ARIEL ELECTRON LINAC

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Abstract

The TRIUMF Advanced Rare Isotope Laboratory (ARIEL) phase I is funded since 2010 June by federal and BC provincial governments. ARIEL I comprises buildings and electron linac; the future phase II includes hot cells, target stations, mass separators and beam transport to ISAC experimental areas. The linac vault and He compressor building were completed 2012. The ARIEL targets building completion is 2013 August. With the exception of the 30 MeV accelerator cryomodule and second klystron and HV power supply, the linac major procurements are complete. This paper reports progress for the following systems: locally manufactured niobium 9-cell cavity, 300 keV electron gun, 4 K cryogenic plant and sub-atmospheric pumps, 290 kW cw klystron and 65 kV DC power supply. Status of the 10 MeV injector cryomodule assembly and beamlines construction will also be addressed.

CONVENTIONAL INFRASTRUCTURE

The ARIEL project, described in Refs. [1,2], is essentially a new front end for the existing ISAC I & II experimental complex. The project contains two new "drive beams" and two target stations to supplement those at ISAC. The conventional infrastructure consists of four main contracts: the ARIEL construction, demolition and excavation, the Stores building, and Badge building. The new Compressor Building forms part of the ARIEL package as does major renovation of the former Proton Hall that has segregated the Electron Hall (e-hall) area from the future BL4N protons vault.

The Stores and Badge building construction was completed in 2011. The e-hall and Compressor building occupancy were taken 2012 November 1st and December 1st respectively. The ARIEL building occupancy was taken 2013 September 1st; and the connecting tunnel was completed one month prior.

The ARIEL cooling water system which provides capacities of 3 MW each to the ARIEL building and e-linac, and 0.3 MW to the compressor building, was completed 2013 June 1st. The site electrical connections to the 5 MW utility feed are made through a 12.5 kV switchgear supplied by Siemens. This connection supplies up to 1.5 MW to klystrons, 0.5 MW emergency power, 1 MW to compressor building, and 2 MW to the ARIEL building. Switchgear was energized 2012 December. A rack farm for magnet power supplies, beam diagnostic and LLRF controls is now complete on the e-hall roof.

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Figure 1: ARIEL building, view south.

ELECTRON GUN

The thermionic gun provides 300 keV kinetic energy electron bunches with charge up to 16 pC at a repetition frequency of 650 MHz. Unique features of the gun are its inverted cathode/anode geometry to reduce dark current, and transmission of rf modulation via a ceramic waveguide through SF6 dielectric. An impedance network inside an HV shroud matches the waveguide to the gridded cathode. The waveguide was received 2012 September from Kyocera. The HV cage containing the Glassman 300 kV supply, isolation transformer and bias and heater supplies was completed 2013 March. The gun electrodes polishing and assembly to the ceramic was completed 2013 May. The SF6 vessel also was received and installed in May. The vessel internal corona domes and shroud were fabricated and installed in the SF6 vessel 2013 September. 200 kV High voltage was first applied in October and a breakdown encountered with the receptacle connecting to the conditioning resistor.

INJECTOR TEST FACILITY

The Injector test facility, under collaboration between TRIUMF and VECC of Kolkata, India, provides an ideal proving ground for e-linac design and operation strategies. It duplicates the e-linac up to the exit of the injector cryo-module with enhanced diagnostic capability. Commissioning this facility began Nov 2011 with a 100kV gun and low energy solenoid beam transport and continued to 2013 Feb. The primary objective is a complete 6D phase space characterisation of the 100 kV beam. The 99% longitudinal phase is ±18.8 deg at 650 MHz and $\Delta p/p \pm 3.7\times10^{-4}$. The measured transverse r.m.s. normalized emittance is 9.3 μm horizontal and

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9.5 µm vertical. Further, a transverse deflecting cavity and scintillator view screen in the momentum analysis stub was used to visualize longitudinal phase space rotation effected by the buncher cavity, and to calibrate and adjust the settings to those believed to be needed to match the beam to that of the injector cryomodule acceptance.

