

# THE INJECTOR CRYOMODULE FOR THE ARIEL E-LINAC AT TRIUMF

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## Abstract

The ARIEL project at TRIUMF includes a 50 MeV-10 mA electron linear accelerator (e-Linac) using 1.3 GHz superconducting technology. The accelerator is divided into three cryomodules including a single cavity injector cryomodule (ICM) and two accelerating cryomodules with two cavities each. The ICM is being built first. The ICM utilizes a unique top-loading box vacuum vessel. The shape readily allows the addition of a 4K/2K cryogenic unit that accepts near atmospheric LHe and converts to 2K liquid inside the cryomodule. The cryomodule design is complete and in fabrication. The 4K/2K cryogenic unit has been assembled with tests scheduled next month. The paper describes the design and status of the cryomodule.

## INTRODUCTION

TRIUMF is now preparing a new high intensity superconducting electron linear accelerator[1], e-Linac, as a key element of the ARIEL project. The e-Linac is specified to produce 10mA of 50MeV electrons as a powerful 0.5MW photo-fission driver to add a complimentary second source of radioactive ion beams for the existing ISAC experimental infrastructure. The e-Linac consists of five 1.3GHz nine-cell niobium cavities each supplying 10MV acceleration with two 50kW power couplers supplying the required beam loaded rf power. The five cavities are housed in three cryomodules, with a single cavity in an injector cryomodule, EINJ, and two identical accelerating cryomodules EAC1 and EAC2 with two cavities in each module. The fully funded first phase of the e-Linac includes the first two cryomodules for a final energy and intensity of 30MeV and 5mA for 150kW driver capability by 2014. The EINJ is presently being fabricated and will serve as the working prototype for EAC1.

TRIUMF began developing EINJ in 2010 in collaboration with the VECC laboratory in Kolkata. VECC requires a photo-fission driver for the proposed ANURIB[2] facility. TRIUMF and VECC have an agreement to jointly design the EINJ cryomodule. Two EINJs are being fabricated and beam tested at TRIUMF with one EINJ being shipped to VECC and the second installed in the e-Linac. The initial EINJ is presently in fabrication. A beam test area is being installed in the ISAC-II building to utilize the existing cryogenics infrastructure with beam tests scheduled for early 2013.

## CONCEPTUAL DESIGN

Cryomodules for 1.3GHz elliptical cavities utilize typically round vacuum chambers with end loaded cold mass assemblies. In applications such as X-FEL involving long linac structures the gas return pipe in the cryomodule acts as both the support strongback for the cold mass and the helium cold return distribution line for the overall cryogenic system. Operation is at 2K with the 2K produced either in a central 2K cold box or in a JT expansion valve close to the cryomodule that transforms a typical 3 bar stream from a 4K cold box to He-II. Heavy ion linacs such as the ISAC-II 40MV linac[3] operate at 4K due to typically lower rf frequencies and hence lower BCS resistance and are typically designed as box cryomodules with the cold mass loaded from above due to the large transverse size of the low frequency low beta cavities.

Although non-standard a top-loading box design (Fig. 1) has some advantages for the e-Linac over an end-loading round variant. Firstly the modular and staged testing/installation sequence of the e-Linac suggests that each cryomodule be self-reliant to convert 4K atmospheric LHe available from dewars or ISAC-II cryogenic system into 2K He-II. To this end the box

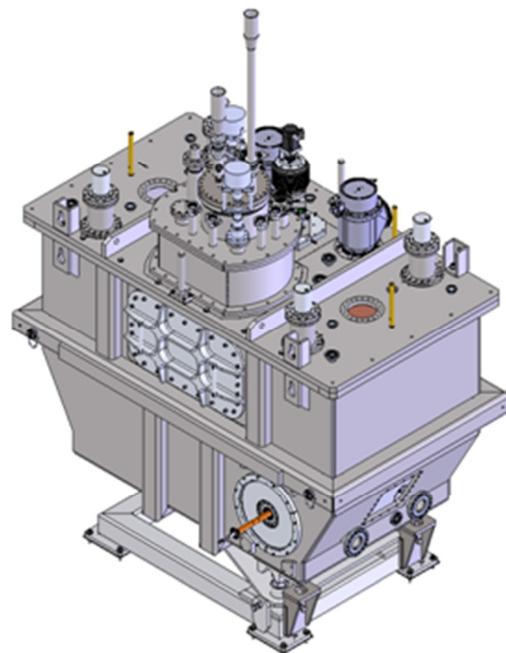


Figure 1: Model of the e-Linac Injector cryomodule.

cryomodule design has sufficient head room that makes possible the addition of a dedicated 4K/2K cryo-insert on each module. Secondly, incorporating features of the ISAC-II design reduces the engineering design effort within TRIUMF and takes best advantage of the existing infrastructure for assembly and test.

