TRIUMF'S INJECTOR AND ACCELERATOR CRYOMODULES

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Abstract

TRIUMF's ARIEL project includes a 50 MeV-10mA electron linear accelerator (e-Linac) using 1.3 GHz superconducting technology. The accelerator consists of three cryomodules; an injector cryomodule with one cavity and two accelerating cryomodules, each having two cavities. One injector cryomodule and one accelerator cryomodule have been assembled and commissioned at TRIUMF, and a second injector cryomodule for VECC is being assembled in Kolkata. Both injector and accelerator cryomodules utilize a top-loaded cold mass design contained in a box-type cryomodule. The design and early test results of both cryomodules are presented.

INTRODUCTION

TRIUMF's new high intensity superconducting electron linear accelerator (e-Linac) is configured as a 50 MeV 10mA device consisting of five 1.3 GHz nine-cell niobium cavities. Each cavity is designed to supply 10MV of acceleration with two 50kW power couplers that supply the required beam loaded RF power of 100kW. The cavities are housed in three cryomodules, one injector cryomodule and two identical accelerator cryomodules, ICM, ACM1 and ACM2 respectively. TRIUMF has recently commissioned the ICM and ACM and is now building a second ICM for the VECC laboratory in Kolkata. The second ICM cryomodule will be completed this year and will be tested using TRIUMF's e-Linac facilities prior to shipment to India.

CRYOMODULE DESIGN

The cryomodule design has been reported elsewhere [1-3]. In brief the module is a top-loading box-like structure with a stainless steel vacuum chamber. The ICM is show in Fig. 1 and the ACM is shown in Fig. 2. The cold mass is suspended from the lid and includes a stainless steel strongback, a 2K phase separator pipe, cavity support posts and the cavity hermetic unit. The hermetic unit consists of the niobium cavities, the end assemblies, an inter-cavity transition (ICT) with a stainless steel HOM damper, the power couplers (FPC) and an rf pick-up.

The niobium cavity (Fig. 3) is a nine cell 1.3GHz cavity based on a TESLA design with modified end sections to accommodate two 50kW power couplers and mitigate higher order modes [4].

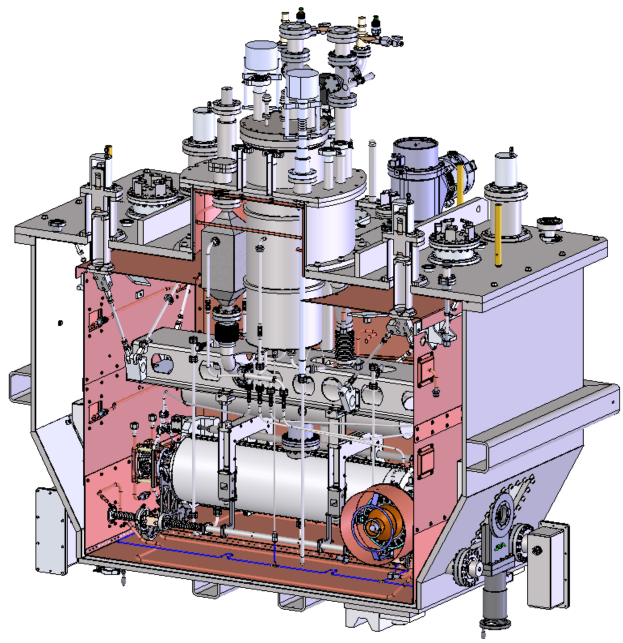

Figure 1: Injector Cryomodule (ICM).

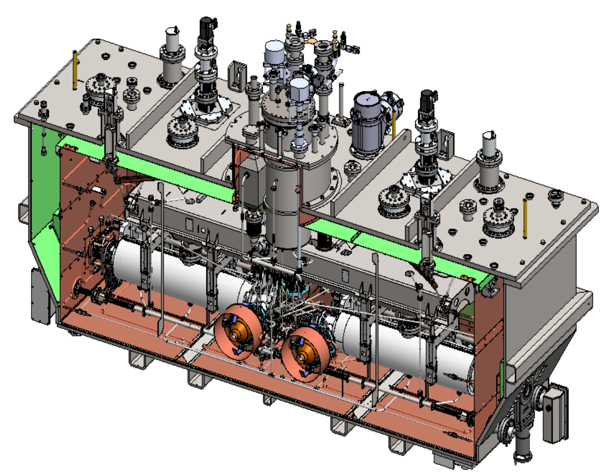

Figure 2: Accelerating Cryomodule (ACM).

