COMMISSIONING OF THE 10MeV ELECTRON INJECTOR CRYOMODULE FOR VECC AT TRIUMF

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Abstract

TRIUMF (Vancouver) and VECC (Kolkata) have been engaged in a collaboration on superconducting electron linacs since 2008. The motivation for the collaboration is to support initiatives at both labs, ARIEL at TRIUMF and ANURIB at VECC, to augment the respective radioactive ion beam (RIB) programs with the addition of a high intensity electron linac driver to produce RIBs through photo-fission. Final design goals are 50MeV and 10mA/3mA at TRIUMF/VECC respectively. Recently the VECC 10MeV injector cryomodule (ICM) was commissioned with beam. A summary of the ICM design and results of the commissioning are presented.

INTRODUCTION

A MW class cw superconducting electron linac (e-Linac) is being installed at TRIUMF as a driver for radioactive beam production as part of the ARIEL project. The e-linac final configuration is planned to consist of five 1.3GHz nine-cell cavities housed in three cryomodules with one single cavity injector cryomodule (EINJ) and two double cavity accelerating cryomodules (EACA, EACB) to accelerate in continuous-wave (cw) up to 10mA of electrons to 50MeV. The e-Linac is being installed in stages. A demonstrator phase (2014) consisting of a 300kV electron gun, EINJ, and a partially outfitted EACA with just one accelerating cavity was installed for initial technical and beam tests to 22.9MeV. An upgrade now installed has a completed EACA to reach an operational goal of 3mA of electrons to 30MeV for first science from the ARIEL ISOL targets (Fig. 1).[1]

TRIUMF began developing the Injector Cryomodule (ICM) in 2010 in collaboration with the VECC laboratory in Kolkata. VECC also requires a photo-fission driver for the proposed ANURIB facility[2]. TRIUMF and VECC jointly designed the ICM (termed EINJ in ARIEL). Two cryomodules have been fabricated and beam tested at TRIUMF. This report describes the design and commissioning of the VECC ICM.

ICM DESIGN

The cryomodule design has been reported elsewhere [3]. In brief the module is a top-loading box-like structure with a stainless steel vacuum chamber (Fig. 2). The cold mass is suspended from the lid (Fig. 3) and includes a stainless steel strongback, a 2K phase separator pipe, cavity support posts and the cavity hermetic unit.

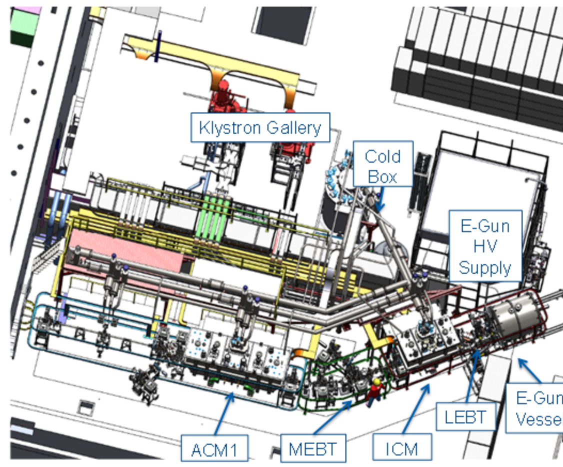

Figure 1: e-Linac at TRIUMF.

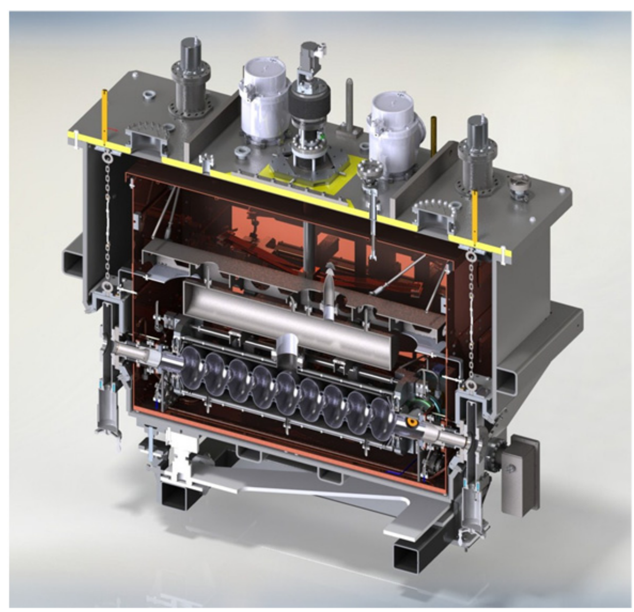

Figure 2: The VECC Injector Cryomodule.

The hermetic unit consists of the niobium cavities, the end assemblies, inter-cavity transition (ICT) with a stainless steel HOM damper, the power couplers (FPC) and an rf pick-up. The end assemblies include the warm-cold transition (WCT), 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.