BEAM LINES

The beam transport sections after the Injector are: the EMBT "Merger" section; the EABT and EHAT before and after the accelerator cryomodule; the EHDT to a 100 kW beam dump; and the EHBT, which transports to the photo-fission targets, consists mainly of a periodic section consisting of six 90° FODO cells, each 4 m in length. The EMBT contains a 36° bend section, the EHDT, a 90-degree section, and the EHBT two doglegs and a bend section to target. All insertions are achromatic. After the Injector, the focusing is performed by magnetic quadrupoles. These are grouped in three classes: (i) weak, < 0.2 T; (ii) medium, < 0.5 T; (iii) strong, < 1.3 T. The weak and medium designs retain the same spherical [4] poles and yolks, but differ in their coils and cooling: air-cooled or chill-plates, respectively. The strong quads follow a conventional water-cooled design, and have cylindrical poles. Prototypes were received 2013 February from *Buckley Systems*, leading to shipments completed in August totaling 80 magnets.

Dipole procurements have followed a separate path using a variety of vendors and custom designs. The three EMBT dipoles were received 2013 July. The eight S34 bends used in EABD and final EHBT bends before the east and west target stations are in shipment from *Everson-Tesla*. The contract for three Y30 bends used in EHDT and the EHBT dogleg was awarded 2013 September. The final tender, for two vertical dipoles for the dogleg, will be let in November.

Beam Diagnostics

Initial beam threading will be facilitated by profile monitors equipped with scintillators and OTR screens. 17 camera boxes and actuator assemblies are now complete. Orbit correction will be performed with the backbone system of 56 four-button type position monitors. All parts are acquired, and assembly in progress. The BPM electronics, which operates in pulse and cw. modes, comprises three blocks: a commercial front-end to down convert the input 650 MHz signals to the IF frequency, a 14-bit ADC and a Spartan-6 FPGA for the digital signal demodulation and filtering. The electronics is currently in production phase. 26 units are needed for the e-hall by 2014 May; 3 are complete, 7 in assembly, and remainder on track.

CRYOMODULES AND CAVITIES

Due to heavy beam loading, five 9-cell cavities at 100 kW/cavity are required to reach the 0.5 MW beam power. The injector cryomodule (EINJ) contains a single 9-cell cavity, and is designed and constructed in collaboration with VECC. The accelerator cryomodules (EACA,B) each house two 9-cell cavities.

The cryomodule design [2] utilizes a box vessel with a top-loading cold mass. A 4 K phase separator, 4 K/2 K heat exchanger and Joule-Thomson expansion valve are installed within each module to produce 2 K liquid. The cold mass is suspended from the lid with mounting posts, struts and strong back; and is surrounded by a LN2-cooled copper box for thermal isolation. A 1 mm warm mu-metal shield is fastened to the inside of the vacuum vessel. The cold mass consists of the cavity hermetic unit, a cold mu metal layer and the tuner. The tuner cold part is the Jefferson lab style scissor type; and is actuated by warm rotary servo motor mounted on the lid. The hermetic unit includes the cavity(s), power couplers, rf pick-up(s), the warm-cold transitions with HOM damping material and warm isolation valves.

The 4 K/2 K cryo-insert has undergone cold testing since 2013 January. Measured: static load of 4 K (2 W) and 2 K (0.5 W) reservoirs. Measured: efficiency of 2 K conversion is 66% at 0.5 g/s mass flow. Measured: 4 K siphon circuit efficiency – extra heat load caused by convection in 4 K reservoir ~15-20 W. After modification, the siphon loop is well behaved with a static load of 1.6 W.

All sub-assemblies of the EINJ are fabricated, and many are assembled. The tank is complete, and the entire assembly that is suspended from the lid is the subject of a mock up to verify that there are no conflicts or interferences. During the final assembly, 2013 Nov., the Nb cavity will substitute a dummy used in the mock up.

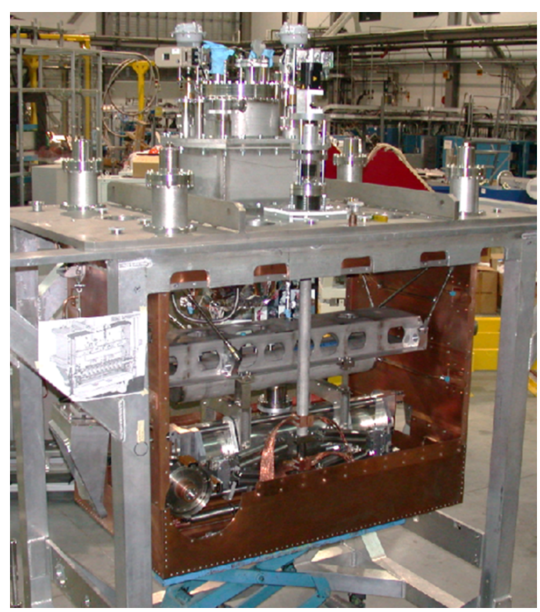

Figure 2: Injector cryomodule internal assembly.