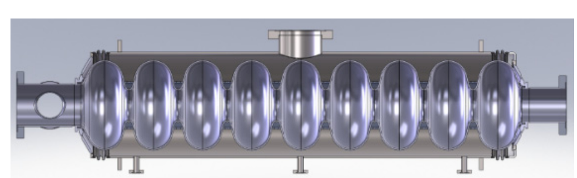

Figure 3: The e-Linac nine cell cavity with jacket.

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The end assemblies include the warm-cold transition (WCT), CESIC HOM damping tubes and beam-line isolation valves. Other features include a scissor jack tuner and warm motor, LN2 cooled thermal isolation box and two layers of mu metal and alignment monitoring via a WPM diagnostic system.

Each cryomodule is outfitted with an on-board 4K to 2K cryogenics insert. The insert consists of a 4K phase separator, a 2.5gm/sec heat exchanger and a JT expansion valve, a 4K cooldown valve and a 4K thermal intercept syphon supply and return.

The vacuum enclosure provides an insulation vacuum and is made of a stainless steel rectangular box with angled ends, to allow access to the warm isolation valves. The enclosure also includes openings for power couplers and an access window for the LHe connections. The top plate also supports: a dedicated 4K to 2K helium conversion unit, two turbo pumps, the tuner drive systems for each cavity, and all the feedthroughs and vacuum ports for the diagnostics.

Strong-back and Struts

The cavity support system (Fig. 4) consists of a stainless steel strut and strong-back assembly. Both are anchored to the lid by four support tower assemblies. The strut assembly is also thermally anchored to the top of the LN2 shield with additional cold straps attached to each strut (copper braided thermal links). The support tower assemblies provide the sealing interface between the isolation vacuum and atmosphere. It also provides the cold mass with vertical and horizontal adjustability (transverse to the beam axis) for alignment. Each support tower supports a different kind of strut configuration. The strut system for both cryomodules is designed with three non-redundant coplanar constraints at each end of the strong-back. Plus, a strut anchored to the middle of the strong-back provides the final constraint. In the case of the EACA, this additional strut is made of titanium in order to minimize the longitudinal thermal displacement of the cavity at the power coupler port locations.

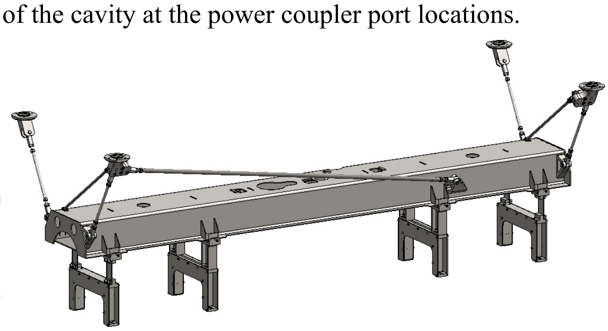

Figure 4: Strut and strong-back assembly.

Each cavity is independently supported by the strong-back with two stainless steel support bracket assemblies. Each assembly has vertical and transverse (horizontal) adjustability to facilitate the final alignment of each cavity. The support bracket assembly for each cavity uses a fixed and flexible configuration that allows the cavity to contract during cool-down. This flexible configuration utilizes two parallel stainless steel flexures that are free to deflect as needed during cool down. Each flexible configuration is used at the end opposite to the power coupler ports.

Tuner System

The tuner system is a modified Jefferson scissor tuner with a custom warm drive system utilizing a servo motor and a resolver placed on top of the cryomodule at atmosphere. As in the Jefferson design, the warm system is spring supported and is allowed to float in order to accommodate the thermal contraction of the cold mass (internal components). The cold scissor system is attached to each cavity's LHe jacket.