The basic concept of the e-Linac cryogenic system[4] replicates the ISAC-II system. A 4K cold box produces 4K liquid at 1.3Bar to a supply dewar that feeds LHe to a common delivery trunk with parallel 4K feed to each cryomodule. A 4K reservoir on board each cryomodule acts as phase separator and the 4K return vapor is sent back to the cold box. The 2K liquid is produced in each cryomodule by passing the 4K liquid through a heat exchanger in counterflow with the returning exhaust gas from the 2K phase separator and expanding the gas to 30 mbar through a JT expansion valve. The header pipe above the cavity string acts as a 2K phase separator and delivers cold gas back through the 4K/2K heat exchanger to the sub-atmospheric pumping system as a liquid load. A second on-board cryo valve delivers helium from the 4K phase separator to the bottom of the cavity string during cooldown. A siphon circuit from the 4K reservoir is used to cool the 4K temperature intercepts with vapour return back to the reservoir.

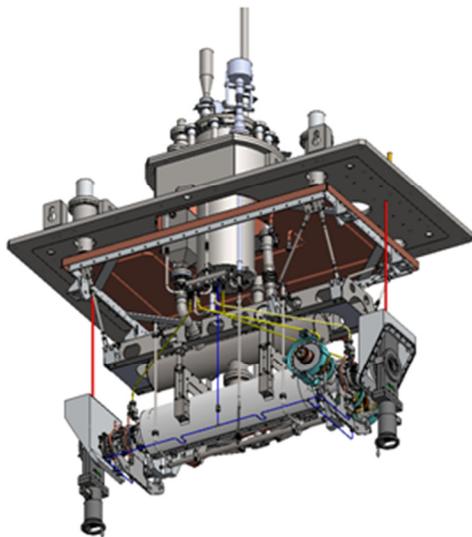


Figure 2: Top plate and cold mass assembly for EINFEL.

## DETAIL DESIGN

### *Vacuum Vessel*

The vacuum vessel is a stainless steel vessel in a rectangular box shape with additional ribs welded on to strengthen against the vacuum load (Fig. 1). A warm layer of 1mm mu-metal sheet is placed in the vacuum space anchored to the vacuum vessel. The entrance and exit beam tube regions are angled to allow the installation of the cold mass as a hermetically sealed unit with warm isolation valves at either end.

The cold mass is supported from the top plate with the following minor exceptions. The beam pipe is connected

at the warm isolation valve to the end flange. In addition each cavity is fed rf power through two couplers mounted horizontally and symmetrically opposed at the 'coupler end' of the cavity. The cold part of the coupler is assembled with the cavity as part of the hermetically sealed unit. After the top assembly has been inserted into the cryomodule the warm end is assembled to the cold end through cutouts in the side of the cryomodule. Two Cornell/CPI 50 kW couplers will be used to feed rf power to each of the 9-cell cavities. The power couplers are on the downstream end to reduce coupler kicks. There are also flanges adjacent to the beam tubes for off-axis wire position monitors (WPM)[5] for alignment purposes. The top plate has a cut out opening to allow independent installation and removal of the cryo-insert (see below). In addition a side panel cut-out allows access to the cryo-insert connections to allow removal of the cryo-insert without pulling the cold mass.

### *Strongback and Cold Mass*

The stainless steel strongback supports the cold-mass and forms a rigid assembly unit (Fig. 2). The cold-mass includes the cavity hermetic unit, cold mu-metal, tuner, 2K phase separator, lower cooldown supply pipe, and diagnostics. The strongback is supported from the top flange of the cryostat through struts. The support struts are equipped with spherical rod ends to avoid any mechanical stresses that may develop during thermal cycling. The hermetic unit consists of the niobium cavity and titanium helium jacket, the cold end of the power couplers, the warm-cold beam-pipe transition including HOM dampers, the cavity rf pick-up and isolation valves. The strongback and struts will thermally contract during cooldown though the reduced length of the module limits this to <4 mm. The vertical contraction does not affect the alignment since this can be compensated for during the initial set-up using the WPM and optical measurements and is repeatable.

### *4K / 2K Cryo-Insert*

The 4K/2K cryo-insert is being built and tested as a separate package. The geometry of the cryogenic unit is chosen to be compatible with pre-testing in an existing cryostat. The insert, shown schematically in Fig. 3, 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 prototype heat exchanger is fabricated by DATE with an estimated capacity of 2.5 gm/sec. A dummy 2K phase separator and three dummy thermal intercept loads are added to the test unit. These are removed during installation to the cryomodules and replaced with the 2K phase separator and actual thermal intercept loads.

