TRIUMF/VECC E-LINAC INJECTOR BEAM TEST

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Abstract

TRIUMF is collaborating with VECC on the design of a 10 MeV injector cryomodule to be used as a front end for a high intensity electron linac. A electron gun and low energy beam transport (LEBT) have been installed in a test area to act as the injector for the cryomodule test. The LEBT includes a wide variety of diagnostics to fully characterize the beam from the gun. A series of beam tests are being conducted during the stage installation. The test configuration details and results of beam tests will be presented.

INTRODUCTION

TRIUMF is now preparing a new high intensity (10mA) 50MeV superconducting electron linear accelerator [1], e-Linac, as a key element of the ARIEL project. In brief the e-Linac consists of five 1.3GHz nine-cell niobium cavities each providing 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 EACA and EACB with two cavities in each module.

TRIUMF began developing EINJ in 2010 in collaboration with the VECC laboratory in Kolkata. As part of the collaboration two EINJs will be fabricated and beam tested at TRIUMF. One EINJ will be shipped and installed at VECC and the second will be installed in the e-Linac. The initial EINJ is presently in fabrication [2].

A beam test area is being installed in the ISAC-II building to eventually test the two injector cryomodules with beam. The site utilizes the existing ISAC-II cryogenics infrastructure and enables testing of the cryomodules well before the expected availability of the e-Linac cryogenics in 2014. The schedule calls for accelerated beam tests in early 2013. Moreover, the injector test facility provides an ideal proving ground for e-linac design and operation strategies. It duplicates the front-end of the e-linac up to the exit of the injector cryomodule with enhanced diagnostics capability for benchmarking both the performance of the gun but also of the various diagnostics themselves. In addition the test installation allows early demonstration and troubleshooting of various e-Linac sub-systems including MPS, controls, beam modes, safety, LLRF, HPRF, cryogenics and important feedback on beam quality, halo formation and high intensity operation. Commissioning this facility began Nov 2011.

INJECTOR LAYOUT

The test layout, shown in Fig. 1 includes an electron gun, a low energy beam transport (LEBT) complete with a beam diagnostics leg, the EINJ cryomodule, a medium energy beam transport and diagnostic end station (MEBT) and beam dump. Two guns are envisaged. In the first phase (present) a 100kV thermionic gun with rf modulated gridded cathode bias is utilized. The cathode rf drive is at 650MHz providing rf bunches for one of every two accelerating buckets. This will soon be replaced by a 300kV gun also with rf modulated gridded cathode bias at 650MHz. The higher energy is needed to achieve efficient capture in the EINJ while the 100kV gun is perfectly sufficient to characterize the rf modulation and commission the LEBT and diagnostics. In both cases the specified peak current is 10mA, with a bunch length of $\leq\pm 20^0$ of 650 MHz (170 ps), a bunch charge of 15.3 pC, an energy spread of $\leq \pm 1$ keV and a transverse emittance of ≤ 30 μm normalized to a 2σ x 2σ cylindrical beam.The rf modulation can also be pulsed to provide a macro duty cycle varying from 0.1% to 99.9% duty cycle at various macro periods.

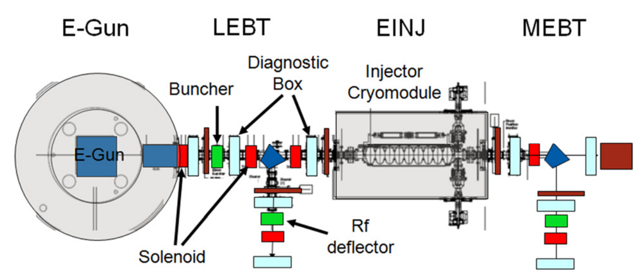

Figure. 1: TRIUMF/VECC beam test configuration.

The LEBT straight section is designed to prepare the beam for acceleration. Three solenoids are used to provide transverse matching and transportation. An initial solenoid provides a waist at the buncher while the two downstream solenoids match the beam to the cryomodule. A 1.3GHz room temperature buncher provides longitudinal matching to the EINJ. An analyzing diagnostic line includes a 90^0 bending spectrometer, diagnostic boxes and a 1.3GHz rf deflector for bunch length measurements.

DIAGNOSTICS

The diagnostics used in the LEBT are shown in Fig. 2. The diagnostics fit in multi-port custom chambers machined out of solid stainless steel bulk material. The

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diagnostic chamber has eight transverse ports, four on the horizontal and vertical axis and four on the 45 degree axis. Two ports are occupied with an ion pump and turbo-pump roughing system respectively leaving six available for diagnostics.

