

BEAM DIAGNOSTIC SYSTEMS FOR THE TRIUMF E-LINAC*

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Abstract

The TRIUMF electron linac will include a suite of diagnostics systems, including current, beam position, and beam profile monitors. This talk presents an overview of the diagnostic systems and gives details about the view screen system, having both scintillator and OTR foils. Diagnostic systems are particularly challenging for the e-linac due to the 500 kW beam power envisaged, with beam currents up to 10 mA at 50 MeV.

THE ARIEL PROJECT AND THE E-LINAC

TRIUMF is Canada's national laboratory for particle and nuclear physics. Current research programs are based around the existing charged-particle accelerators: a 500 MeV hydrogen-ion cyclotron, a suite of linear accelerators for rare isotopes at the Isotope Separation and ACceleration (ISAC) facility, and low-energy medical cyclotrons. A new facility, called the Advanced Rare IsotopE Laboratory (ARIEL), will augment the ISAC Rare Isotope Beam (RIB) science program. The flagship of the ARIEL project is the construction of a 50 MeV, high-average current (10 mA) continuous wave (CW) linear accelerator called the e-linac.

DIAGNOSTIC REQUIREMENTS

Beam diagnostics is an essential part of any charged-particle accelerator. Accurate beam measurements are important both for the beam set-up and for monitoring beam properties during the production run. Any equipment within 3 m of the e-linac must resist radiation damage sufficiently to ensure that severe data corruption occurs less than once per year in a field of 10 mSv h^{-1} . The beam current must be known with sufficient accuracy to precisely quantify beam loss down to one part in ten thousand (or better) for a 10 mA beam. The absolute uncertainty in the beam position with respect to external survey markers needs to be less than 0.2 mm to prevent compromising the beam orbit correction algorithm. The beam profile measurements must be accurate as they are used to measure the emittance and to support dithering magnetic elements.

BEAM POSITION MEASUREMENT

There will be fifty-four beam position monitors at the facility: twenty-two along the e-linac itself and thirty-two along the high energy beam transfer line. The general absolute accuracy of beam position measurements is expected to be around $500 \mu\text{m}$. The required relative position resolution is $100 \mu\text{m}$. Each monitor consists of the set of four

electrodes, associated electronics and interconnection cables. Two types of electrodes will be used: button pickups and stripline pickups. Although the stripline BPM provides a higher signal strength, tight space constraints at low and medium energies favoured buttons that are significantly smaller in dimensions.

Each button electrode is essentially a 1 mm thick, 12 mm diameter disk mounted at the pin tip of a SMA feedthrough (Fig. 1). The feedthrough is welded on a NW16 flange. The torque of the fastening bolts can be adjusted in situ to equalize the signal from the pickups composing the BPM. A special alignment groove is machined to improve the installation accuracy. The button pickups are manufactured by Kyocera according to TRIUMF drawings. Three complete BPMs have been manufactured and are installed at the test facility. First beam data are available.



Figure 1: A photograph of the button electrode.

The stripline design (Fig. 2) is modelled after work done at Cornell. The Cornell design was adjusted to the 650 MHz operating frequency and the 2 inch beam pipe diameter. The striplines are about 11.5 cm long but the whole assembly including flanges extends to 20.7 cm. The prototype unit will be manufactured and tested in June of 2012. Position sensitivity of both button and stripline BPMs are 1.4 dB/mm for the 2 inch beam pipe. The estimated signal strength of the button BPM is about -30 dBm at the nominal beam current of 10 mA. The strength of the stripline BPM signal is expected to be stronger by 13 dB.

The BPM signal processing electronics is required to operate in both the pulsed beam tune-up mode and the CW operation mode. Electronics consist of a front end unit and

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a DSP module. The front-end is a commercial BERGOZ AFE board customized for 650 MHz. This 4 channel board down converts the input signals to the IF frequency of 26MHz and performs the subsequent amplification. The IF signal processing electronics is presently under development. It includes a 14-bit ADS6445 ADC from Texas Instrument and Xilinx Spartan-6 FPGA. The FPGA performs ADC data deserialization, signal demodulation, filtering and data output via Ethernet connection. The electronics for a single BPM is assembled inside a 19 inch rack mount 1U enclosure. The expected output bandwidth is around 500 kHz which is compatible with the machine protection system requirements. BPM electrodes and electronics will be connected by 3/8 inch coaxial cables with the average length of 200 ft. The expected signal attenuation is 7 dB.