The 4K/2K test unit is assembled and tests are imminent. Tests will include (1) static load measurements (2) 2K production efficiency (3) thermal siphon circuit cooling capacity (4) cooldown procedure and (5) cryogenic diagnostics operation.

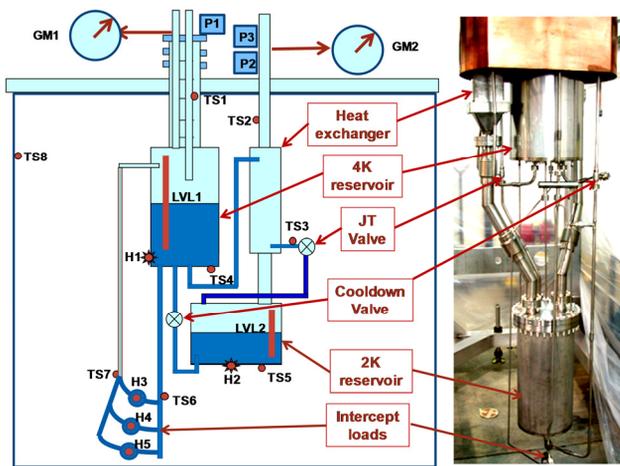


Figure 3: 4K/2K test unit with schematic and test diagnostics including temperature sensors (TS), variable heaters (H), gas meters (GM), pressure sensors (P) and level probes (LVL) and the actual unit as assembled prior to first cold test.

### Alignment

A cavity alignment of  $\pm 0.5\text{mm}$  is specified. The alignment is done using a combination of Wire Position Monitor (WPM)[5] sensors and optical targets. Before final treatment of the cavity a WPM bracket is attached to the upstream and downstream cavity beam tube. 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 then assembled into the cold mass and supported from the lid resting on an assembly frame with for and aft features replicating the beam port and 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 final position.

### Developments

**Power coupler assembly mock-up:** The alignment strategy requires that the cold mass be allowed to move during warm-up and cooldown without undo stress on components. Specifically the power couplers and warm-cold transition sections need sufficient flexibility. The coupler is flexible through transition bellows and an internal universal coupling. An exoskeleton gymbal has been designed to allow the warm and cold end of the coupler to move while maintaining the concentricity of the inner to outer conductor and reduce stress build-up in the coupler windows. This gymbal was tested in a mock-up of the cavity and tank wall geometry. The mock-up is also useful to help establish the jigs and fixtures required to install the warm- end of the coupler through the outer side wall.

**Scissor tuner mock-up:** A spare scissor tuner assembly has been loaned from J-Lab. A mock-up of the cavity tuning geometry is used to test the tuner using a mechanical spring with a force loading of 4500N/mm comparable to that of the cavity. The ISAC-II rotary servo motor with ball screw is being used to drive the tuner. The mock-up is useful in benchmarking the tuner motor under the typical loads and to test the rate, response and backlash in the mechanism (Fig. 4).

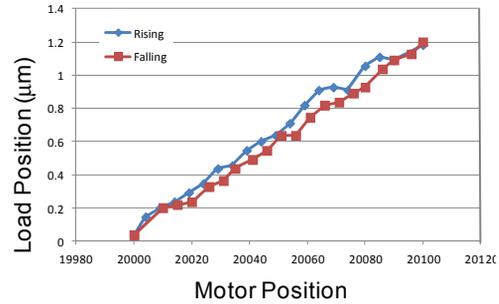


Figure 4: Correlation of mock cavity length with motor position for 1 micron cycling.

## STATUS

The tank and lid are being manufactured by a local shop. The strongback and strut supports are being fabricated at TRIUMF. The cavity is being fabricated at PAVAC. A 7-cell replica cavity in copper has been fabricated and is being used for HOM studies. The first Nb cavity inner cells are nearing completion with coupler and tuner end groups to follow. Two 50kW couplers are being conditioned in a dedicated waveguide box station. The 4K/2K test stand will be tested first without MLI to check for cold leaks and function of diagnostics then wrapped in MLI for performance tests. The cold mu-metal has been designed and will be manufactured at Amuneal. The scissor tuner will be ordered from Incodema pending completion of performance tests at TRIUMF. The LN2 shield is in fabrication at TRIUMF. The warm-cold beam pipe transition section with HOM dampers is undergoing final studies to determine placement of HOM diagnostics.

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