The diagnostics comprise devices for a wide range of beam intensities. More details can be found in [3]. A standard water cooled Faraday cup (FC) can dissipate beam powers up to 200W. A high power Faraday cup (HPFC) is designed to take the full 1kW and is positioned at the end of the beamline. A high power slit (HP-Slit or Linear profile monitor (LPM)), shown in Fig. 3, consists of a water cooled copper plate with two 1mm slits cut at 45 degrees to the plate and 90 degrees from each other.

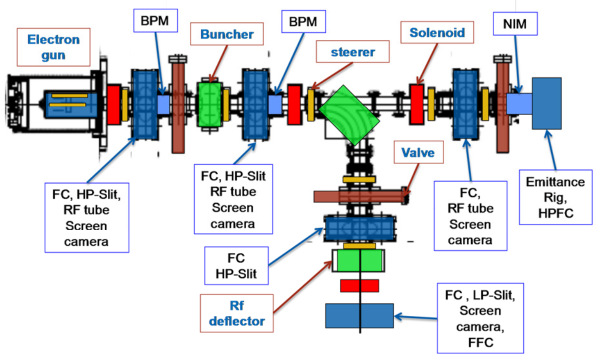

Figure 2: LEBT beam diagnostics, optical elements and rf devices.

The HP-Slit can absorb about 200W. An identical low power device, LP-Slit, has no water cooling provision and can dissipate a few watts only. The slit device is positioned on a 45 degree diagnostic port and when scanned in front of a Faraday cup gives beam x and y profile information. The device also doubles as an emittance defining slit when fixed in the beam. In longitudinal analysis mode the HP-slit in the box upstream of the analyzing dipole is used as an object slit and the HP-slit in the box upstream of the rf deflector is used to select an energy slice. The rf deflector is then used to analyze the time width of the selected beam. The slit plate also has a 2mm collimator to be used in a fixed mode to define the beam shape.

Several scintillator screens are used in the line. Each monitor includes two or three targets, optics and a camera. Possible target options are a 0.5 mm thick piece of gold-plated Yttrium Aluminium Garnet (YAG) scintillators, Chromox scintillators and a calibration target. An Optical Transition Radiation (OTR) screen is available for the MEBT. The screens can only dissipate a few Watts of beam power. A third type of profile device is the Allison type high power emittance scanner [4]. The device is designed to take up to 1kW with power densities up to 20W/mm^2. In brief the device consists of a front plate that selects a slice of the beam and a set of steering plates that scan the beamlet across a back slit to a Faraday cup to define the beam divergence. Quadrant button-type BPMs are also used for non-intercepting beam position information.

In the time domain an intercepting 50Ω co-axial fast Faraday cup (FFC) is used to measure bunch characteristics with a lower limit resolution of ~100ps. A non-intercepting monitor (NIM) capacitive pickup is used to record beam phase information. Higher resolution timing information is available from an rf deflector.

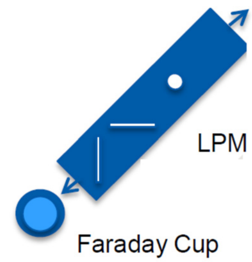

Figure 3: The LPM scanning slit profile monitor and collimator.

RF DEVICES

There are two rf devices installed in the LEBT; a 1.3GHz buncher operating in TM010 mode and a 1.3GHz deflecting cavity operating in a TM110-like mode.

Buncher

The bunching cavity is manufactured by Niowave and is identical to cavities designed and fabricated for the EMMA FFAG project at Daresbury [5]. Beam dynamics set the maximum required peak electric field on axis to 0.5MV/m and this corresponds to an integrated voltage defined by $V_0 = \int E_z dz = 30\,\mathrm{kV}$ based on a field profile from CST. The effective voltage of the cavity for β=1 φ=0 particle is normalized by $T_0 \cong 0.78$ to V_{acc}=23.4kV. The measured shunt impedance, $R_{sh}=V^2/2P$, of the buncher cavity is 3.3MΩ. This converts to a linac shunt impedance ($R=2R_{sh}T_0^2$) of R=4.0MΩ for Q_0=20000 and R/Q=200Ω. The normalized transit time factors ($T_n=T/T_0$) at 100keV and 300keV are 0.64 and 0.89 respectively.