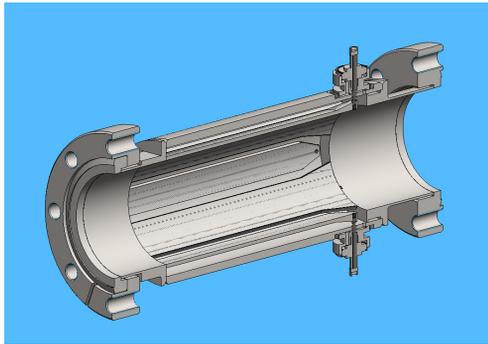


Figure 2: A cross-section of the stripline BPM.

BEAM CURRENT MEASUREMENT

The beam current measurements will be performed using Faraday Cups (FCs) at low energies and DC current transformers and beam dumps at medium and high energies. Even at low energies the beam power can reach a substantial value of 3 kW making the Faraday Cup design quite challenging. While the design of a high power version is in progress, a 300 W version is available for beam tests and usable for beam energies of 100 keV to 300 keV (Fig. 3). This version is operated in the pulsed modes at low beam duty cycles. The modular design of the TRIUMF FC simplifies serviceability. A high vacuum compatible VCR fitting connects the cup to the insulator tube assembly. The water lines pass through the isolator tube assembly and are used for current signal readback.

The beam current in the CW regime will be measured with DC current transformers. Presently, one unit, model NPCT-115-HR (high resolution option), has been purchased from Bergoz Instrumentation. The transformer enclosure which is under construction includes a piece of 2 inch beam pipe with a ceramic gap protected from the beam by a metal shield. Conflat flanges are welded at each end with a short edge-welded bellows at one end, to allow for lateral movement and reduce stresses on the ceramic isolator. Water cooling circuits on either end of the beam pipe prevent the sensor from overheating during bake-out.

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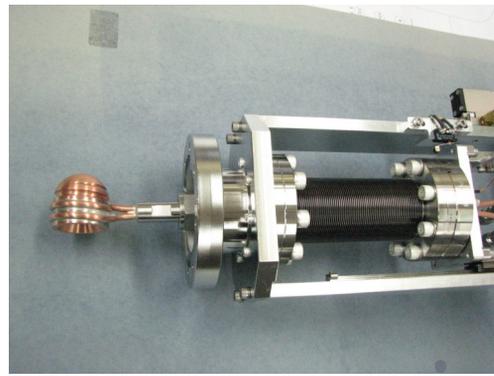


Figure 3: 300W Faraday Cup design.

To reduce the output data drifts, it is critical to control the transformer temperature to an accuracy of better than 0.2 °C. To this end, temperature sensors and heating elements are mounted at various points in the assembly. The temperature will be adjusted by a controller unit. Three layers of mu-metal and outer carbon steel cover will provide attenuation of the external magnetic field, in particular, the residual field of the TRIUMF cyclotron located in the vicinity of the e-linac.

BEAM PROFILE MEASUREMENT

View Screen

Beam profile measurements can be performed at all energies with view screen systems. Each system consists of a thin screen, optical pathway and camera (Fig. 4). For low energies, a 500 μm thin piece of gold-plated Yttrium Aluminium Garnet (YAG) scintillates when intercepting beam. The 10 nm Au coating provides a conductive surface that drains any low-energy electrons which were deposited in the target. At higher energies (currents above a few μA) the screen will be a 10 μm thick Pyrolytic Graphite foil. The Graphite foil will produce Optical Transition Radiation (OTR) when intercepting the electron beam. In either case an optical pathway transports the light away from the beam-line and into a lead-shielded camera box. The camera can be triggered by the output of the electron gun RF signal or through a software interface.

