

STATUS OF BEAM DIAGNOSTICS SYSTEMS FOR TRIUMF ELECTRON LINAC*

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Abstract

TRIUMF laboratory is currently in a phase of the construction of a superconducting 50 MeV 10 mA CW electron linac to drive photo-fission based rare radioactive isotope beam (RIB) production. The project imposes certain technical challenges on various accelerator systems including beam diagnostics. In the first place these are a high beam power and strongly varying operating modes ranging from microsecond beam pulses to the CW regime. Diagnostics development interleaves with the construction of the diagnostic instrumentation required for the test facility which delivered the first beam in fall of 2011. The paper reports the present status of various diagnostics systems along with measurement results obtained at the test facility.

INTRODUCTION

As a part of the effort to substantially expand the Rare Radioactive Isotope Beam (RIB) program, TRIUMF is currently in a phase of the construction of a 50 MeV 10mA CW superconducting electron linac as a driver for production of neutron-rich isotopes via photo-fission reactions [1]. Putting in operation the linac, new target stations and a new mass separator will double the amount of RIBs that can be delivered to the users simultaneously. A planned addition of a new proton beam extracted from the existing 500MeV cyclotron will complete the expansion project (Fig.1).

The electron accelerator will comprise a gridded 10mA 300 keV thermionic electron gun operated at 650 MHz, a 50 MeV superconducting CW linac and, a 70 m long beam transport line. The linac will consist of three cryomodules housing five 1.3 GHz 9-cell cavities of the TESLA type. Future upgrade foresees a recirculation ring to nearly double the final beam energy. It is also proposed to use the same ring to accommodate an infrared free electron laser. To prove the chosen design and operation strategies the injector test facility has been setup and produced the first beam in November of 2011.

Design challenges are primarily associated with a substantial (half a Megawatt) beam power in the CW mode. Clearly, commissioning and tuning modes are necessary to safely deliver the beam all the way to the targets or dedicated beam dumps. It is presently seen that the beam tuning will be accomplished with beam pulses as short as few microseconds. A number of development projects were launched about three years ago in order to design the diagnostics capable of supporting all the

variety of beam modes. As for today most of these projects have been completed. Production of mechanical

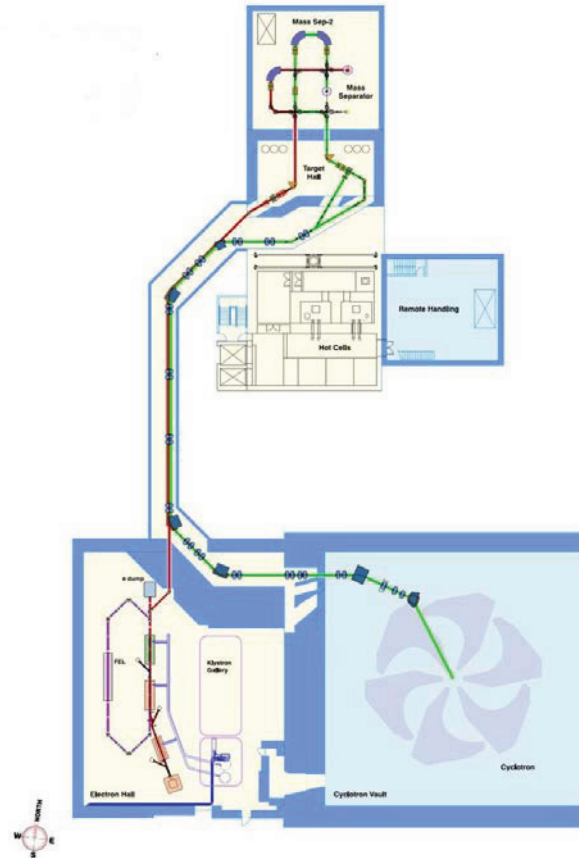


Figure 1: Layout of the TRIUMF Advanced Rare Isotope Laboratory which includes the electron linac and a new proton beam line, target hall and mass separator.

and electronic devices is in progress. Part of them is mounted at the injector test facility where it will be used for beam studies and relocated to the accelerator hall at later times. Installation of other systems to the final destination is planned to start in a month or two.

