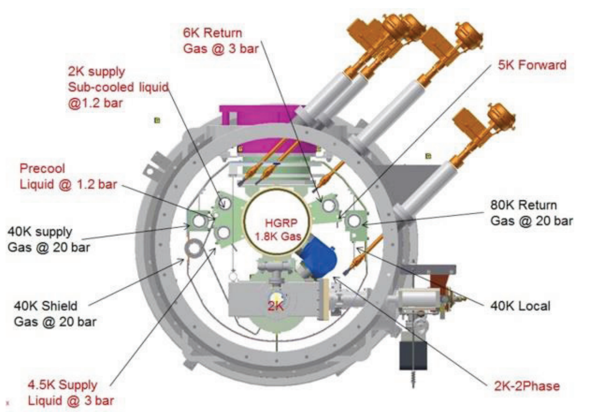


Figure 5: Piping system inside the cryomodule.

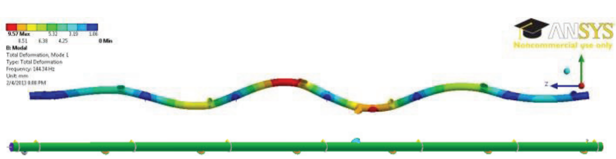


Figure 6: Natural frequency of the 1st mode of 2-phase pipe and the model showing the supports.

THERMAL SHIELD AND COOL DOWN

The radiation and convection heat loads are reduced by operating the shield at 40K and wrapping it with 30 layer multilayer insulation (MLI) blankets, in a vacuum environment. The magnetic shield, which is made of 0.5 mm Mu-metal sheets, will be mounted to the exterior of the 40K thermal shield to screen the Earth's field and any other stray magnetic field from the cavities.

The thermal shield is made from aluminum AL 1100-H14 sheets, with the upper section being thicker to support the weight. The sheets as shown in Fig. 7 are connected with fasteners as a rigid assembly with a good thermal contact. Reinforcement rings are attached to increase the mechanical stability.

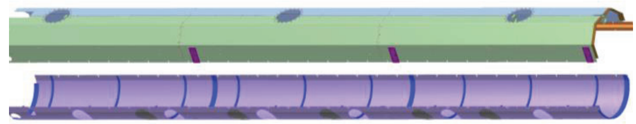


Figure 7: Upper and lower sections of the thermal shield.

To avoid excessive stress due to asymmetric cooling during the cool-down process, some slots (Fig. 8) are machined at the upper-lower section to unload the force.

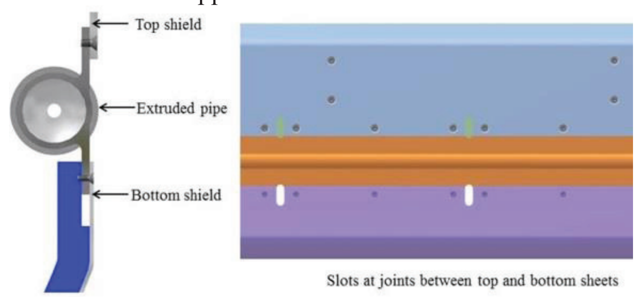


Figure 8: Joints between top and bottom sheets.

The thermal shield will be cooled by the 40 K delivery line which is connected to one side. As a result, the cool-down process will be asymmetric requiring a more detailed analysis.

Static heat loads includes conduction through the support post and radiation from room temperature vacuum vessel. With 30 MLI blankets covered on the shield, the radiation heat fluxes from room temperature are assumed to be 1.25 W/m^2. In the extruded pipe for the 40 K helium gas delivery, a convective heat transfer coefficient of 0.11 W/cm^2-K was estimated. The simulated results indicated that with a slow cooling rate of 4 K/hour, the temperature gradient reaches a maximum of 15 K on the entire shield, occurring 20 hours after the start of the cool down. Results are given in Fig. 9). Once