Concerning the accelerator cryomodule, EACA, 95% of the design and detailing tasks are performed and fabrication is imminent. The lid is already received and the tank ordered.

The nine-cell 1.3 GHz elliptical cavity borrows the TESLA/ILC type inner cell geometry but uses modified

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end groups to accommodate the large power couplers and to mitigate HOMs. The HOM spectrum of the copper prototype has been measured [5] up to 4 GHz.

The first ARIEL cavity was received from *PAVAC Industries* of Richmond 2013 May 28. Subsequently, the cells were tuned to achieve field flatness, the cavity BCP etched, and cavity tested. No quenching or field emission was detected up to a field of 10 MV/m. The measured quality factor ($Q = 3\times10^9$) is not adequate, and the cavity has been sent for furnace degassing at FNAL. The second cavity is fabricated, tuned and etched, and ready for testing. The third cavity is in fabrication.

CRYOGENIC EQUIPMENT

In essence the cryogenics contains two components: a system responsible to deliver 4 K liquid He to a dewar; and a system to produce 2 K sub-atmospheric He inside the cryomodules. The first comprises a helium refrigerator-liquefier (HELIAL 2000 cold-box), and oil removal and gas management systems (OR/GMS), both delivered by *Air Liquide Advanced Technologies* (France) in 2013 March; and main and recovery compressors delivered by *Kaeser* in 2013 January; and 1000 litre dewar. Further, this system contains a helium gas storage tank fabricated locally, and variety of warm He piping completed 2013 September. All connections and services for this equipment are now complete. Presently, preparations are underway for the 4 K acceptance test in November.

Figure 3: Helium dewar (left) and 4 K coldbox (right).

Concerning the 2 K sub-atmospheric system, four pumps were delivered by *Busch* 2013 March and one successfully tested; the forward 4 K line to cryomodules is anticipated delivered October, the return line is recently tendered, the return heat exchanger is expected delivered in October; and the 4 K/2 K (in-cryomodule) insert is prototyped and installed in the Injector.

RADIO-FREQUENCY EQUIPMENT

The ARIEL project has procured two 290 kW klystrons from CPI, and two 600 kW HV supplies from *Ampegon/ Comark* (formerly *Thomson*). The first klystron was factory tested to 300 kW in 2013 January, and installed at TRIUMF [3] in June; and the 300 kW circulator and water-cooled loads added in September. The 65 kV power supply was factory tested in May and installed at TRIUMF 2013 August. All connections and services for this equipment are now complete. Presently, preparations are underway for the acceptance test in October. The second klystron and HV power supply will be delivered 2014 March.

Figure 4: klystron, circulator and loads.

The first klystron will initially be deployed to drive the injector cryomodule (EINJ) for a beam test starting 2014 May. After the second klystron is installed, the first will be switched to drive the accelerator cryomodule (EACA). In the ARIEL II phase of the project, the second klystron will drive the second cryomodule EACB, and a dedicated 150 kW RF source will be found for EINJ.

Power Coupler Conditioning Station

A routine procedure is now established: one week bakeout of warm window under N2 flow at 100 C. Four couplers have been conditioned at room temperature. 12.5 kW cw in traveling wave (TW) and 10 kW pulsed in standing wave (equivalent to 40 kW in TW) are achieved.

CONCLUSION

We are justified to report excellent progress across all areas: delivery and test of 1st ARIEL cavity; ARIEL building occupancy; imminent acceptance tests of Klystron & HVPS and 4 K Cryogenic Plant. The following milestones are anticipated: e-gun complete 2013 Nov; Injector Cryomodule complete 2013 Dec; beam test start at ISAC/VECC 2014 January; and Accelerator Cryomodule beam test 2014 Sept.

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