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Each cryomodule is outfitted with an on-board 4K to 2K cryogenics insert. The insert consists of a 4K phase

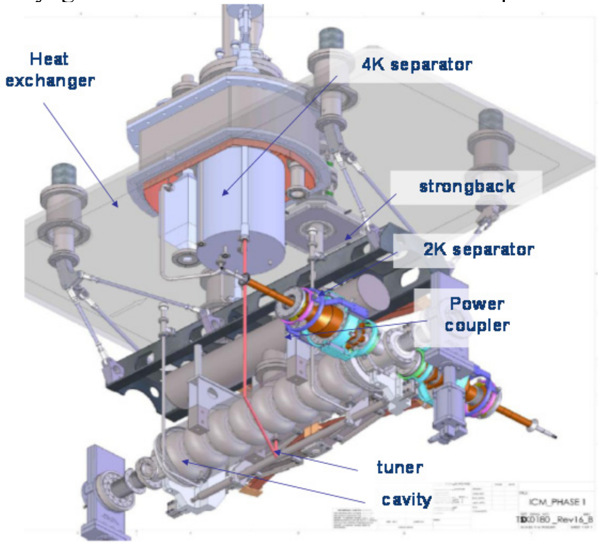

Figure 3: Model of the Injector Cryomodule.

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. During cooldown the 4K valve is used to direct LHe to the bottom of the 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 4K phase separator.

Cavities

The cavity parameters include rf frequency=1.3 MHz, L=1.038m, R/Q=1000, Ea=10MV/m. For Qo=1e10 the cavity power is Pcav=10W. A rendering of the jacketed cavity is shown in Fig. 4 and a photo of the unjacketed cavity is shown in Fig. 5.

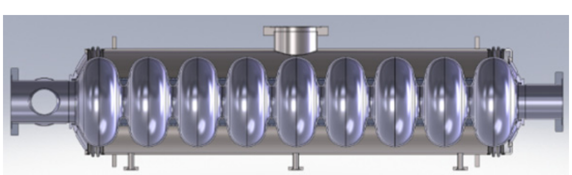

Figure 4: The e-Linac nine cell cavity with jacket.

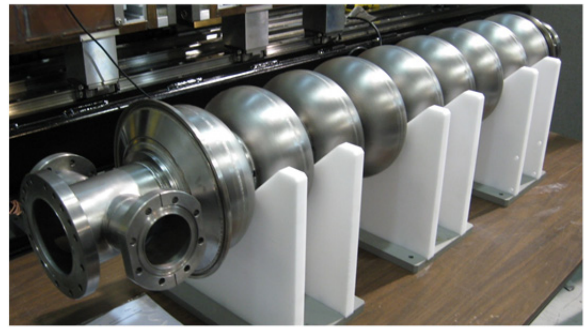

Figure 5: A photo of the unjacketed VECC ICM cavity.

The inner cells take their shape from the Tesla nine cell cavities but the end groups are modified to accept the two power couplers and to help push HOMs to dampers located on each end. On the power coupler end there is a stainless steel damping tube coaxial with the beam tube and extending into the beam tube by 17mm. On the opposite end of the cavity a coaxial CESIC tube is used. Each tube is thermally anchored at 77K and thermally isolated from the cavity by a thin walled stainless steel bellows. The dampers are sufficient to reduce the HOMs to meet the BBU criterion of $R_d/Q*Q_L<1e6$. The beam tube diameters on the coupler end and opposite end are 96mm and 78mm respectively. The vacuum jacket is made from Ti with a bellows on either end. A single 90mm diameter chimney allows for large cw rf loads of up to 60W per cavity assuming a conservative heat transfer of 1W/cm^2.

The VECC cavity has been fabricated by PAVAC. The cavity is tuned, degreased, then given a 120micron BCP before degassing at 800C and final 20 micron etch and tuning. Cavity jacketing is done at PAVAC.

10MeV BEAM TEST

A `10MeV Beam Test' was part of the ICM final characterization.

Cryomodule Preparation

The FPCs are conditioned in an off-line test stand. A 30kW IOT is used for the conditioning. The couplers are installed on a waveguide box and power is transmitted to a dummy load. Preparation involves extended bakeout (five days) at 100C with N2 flowing to cover the ceramic. RF conditioning involved both TW (18kW cw) and SW mode (10kW pulsed) with adjustable short for ~five days.

The cryomodule hermetic unit is assembled in a Class 10 clean room. The hermetic unit is then delivered to the cryomodule assembly area where the unit is raised into position to be attached to the strong back followed by the completion of the top assembly and final installation in the vacuum vessel. The ICM is then delivered to the electron hall.

Cryomodule Installation

To perform the test the linac is warmed and TRIUMF EINJ cryomodule is taken off-line and the VECC ICM is installed in its place. Since the TRIUMF EINJ and VECC

ICM are virtually identical the ICM could be plugged in without any alterations to the installed equipment.