DIAGNOSTICS SYSTEMS

The diagnostics of the linac and the transport line includes a noticeable number of various devices and systems. The list of devices requested by beam physicists consists of 55 beam position monitors, 14 wire scanners and 28 view screens, 11 Faraday cups and beam stops, two DC current transformers, several beam defining slits and special monitors to protect targets and beam dumps.

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Most of the diagnostics will be mounted on octagonal boxes to share the same space longitudinally. To minimize the wake impedance presented by a diagnostics box to the beam a so-called RF-shield device will be inserted into the box during routine operation. Not all the e-linac diagnostics systems are presented and discussed in this paper. Some were reported elsewhere [2, 4]. The beam loss monitoring and machine protection, which are both critical for the operation of the facility are subjects for a dedicated paper.

Beam Position Monitor (BPM)

The absolute accuracy of beam position measurements is expected to be better than 500 μm . The required relative position resolution of 50 μm is not very high and is easily achievable. Both button and stripline BPMs have been designed for the project. Although the stripline BPM delivers higher signal strength, the button BPM, which is substantially smaller in dimensions, was eventually chosen for production due to tight space constraints.

Each button electrode, that is 12 mm in diameter, is mounted at the pin tip of an SMA vacuum feedthrough welded to a NW16 flange (see Fig. 2). A special alignment groove is machined in the flange to improve the installation accuracy. The button pickups were manufactured by Kyocera Corporation according to TRIUMF supplied drawings. The requested manufacturing tolerance of 50 μm for the button concentricity and surface parallelism with respect to the alignment groove were verified in the dedicated mechanical measurements. About 80% of 216 buttons passed the tolerance requirement and all buttons are acceptable in achieving the expected absolute accuracy.



Figure 2: The button electrode for beam position measurements.

A torque adjustment in situ of the fastening bolts will be used to balance the calibration signal strength delivered by individual pickups composing each BPM. It is also planned to perform BPM calibration by using inter-electrode coupling. Three complete BPM were installed at the injector test facility. First beam data have been obtained and demonstrated good agreement with design values.

The stripline BPM was also developed by adjusting the Cornell design to comply with the 650 MHz bunch repetition frequency and a smaller diameter (50 mm) of the beam pipe. Position sensitivity of both button and stripline BPMs is around 1.4d B/mm. The estimated signal strength of the button BPM is about -30 dBm at the nominal beam current of 10mA (confirmed by measurements). The stripline BPM signal is expected to be stronger by 13 dB. The prototype of the stripline BPM was recently manufactured, characterized and scheduled for installation at the test facility.

The BPM signal processing electronics was challenged to operate in both the pulsed beam tune-up mode with the pulse width as short as 1 μs and in the CW operation mode. The electronics development has consumed a substantial amount of efforts. Each BPM module (Fig.3) processes all four signals from a single BPM and consists of three interconnected boards each implementing a well-defined function: a front-end unit, a digitizer and a digital signal processing (DSP) module. The modular approach permits combination of custom and commercial blocks in the same module. It will also facilitate possible future upgrades.



Figure 3: BPM signal processing electronics with the top cover removed.

The front-end unit is a modified commercial BERGOZ Instrumentation AFE board customized for the operating frequency of 650MHz. This four channel plug-in module down converts the input signals to the IF frequency of 26MHz and performs subsequent amplification. The modification to the board included addition of a 20dB low noise RF- amplifier and replacing the IF amplifier to increase an overall gain by 30dB. The IF signals are digitized by an in-house developed custom module based on a 14-bit ADS6445 ADC from Texas Instrument. The IF signal sampling is performed at rates of up to 125 MHz. Data are then transferred to a Xilinx Spartan-6 FPGA. The FPGA performs the ADC data deserialization, signal demodulation and digital low pass filtering. Fresh data are available approximately each microsecond. The data are also stored in 1k sample deep buffers that can be latched by an external signal for post mortem analysis. The same FPGA runs the Xilinx MicroBlaze soft processor that

accesses the FPGA registers and outputs data via Ethernet and RS232 ports. The electronics is assembled inside a 1U rack enclosure and currently is in production phase.

Current Monitors

The beam current will be measured using Faraday Cups (FC) and current transformers. There have been developed three different versions of Faraday Cups. Even at low energies of 100-300 keV the beam power reaches substantial values making the design quite challenging. A 300W low energy version was designed to operate in combination with a 1 mm slit scanner, thus, allowing measuring the beam transverse profile at beam currents substantially higher than it is possible with view screens. Four FC monitors of this type are currently in use at the test facility. The devices were proved to have a bandwidth of about 1 MHz on a 50 Ohm load.