Warm-Cold Transition and Intercavity Transition

The cavity ends are coupled to a warm-to-cold transition (WCT) assembly that connects the cavity to the warm isolation valves shown in Fig. 5. The temperature staging is done by two sets of bellows, one LN2 and one LHe thermal intercept. Separating the thermal intercepts (80K & 4K) is a thin-wall stainless steel hydro-formed bellows with four G10 support rods. The LN2 thermal intercept also marks the location of the WCT assembly-LN2 shield interface. Following the LN2 shield is an edge-welded bellows that is welded to the WCT warm flange which is connected to the warm isolation valve. The combination of hydro-formed and edge-welded bellows was chosen to provide high thermal impedance from the 80K to 4K intercepts and to provide greater flexibility for thermal contraction between the cold mass components and the fixed isolation valve.

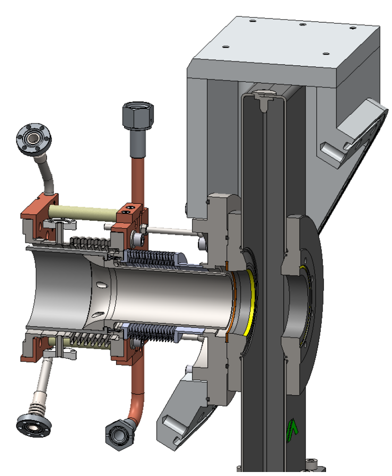

Figure 5: WCT Assembly.

After cool-down, the cavity and WCT assembly translate a total of 4mm upwards due to thermal contraction of the support mechanism components. Upon thermalization, the WCT assembly provides a load of ~ 0.15 W to the cavity, 0.3W to the 4K circuit, and around 10W to the LN2 circuit.

The inter-cavity transition (ICT) is a more evolved design of the warm-cold transition that makes the hermetic connection between both cavities in the ACM cryomodules. The LHe thermal intercept is machined into the end flanges of the ICT. Two hydro-formed bellows are welded to a center assembly containing the high-order mode (HOM) damper and an LN2 thermal intercept. This LN2 thermal intercept serves to extract the RF load from the HOM damper. It is supported by a single stainless steel rod which is in contact with the end flanges of both cavities through adjustable vee-blocks and ball ends (for single-point contact).

4K/2K Cryoinsert

The 4K/2K cryo-insert, shown in Fig. 6, includes a 4K phase separator, 4K/2K heat exchanger, JT expansion valve, 4K cooldown valve, LN2 cooled thermal shield, warm mu-metal layer plus siphon circuit for intercept cooling. The heat exchanger is fabricated by DATE with an estimated capacity of 2.5 gm/sec.

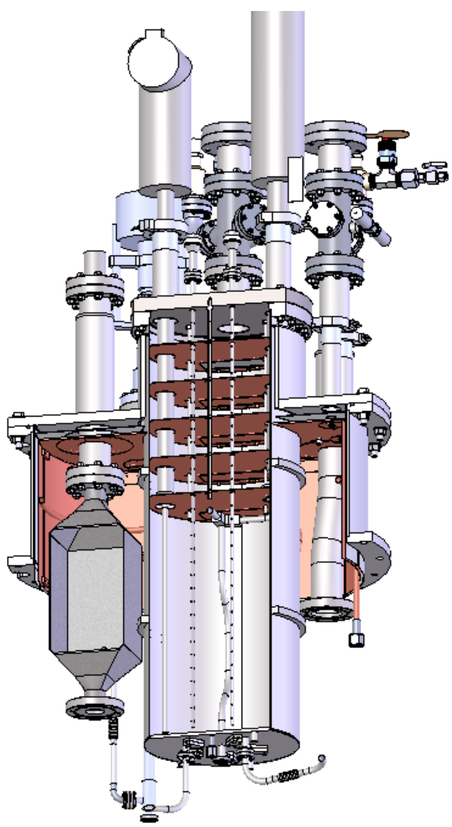

Figure 6: 4k-2k Cryo-insert.

Both the 4K and 2K helium spaces contain a safety relief mechanism containing a pressure relief valve and a burst disc. The insulation vacuum space is also safeguarded by a pressure relief valve ("burp plate"). The maximum pressure allowed in any internal space of the cryomodule is 14 psi thereby avoiding the need for pressure vessel certification.