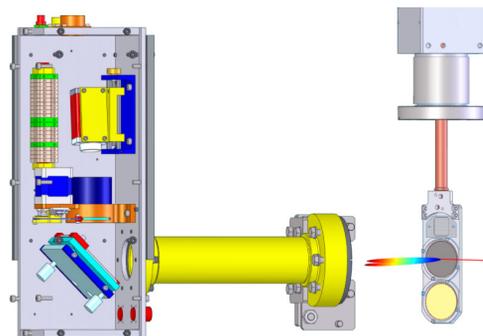


Figure 4: Components of a view screen system.

The image is collected from the camera using a modified version of the areaDetector prosilica driver. The driver module is part of the synApps EPICS extension package maintained at the Argonne National Laboratory. Software algorithms transform the image into beam space, correct for non-linear optical distortions and adjust individual pixel intensities based on the light collection efficiency of the system. Next, useful pieces of information such as beam centroid and width are extracted. Finally, the image can be styled with false-colouring, axes and visual annotations. When an operator chooses to keep an image it is stored in three stages of processing. An XML file containing the current state of user-defined beam parameters and the current processing options is generated along with the image data. An interface to control the view screens and display profile data has been created using the Extensible Display Manager for EPICS.

Wire Scanner

A wire scanner monitor is being designed to meet the requirements of the e-linac. The radiation fields in the accelerator vault will be up to 5 mSv h^{-1} for gammas and fast neutrons or $5 \times 10^3 \text{ n/cm}^2/\text{s}$. Clearly no electronics can be placed close to the beamline. The SCRF vacuum of 1×10^{-8} torr demands that the motion be transferred from the air side via bellows. The bellows material will be AM350 for endurance under high acceleration. A beam profile resolution of $25 \mu\text{m}$ is desired, along with a wire speed greater than 3 m s^{-1} to prevent wire melting caused by beam heating. Two orthogonal wires will move through the beam at 45° . There will be two modes of operation. For low duty cycle beam pulses, wire motion may be paused for each measurement. For high power CW beams the wires will fly through as quickly as possible. The wires will retract through a gap to shield them from the magnetic field of the beam when parked.

Similar to previous designs [1], a rotary motor will turn a drum with a helical slot machined into its surface. A follower will ride in the channel and push the wire holder fork through the beam. The pitch is 144 mm per revolution in the constant speed zone. At the park position, the pitch is small so that the motors holding torque will prevent the vacuum force from pulling the fork into the beam.

A stepper motor will be used as they are relatively radiation hard. An Anaheim Automation 34Y314D-LW8 stepper motor with 200 steps per turn will provide up to 1700 oz – in of torque. It will be powered by an Anaheim MLA10641 microstepper driver which provides a 160 VDC bus, 10 A peak output current and bipolar operation.

An open loop step program will be used as the speed will be too fast for closed loop feedback. An EPICS IOC will communicate with a ProDex VME motor controller card (Fig. 5). An interface bus and card will transfer the signals to the motor driver. This system is well proven at TRIUMF, but only for slow speed motors. A radiation hard, wire wound linear potentiometer may be used to check that

the motor does not miss steps.

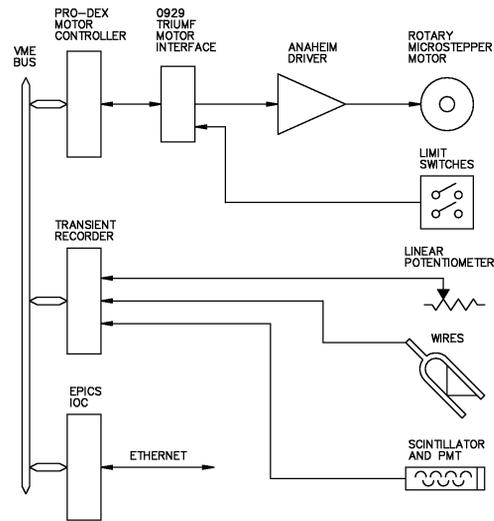


Figure 5: A block diagram of the proposed electronics for the wire scanner.

The wires are carried by a machined Macor fork. They are spring loaded to allow for thermal expansion and their continuity will be monitored. The wire currents will be measured by impressing them across resistors and measuring the resulting voltage with a transient recorder. A fast current-to-voltage amplifier may also be developed. The signal may also be derived from a downstream scintillator and photomultiplier. NE110 plastic scintillator material is a candidate.

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