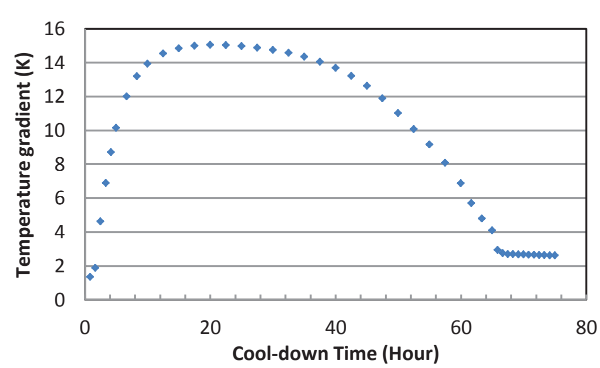
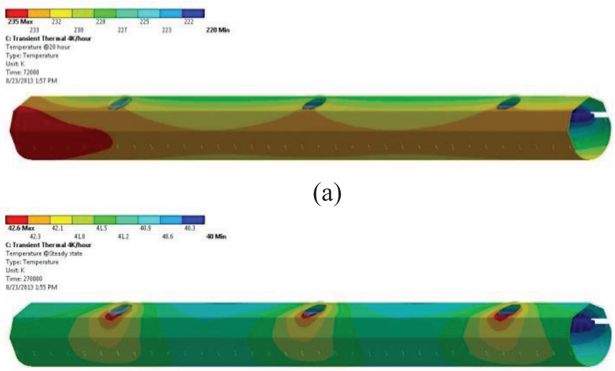


Figure 9: Temperature gradient on 40 K shield as a function of time during cool-down.

fully cooled down, the steady state maximum temperature gradient will be only 2.6 K. At the worst scenario when the temperature gradient over the shield reaches the maximum, the thermal shield will be bent with a maximum relative deformation of 4.6 mm (Fig. 10), and the maximum stress will be about 60 MPa occurring at the corner of the slots.



(a)

(b)

Figure 10: Temperature distribution on the shield (a) at 20 hours after cool-down started and (b) at steady state.

ALIGNMENT AND ASSEMBLING

The HGRP defines the reference for the precision alignment of the beam-line string. Relative vertical alignment is ensured by precision machining on the interfacing surfaces of the supports, with a single machine tool setup at the final stage after all welding is done and a vibration stress relief is performed. The transverse and longitudinal alignment is obtained by the alignment pins on the support plates. The alignment key or a flexible cavity support allows the beam-line components to slide longitudinally relative to the HGRP during thermal cycling.

To accommodate the HGRP thermal contraction at cold relative to the vacuum vessel, the two side posts are slidable over the top flanges while the central post is locked in position. Details of the design are shown in Fig. 11. The central position of the side posts are pre-shifted at room temperature and will be concentric to the vacuum vessel flange at cold.

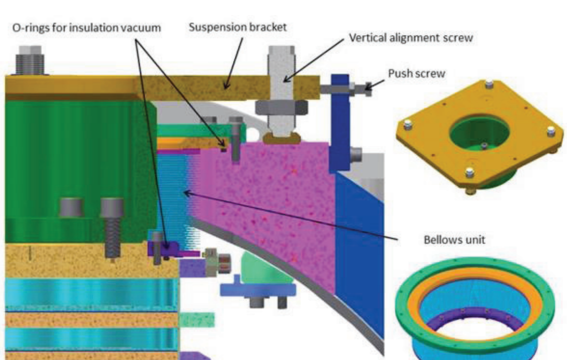


Figure 11: Post alignment components.

The prototype design foresees that it could be a spare module in the series linac that the final welding or connection for the cryogenic pipes will be made in-situ. In addition, the design also allows easy dismounting the whole assembly for replacing some components. The assembly sequence is that the beam-line string will be assembled in the clean room, and then attached to the HGRP. Once the cold mass is assembled, it will be rolled into the vacuum vessel on its rail system (see Fig 12).

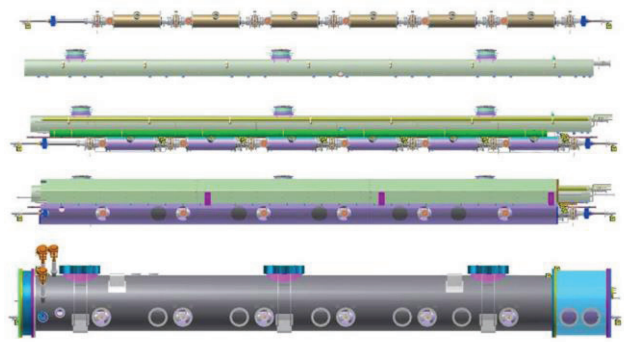


Figure 12: Prototype assembly sequence.

STATUS AND OUTLOOK

The major components of the cryomodule prototype are under fabrication. We anticipate starting the assembly process in November 2013, and have it completed and ready for test by the end of 2014.

ACKNOWLEDGMENTS

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