During cooldown the 4K valve is used to direct LHe to the bottom of the cold mass until 4K level is reached. The level in the 4K reservoir is regulated by the LHe supply valve, the level in the 2K phase separator is regulated by the JT valve and the 2K pressure is regulated by the sub-atmospheric line valve. Piping within the module delivers the syphon supply to a number of 4K thermal intercept points (WCT, ICT and FPC) and then returns the two phase LHe back to the top of the 4K phase separator.

Alignment

A cavity alignment of ±0.5mm is specified. The alignment is achieved using a combination of Wire Position Monitor (WPM) sensors and optical targets. Before final treatment of the cavity, a WPM bracket is attached to the upstream and downstream cavity beam tubes. The WPM holders on the bracket are indexed to the cavity center using beam tube reference targets. Each bracket is equipped with two WPM holders, one right and one left of the beam center, and two optical targets. The cavity is assembled in the clean room to form a hermetically sealed unit. It is then assembled into the cold mass and supported from the lid, which would rest on an assembly frame with fore and aft features replicating the beam port, WPM, and optical target positions. After the cold mass is inserted into the tank, the support towers are adjusted using WPM and optical targets as reference to bring the cold mass on line. Later, after cooldown and full thermalization, the support towers are re-adjusted to its final positions.

Alignment of the ACM cryomodule follows a similar process with an additional clocking step of each cavity with respect to each other. This clocking is done by using optical targets and an adjustable assembly stand. Once both cavities are aligned and clocked to each other, the assembly stand is locked and cleaned. Then the cavity assembly is completed in the clean room. Once the cavity assembly comes out of the clean room and is attached to the strong-back, the alignment of the cavity assembly is completed using the WPM optical ports, before and after cool-down.

PROTOTYPE STRATEGY

The cryomodule prototype strategy utilizes the ARIEL1 and ARIEL2 cavities to qualify the two cryomodule types. ARIEL1 is chosen for ICM production while ARIEL2 is chosen for ACM installation along with a `dummy' cavity that occupies the second cavity space in the cryomodule. The dummy cavity contains all the interfaces to the helium system so that all helium piping surrounding the dummy will be final. In addition the dummy cavity is installed with a DC heater to replicate cavity active loads and WPM brackets to permit alignment studies. The one cavity ACM variant we term `ACMuno'. This configuration allows a full cryo-engineering characterization of the cryomodule. The ICM and ACM preparations each consist of hermetic unit assembly in the clean room, top down assembly in the ISAC beam assembly area and installation in the vacuum tank. The ICM assembly was completed and full cold test

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was done in the ISAC-II clean room before installation in the e-hall. Due to the size of the ACM it was delivered direct to the e-hall after the top plate was installed and the warm couplers were added there.

TEST RESULTS

Cooldown to 4K and production of 2K was straightforward. The static heat loads are measured by observing the rate of falling level after the supply valves are closed to the volume and noting the volume change of LHe per unit time and the heat of vapourization. The rate of 2K production is measured by closing the 4K supply valve while regulating the JT valve to keep the level constant in the 2K space. In this case the falling level in the 4K space is a combination of the static loads of the 4K and 2K space plus the vapour lost due to expansion from atmosphere to 31.5mbar. The 77K static load is measured by noting the warmed GN2 flow required at the exhaust side in order to keep the LN2 thermal shield cold. In this case the measurement is an overestimate since it was difficult to regulate the LN2 at a lower level but the thermal shield was always cold. Measured values for the ICM are shown in Table 1 compared to estimates made during the engineering phase. The 2K production efficiency improves as a function of mass flow as the temperature of the heat exchanger and JT valve decreases. Values are 70% at 0.5g/s, 80% at 1g/s and 86% at 1.5g/s.

The tuner range was measured at +400kHz – the tuner motion was very stable and the cavity frequency could be stepped very precisely over this range.

Table 1: Measured Cryogenics Performance for ICM

Parameter	Est.	Meas.
4K static load – no syphon	2W	3W
4K static load with syphon	6W	6.5W
2K static load	5W	5.5W
77K static load	100W	<130W

The future plan at TRIUMF will be to replace the dummy cavity following the completion of ICM2 for VECC.

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