A kW-level low energy version was recently designed with the aim to intercept the full beam and is currently in the production stage. It can dissipate up to 3kW of the beam power provided the beam size is not too small (typically larger than 1 mm rms). The design was verified by thermal and stress analysis using COMSOL Multiphysics.

For beam tuning purpose a high energy version of FC was designed. The cup is made of tungsten alloy and will fully stop electrons with the energy of up to 75 MeV. This one can take only 100W of beam power. At present manufacturing of the prototype unit is in progress.

The beam current in the CW regime or with long beam pulses will be measured using DC current transformers. Presently, one unit, model NPCT-115-HR, has been purchased from Bergoz Instrumentation. The associated development is reduced to the design of the transformer enclosure which has to provide the required attenuation of the external magnetic field, in particular, the residual field of the TRIUMF cyclotron. The transformer protection during bake-outs and temperature control with an accuracy of better than 0.2 C are incorporated into design.

View Screen

Sixteen view screen monitors will be installed at the beginning and this number is likely to increase in the near future. Each monitor includes two or three targets, optics and a camera (Fig. 4). Possible target options are a 0.5 mm thick piece of gold-plated Yttrium Aluminium Garnet (YAG) scintillator, an Optical Transition Radiation (OTR) screen and a calibration target. To sustain higher beam currents we presently plan to use a 10 to 30 μm thick Pyrolytic Graphite foil as the OTR screen. The targets are positioned into the beam with a stepper motor driven actuator. All targets are rotated by 45° with respect to the beam direction.

Light produced by the beam on targets is extracted through a fused silica window, reflected by a flat mirror by 90° and collected by a lens on a 12bit GigE CCD camera. The camera is tilted by 7° with respect to the optical axis to correct for the target tilt. A motorized iris adjusts the light intensity on the camera. The whole

optical pathway is encompassed into the light tight enclosure. The camera is protected by a lead shield. The monitor control, image acquisition and processing are

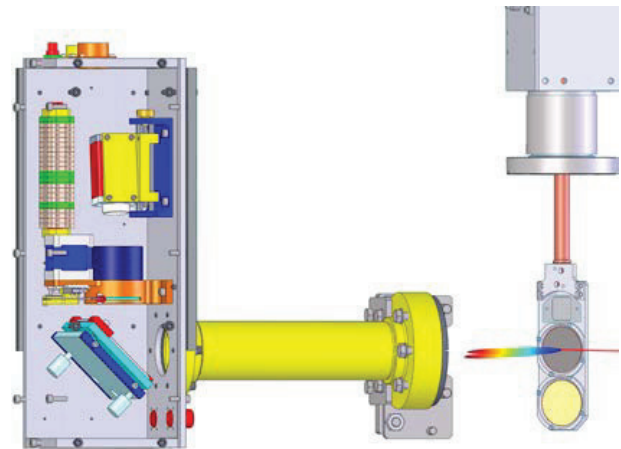


Figure 4: The view screen monitor.

entirely implemented within the EPICS environment. View screens will be slightly different at low and high beam energies to account for a smaller field of view at higher energies. Substantial part of the hardware have been manufactured and installed at the test facility. Software support is intensively tested. OTR target development is in progress.

Wire Scanner

In addition to view screens, wire scanner monitors are being developed to extend capabilities of beam profile measurements. Wire scanners typically possess a much higher dynamic range that makes possible measuring the beam halo. Another attractive possibility is to design the device sufficiently fast so it can operate at the full beam current. Calculations show that a carbon wire needs to travel through the beam at speeds of about 3m/s to survive the 10 mA and 50 MeV electron beam with the size of about 0.5 mm FWHM.

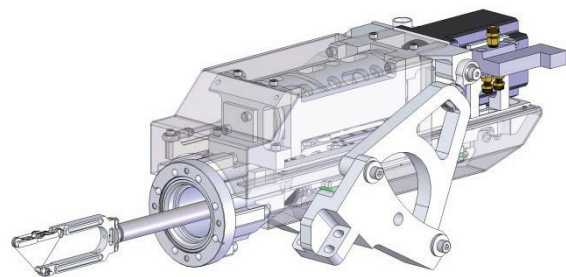


Figure 5: Second prototype design of the fast wire scanner.

