BEAM DIAGNOSTICS DEVELOPMENT FOR TRIUMF E-LINAC*

V.A. Verzilov#, P. Birney, D.P. Cameron, J. Van Holek, S.Y. Kajioka, S. Kellogg, M. Lenckowski, B. Minato, W.R. Rawnsley, TRIUMF, Vancouver, Canada
J.M. Abernathy, D. Karlen, D.W. Storey, Victoria University, Victoria, Canada

Abstract

TRIUMF is currently in a phase of the construction of a superconducting 50 MeV 10 mA CW electron linear accelerator (e-linac) to support the photo-fission based rare radioactive isotope beam production program. The project imposes certain technical challenges to various accelerator systems including beam diagnostics. In the first place these are a high beam power and widely varying beam operating modes: from very short beam pulses to the CW regime. A number of development projects have been started with the aim to construct the diagnostic instrumentation required for commissioning and operation of the facility. The paper reports the present status of the projects.

INTRODUCTION

As a part of the effort to expand the Rare Radioactive Isotope Beam (RIB) program, TRIUMF has started 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]. The facility will comprise a gridded 300 keV thermionic electron gun operated at 650 MHz, a 1.3 MHz superconducting linac, a 70 m long transfer line and the Target Stations for RIB production. Future expansion foresees a recirculation ring to bust the beam energy up to 75 MeV. While civil construction works are carried on, chosen design and operation strategies can be proved at the injector test facility that produced the first beam in November of 2011.

Design challenges are largely associated with a substantial (half a Megawatt) beam power in the CW mode. Clearly, commissioning and tune-up 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 may require beam pulses of a few microseconds short. A number of development projects were launched about two years ago in order to design the diagnostics capable of supporting all the variety of beam modes. As for today all these projects are either close to completion and moving into production phase or at least reached the maturity state.

DIAGNOSTICS SYSTEMS

Not all the e-linac diagnostics devices are presented and discussed below. Some were reported elsewhere [2]. The beam loss monitoring and machine protection, which are both critical for the operation of the facility are subjects for a dedicated paper.

*Funding is received from National Research Council of Canada
#verzilov@triumf.ca

Beam Position Monitors (BPM)

The general 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 should be easily achievable. Both button and stripline BPM monitors have been designed for the project. The stripline BPM provides a higher signal strength and better absolute accuracy. The button BPM, which is substantially smaller in dimensions, was demanded for locations with tight space constraints.

Each button electrode, that is 12 mm in diameter, is mounted at the pin tip of a SMA vacuum feedthrough welded to a NW16 flange (see Fig. 1). A special alignment groove is machined to improve the position accuracy. The required absolute accuracy is expected to be achieved by a torque adjustment in situ of the fastening bolts to balance the calibration signal strength delivered by individual pickups composing a BPM. The button pickups are manufactured by Kyocera Corporation according to TRIUMF drawings. Three complete BPM were installed at the injector test facility. First beam data are available.

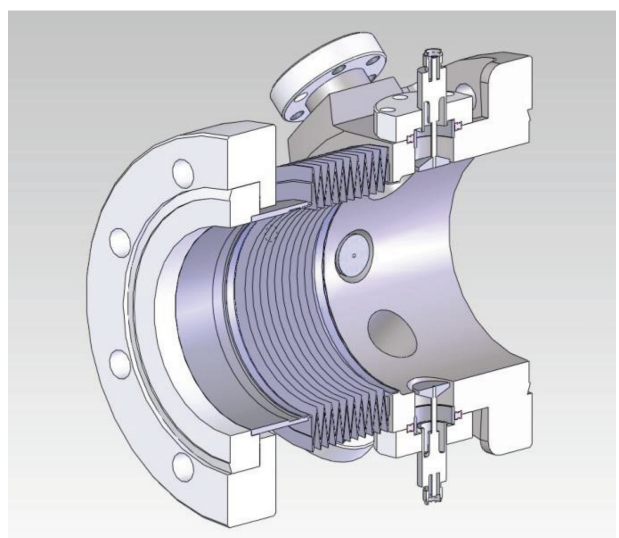

Figure 1: A cross-section view of the button BPM.