Deflector Cavity

The deflector cavity is designed after a Cornell deflecting cavity [6] but with simplifications to ease manufacturing. A TM110 pillbox vertically deflecting mode cavity is modified with entrance and exit nose cones that generate a concentrated magnetic deflecting field at entrance and exit and provide an on-axis vertical dipole field (Fig. 4) to enhance the effective perpendicular shunt impedance given by $R_\perp = \frac{(V_\perp)^2}{P} = \frac{(V_\perp)^2 Q}{\omega U}$ where $V_\perp$ is the effective perpendicular voltage gain from the magnetic and electric dipole components, Q is the quality factor of the mode and U is the stored energy. The vertical deflection is given by $y' = \frac{dy}{dz} = \frac{1}{\beta^2}\frac{V_\perp}{E}$ where E is the total energy of the electron. For β=1 CST gives $\frac{R_\perp}{Q} = 940\Omega$ while at β=0.78 (300keV) and β=0.55

(100keV) $\frac{R_\perp}{Q} = 480\Omega$ and $\frac{R_\perp}{Q} = 160\Omega$ respectively with an expected Q of 10000.

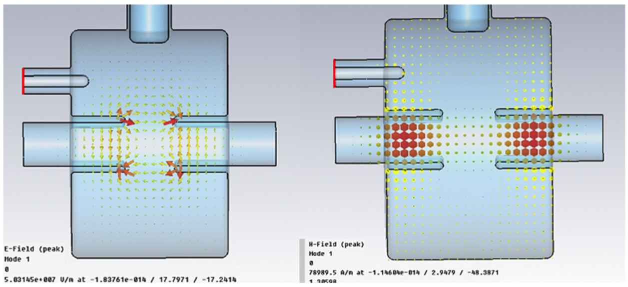

Figure 4: Electric and magnetic components of deflector field.

INSTALLATION AND BEAM TESTS

The equipment is being installed in stages. Presently the 100kV gun, complete LEBT and analyzing station are installed. The EINJ is in fabrication [2] and the MEBT station has components both in fabrication and in final design including a 30kW beam dump. The equipment is pre-cleaned in ultrasound and assembled in a clean room as major sub-assemblies. Each sub-assembly is then transported to the test area and installed into the system. When joining the new equipment to the existing equipment the open volume is slightly pressurized with filtered N_2 to reduce the risk of particulate contamination. The sealed line is evacuated and baked at ~150C for 48 hours. Typical vacuum is in the low 10^{-9} Torr range.

A series of beam tests have been organized with the installed equipment. These tests are designed to measure the properties of the beam but most importantly to establish techniques and procedures, qualify and characterize diagnostics and troubleshoot and evaluate sub-systems all well in advance of the e-Linac final installation. Initial beam tuning confirms the beam dynamics modeling for the solenoid and correctors. The emittance scanner has been characterized over a wide range of beam intensities with emittances recorded for peak power densities up to 100W/mm^2[4]. Measurements demonstrate an emittance of 90% of the beam within 30µm. The horizontal beam emittance as a function of bunch charge selected from the 100kV gun is shown in Fig. 5.

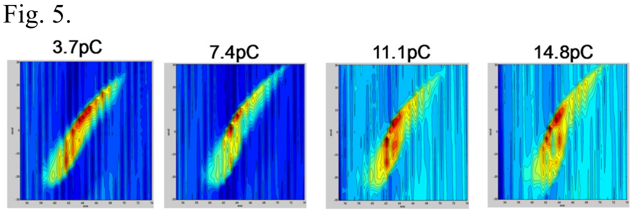

Figure 5: Horizontal emittance scan at various bunch charge settings.

The gun rf has been successfully used to provide a variable duty factor beam to adjust the beam intensity for different tuning regimes near the peak bunch charge. Typical low intensity operation is at 1kHz repetition rate with 1µsec macro-pulses (0.1% duty) with 10µA average beam current. All diagnostics including LPMs, FCs, FFCs and NIM have been characterized with beam and function as designed. The BPM and electronics have been characterized by scanning the beam with steering correctors. Both Chromox and YAG screens have been characterized. Charging up of YAG screens has been mitigated by depositing a thin gold coating on the surface.

The two rf devices are installed and commissioned. The measured installed Q of the buncher is 18500. The measured values on deflector transverse shunt impedance is $\frac{R_\perp}{Q} = 400\Omega$ for β=0.78 with a measured Q of 5400. The shunt impedance is slightly down from initial estimates due to a slight difference in actual nose positions compared to that of the simulations. The Q of the deflector was 8700 during the bench test before final cleaning so we suspect some surface pollution. Both buncher and deflector have been phase locked to the gun rf and first beam tests have been completed. The buncher effective voltage has been verified in beam based TOF tests. Fig. 6 shows the first demonstration of rf deflection of the beam on a scintillator screen. Future tests will involve characterizing the longitudinal emittance at various gun conditions.

The 300kV gun is being prepared for installation starting in Oct. 2012. The EINJ is in fabrication for installation and accelerated beam tests in early 2013.

Figure 6: Beam on a scintillator screen with rf deflector off and with rf deflector on at 0 degrees.

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