The 300kV e-Gun and LEBT transport are used to inject the beam to the ICM and the downstream 10MeV beam dump is used to calibrate the energy gain. Isolation vacuums are established in the cryomodule and in the two power couplers. The cryomodule isolation vacuum is 9.97e-7, 5.73e-8, and 1.66e-8 Torr at room temperature, LN2 temperature and at 4K respectively. The cavity beamline vacuum at room temperature was 9.4e-9 Torr.

Cryogenics Characterization

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 is difficult to regulate the LN2 at a lower level but the thermal shield remains 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 shown in Fig. 6.

The FPC cold sections are cooled with LN2 loops, 80 K thermal links and 4 K syphon loops which intercept the RF dynamic load at the 80 and 4K intercepts. During the beam commissioning 10~12 kW RF power was delivered through the FPCs in standing wave mode at very weak beam loading. The temperature sensors related to the coupler syphon loops indicated that the syphon loops work well. There is ~0.32W and ~1.2W RF load to the 4K reservoir for a total forward power (for 2 FPCs) of 5kW and 10kW respectively.

Table 1: Measured Cryogenics Performance for ICM

Parameter	Estimate	Measurement
4K static load with syphon	6W	4.5W
2K static load	5W	5W
2K production efficiency	82%	85%
77K static load	100W	<130W

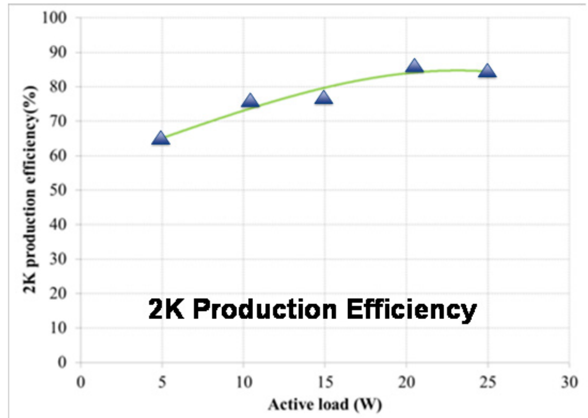

Figure 6: 2K production efficiency as a function of heat load.

RF Characterization

RF measurements include cavity turn on and phase/amplitude lock, tuner frequency range and tuner lock, microphonics measurements and beam acceleration. The tuner range is measured at +400kHz – the tuner motion is very stable and the cavity frequency can be stepped very precisely over this range. Due to the excellent frequency stability and broad bandwidth phase lock could be obtained with stable forward power even without the tuner but the tuner lock was easily achieved in any case.

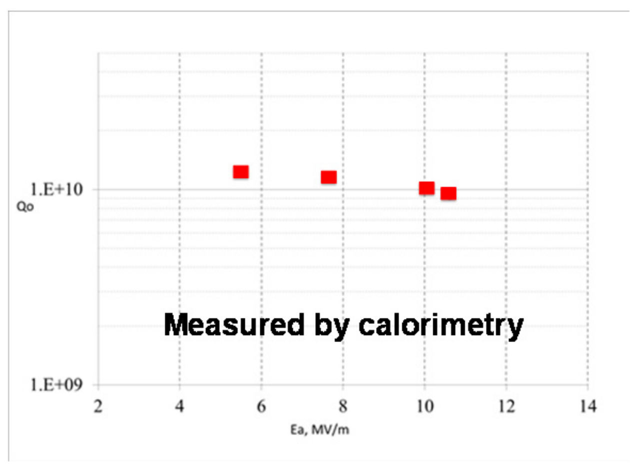

Figure 7: RF performance of the installed cavity.

Cavity quality factors are estimated based on calorimetric measurements. The performance is presented in Fig. 7. After RF conditioning a value of Q_0=1.03e10 was measured at an acceleration gradient E_a=10MV/m meeting the design goal.The Q_0 values in the cryomodule are equivalent to the values measured in the vertical test indicating the magnetic shielding is sufficient and the HOM dampers do not load the fundamental mode. A low intensity beam was used to calibrate the gradient. A final energy of 10.5MeV was achieved at the beam dump corresponding to a cavity gradient of more than 11MV/m.

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FUTURE PLANS

The VECC ICM is now off-line and waiting for VECC engineers to visit TRIUMF to participate in preparing the cryomodule for travel to India. This involves removing the warm couplers and providing reinforcing tensioners to prevent excessive movement from side loads during transport.

ACKNOWLEDGMENT

Thanks to the strong TRIUMF technical team for their careful preparation and assembly.

REFERENCES

[1] S. Koscielniak, et al, `TRIUMF ARIEL e-Linac Ready for 30 MeV', TUPAB022, proceedings of this conference.
[2] A. Chakrabarti, et al., `The ANURIB project at VECC – Plans and preparations', NIM, Vol 317, PartB, Dec. 2013, p. 253.
[3] R.E. Laxdal, et al., "The Injector Cryomodule for the ARIEL e-Linac at TRIUMF", MOPB091, LINAC12.