The stripline BPM (see Fig. 2) was developed based on work done at Cornell. The Cornell design was adjusted to comply with the 650 MHz bunch repetition frequency and a smaller diameter (50 mm) of the beam pipe. The prototype unit is currently being assembled. Position sensitivity of both button and stripline BPMs is 1.4 dB/mm. The estimated signal strength of the button BPM is about −30 dBm (confirmed by measurements) at the nominal beam current of 10mA. The stripline BPM signal is expected to be stronger by 13 dB.

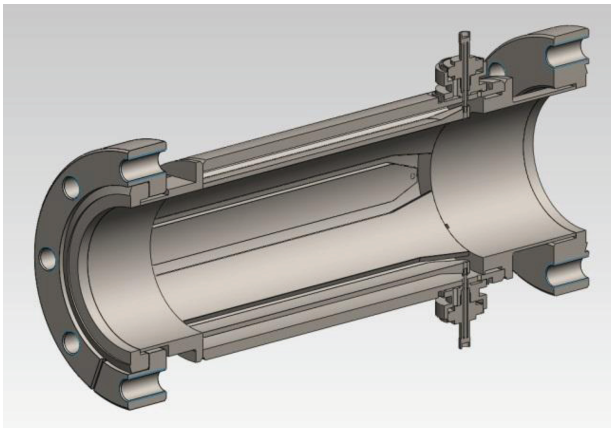

Figure 2: A cross-section view of the stripline BPM.

The BPM signal processing electronics was challenged to operate in both the pulsed beam tune-up mode with the pulse width as short as 1us and the CW operation mode. The electronics development has required a substantial amount of efforts and presently the prototype module is fully ready for beam tests. Electronics comprises a front-end unit, a digitizer and a digital signal processing (DSP) module. The front-end is a commercial BERGOZ Instrumentation AFE board customized for the 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 IF signals are digitized by an in-house developed 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 Xilinx Spartan-6 FPGA. The FPGA performs the ADC data deserialization, signal demodulation and filtering. Fresh data are available approximately each microsecond. 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.

Current Monitors

The beam current will be measured using Faraday Cups (FC) at energies of 100-300 keV and DC current transformers at higher energies. Even at low energies the beam power reaches substantial values making the Faraday Cup design quite challenging. Two FC designs have been developed. A 300W version was designed to operate in combination with a 1mm slit scanner, thus, allowing measuring the beam transverse profile at beam currents substantially higher than it is possible with view screens. Four FC monitors 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.

Design of a higher power version was recently completed. The high power Faraday Cup can dissipate up to 3kW of the beam power provided the beam size is not too small (typically larger than 1mm rms). The design was verified by thermal and stress analysis using COMSOL Multiphysics. A special feature of the TRIUMF design is the modularity achieved by employing a high vacuum compatible VCR fitting which significantly simplifies device serviceability.

The beam current in the CW regime and with long beam pulses will be measured with 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 future. Each monitor includes two or three targets, optics and a camera (Fig. 3). 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 10-30 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.

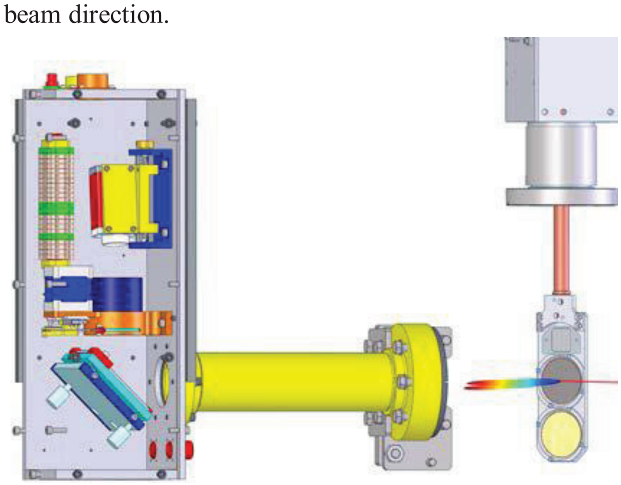

Figure 3: The view screen monitor.