The wire scanner is similar to the DESY-Zeuthen design [3] with a drum cam replacing the slot winding cylinder. The cam has flat ends enabling acceleration of the cam to full speed before the scanner motion begins. The scanner follows a sinusoidal velocity profile up to a

constant speed section before a similar deceleration. Two orthogonal wires pass through the beam at 45 degrees. There will be slow and fast modes of operation. With low duty cycle beam pulses, wire motion may be paused for each measurement. For high power CW beams the wires will fly through the beam at a high speed. The motor control electronics based on commercially available components have been purchased and is presently in the evaluation phase

The first prototype has been built and bench tested. During evaluation, the prototype ran consistently at 3.0 m/s. A second prototype design is complete and being reviewed before manufacture. It focuses on providing an increased stroke, more compact dimensions, a stiffer frame, and improved wire fork design. The first prototype will be installed at the injector test facility for continued testing.

Beam Phase and Bunch Length Monitors

The thermionic gun produces electron bunches with the duration of about 100 ps and longer. Two broadband devices were designed with a purpose to evaluate the bunch length on this time scale. The first one is a beam intercepting pickup resembling a piece of a tapered coaxial line attached to a high frequency vacuum SMA feedthrough. The pickup is built into a standard ConFlat flange (see Fig.6) and was simulated and later measured to have a bandwidth of 8-10 GHz. A bunch length of 200 ps (fwhm) was measured with this device that was consistent with the beam dynamic expectations.

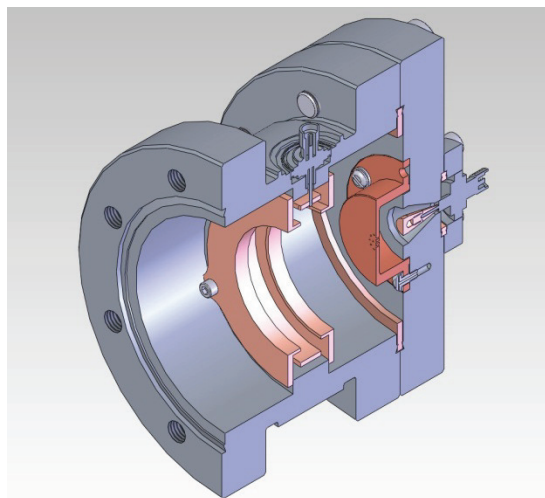


Figure 6: A cross-section of the capacitive and coaxial pickups assembly.

In contrast, the second broadband monitor is a non-intercepting capacitive pickup. By construction it can be thought of as a 50 Ohm transmission line bent to form a nearly closed circle (Fig.6). Signals are available from both ends of the line and can be either combined or used independently. Due to a high pass frequency response of the monitor the direct data interpretation is complex. It was used to measure the beam phase. To reduce the beam

position dependence of phase measurements both outputs need to be combined.

After bunches are compressed by the buncher cavity to sub 10 ps durations they are outside of the reach by the described monitors. An RF deflecting structure was designed and successfully applied for this purpose.

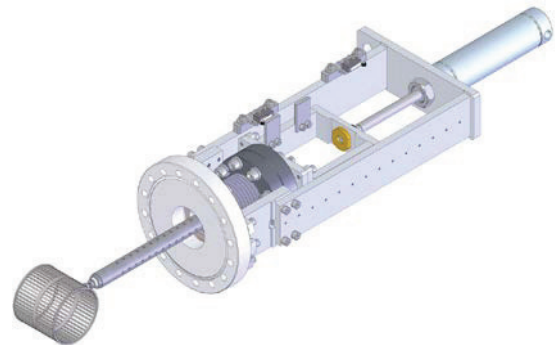


Figure 7: RF-shield device will be used to derive beam phase and intensity.

A special device, an rf-shield, was designed to minimize wake impedance exhibited by a diagnostics box to the high power beam (Fig.7). The device is essentially an actuated cylinder of the same inner radius as the adjacent beam pipe. It is inserted when no other device occupies the box inner space and ensures the continuity of the vacuum enclosure seen by the beam. The cylinder is electrically isolated and a broadband signal generated by the beam is available for pick-up. The device will be used to measure the phase and amplitude of the ac component of the beam induced signal. Few such devices were built and installed at the test facility [4].

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