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 entirely implemented within the EPICS environment.

ISBN 978-3-95450-122-9

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 rms.

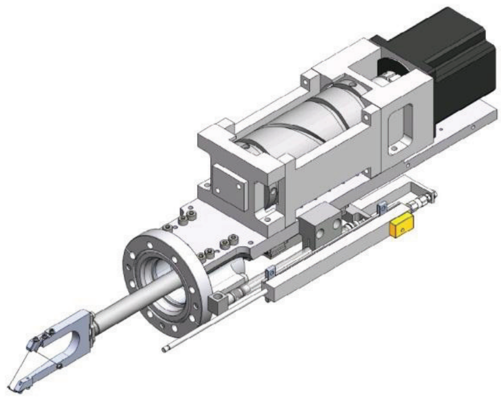

Figure 4: The preliminary design of the fast wire scanner.

To achieve such high speeds we closely followed earlier DESY-Zeuthen design [3] but replaced their slot winding cylinder with a drum having a variable pitch helical slot. The pitch is 144 mm per revolution in the constant speed zone. Close to the park position, the pitch is small to facilitate acceleration and deceleration of the drive mechanism. Two orthogonal wires will move through the beam at 45°. 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 preliminary design of the mechanics has been completed (see Fig.4) and the prototype unit is being manufactured.

The motor control electronics based on commercially available components have been purchased and is presently in the evaluation phase.

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 in to a standard conflate flange (see Fig. 5) 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.

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 (see Fig.5). 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.

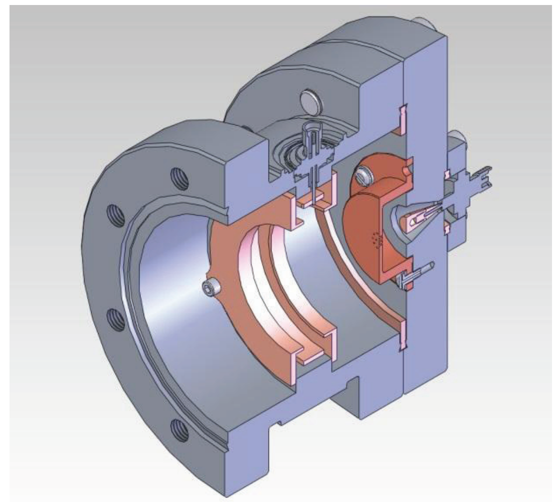

Figure 5: A cross-section of the capacitive and coaxial pickups assembly.

After bunches are compressed by the buncher cavity to sub 10 ps durations they are outside of the reach by the described monitors. A RF deflecting structure was designed for this purpose and is currently being commissioned.

ACKNOWLEDGMENT

The authors would like to thank C. Sinclair for valuable recommendations and assistance with the design of various diagnostics systems, M. Sachwitz for sharing details of the DESY-Zeuthen wire scanner design and M. Rivers for the development of the areaDetector EPICS module.

REFERENCES

[1] L. Merminga et al., “ARIEL: TRIUMF’s Advanced Rare Isotope Laboratory,” IPAC’11, San Sebastian, Spain, September 2011, WEOBA01, p. 1917 (2011);
[2] A. Laxdal *et al*: “High Power Allison Scanner for Electrons” BIW 2012, Newport News, USA, TUCP04; http://www.JACoW.org.
[3] U. Hahn, N.V. Bargen, P. Castro, O. Hensler, S. Karstensen, M. Sachwitz, H. Thom, “Wire scanner system for FLASH at DESY,” DESY, Hamburg, NIM A 592 (2008) 189-196.