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COMMISSIONING OF THE ARIEL E-LINAC BEAM LOSS MONITOR SYSTEM

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Abstract

The commissioning of the Advanced Rare Isotope Laboratory (ARIEL) facility at TRIUMF is underway. The 30 MeV e-linac has successfully been commissioned to 100 W, and to further increase the power to 1 kW the beam loss monitors (BLM) of the Machine Protection System (MPS) must be fully operational. There are currently two types of BLMs employed in the e-linac; long ionization chambers (LIC) and scintillators, consisting of a small BGO coupled to a Photo-Multiplier Tube (PMT). A front-end beam loss monitor board was designed at TRIUMF to meet the strict requirements of the BLMs: a trip of the beam occurs on 100 nC in 100 ms of integrated beam loss, and the trip must occur in < 10 µs. This contribution reports on the status of the 1 kW BLM system commissioning and gives an outlook as the power is increased to the full 300 kW.

INTRODUCTION

The ARIEL facility [1] at TRIUMF is currently in its early commissioning phase. The ARIEL project itself consists of many phases: Phase 1 covers the construction of the electron-linac beamline in the electron hall and commissioning up to 100kW, and Phase 2 includes the construction and commissioning of the beamline up to the 100 kW electron converter target for the production of Radioactive Ion Beams (RIB) using photo-fission. Other phases include a beamline switch-yard, high resolution spectrometer, a charge breeding facility, and the construction of an additional proton beam line for the production of RIB using the Isotope Separation On-Line (ISOL) method. The total available power of the electron beam is 300 kW (10 mA cw beam current at 30 MeV), but the beam dump and the electron converter target will limit the operation to 100 kW for the foreseeable future. Currently ARIEL is in phase 1, and the power is limited to 100 W until the Machine Protection System (MPS) is fully commissioned.

The MPS for ARIEL [2] consists of several different aspects, including beam loss monitors, beam position monitors, and administrative controls. As the final line of defense in case of an errant beam spill, the requirement on the BLMs is that they must trip the accelerator if an integrated beam spill of 100 nC in 100 ms occurs. This can take place by the following two beam spill scenarios at the extremes of time and loss: the full 10 mA electron beam is spilled in 10 µs, or 1 µA of beam spill sustained loss over 100 ms. This trip level is defined as a catastrophic loss event and requires that the beam be turned off in 10 µs, calculated as the time required to raise the temperature of the material to 200 °C in a worst-case scenario.

The BLMs also protect against chronic loss of the electron beam, defined as losses below the catastrophic level but greater than 1 W/m, or ~30 nA/m average beam loss. Unlike a catastrophic loss scenario which can cause immediate damage to the accelerator, a chronic beam spill is a concern for long-term activation of components for hands-on maintenance. Therefore it does not require an immediate trip, and instead will send out warnings to the operators on duty and reduce the duty factor if necessary.

The commissioning of the MPS BLMs in the electron hall is being done in stages. The first stage involves increasing the beam power from 100 W to 1 kW, starting with the low-energy section (ELBT) at 300 keV, followed by the medium energy section (EMBT) at 10 MeV, and finally the high energy section (EHAT) at 30 MeV. Figure 1 shows a layout of the electron hall which indicates the different areas separated by energy. The low-energy and medium-energy sections have been fully commissioned and are ready for 1 kW beam power, while the high energy section BLM commissioning is underway.

BEAM LOSS MONITORS

There are two types of BLMs employed at in the e-linac: LICs (see Fig. 2) and PMTs, the latter consisting of a 1 cm^3 BGO scintillator coupled to a PMT (see Fig. 3). The length of the LICs is variable, ranging from 0.5 m to 3 m, depending on sensitivity and space requirements. The LICs are filled with a constant flow of Argon gas for prompt charge collection. A positive high voltage is applied to the outer conductor, and the signal is taken from the inner conductor. The PMTs use a modified base with three different gain settings, corresponding to 1 dynode, 2 dynodes, or 3 dynodes of amplification. The HV of the PMT can be varied to adjust the gain setting as well. The PMTs are equipped with an LED housed inside the device, which is used for calibration purposes and for self-checks to ensure each PMT is properly working. Both types of BLMs have demonstrated a range of 10^6, from ~100 pA to ~100 µA. This large sensitivity meets both the catastrophic and the chronic beam loss requirements.

TRIUMF BEAM LOSS MONITOR MODULE

The TRIUMF Beam Loss Monitor module (TBLM) [3], shown in Fig. 4, is a front-end electronics board developed

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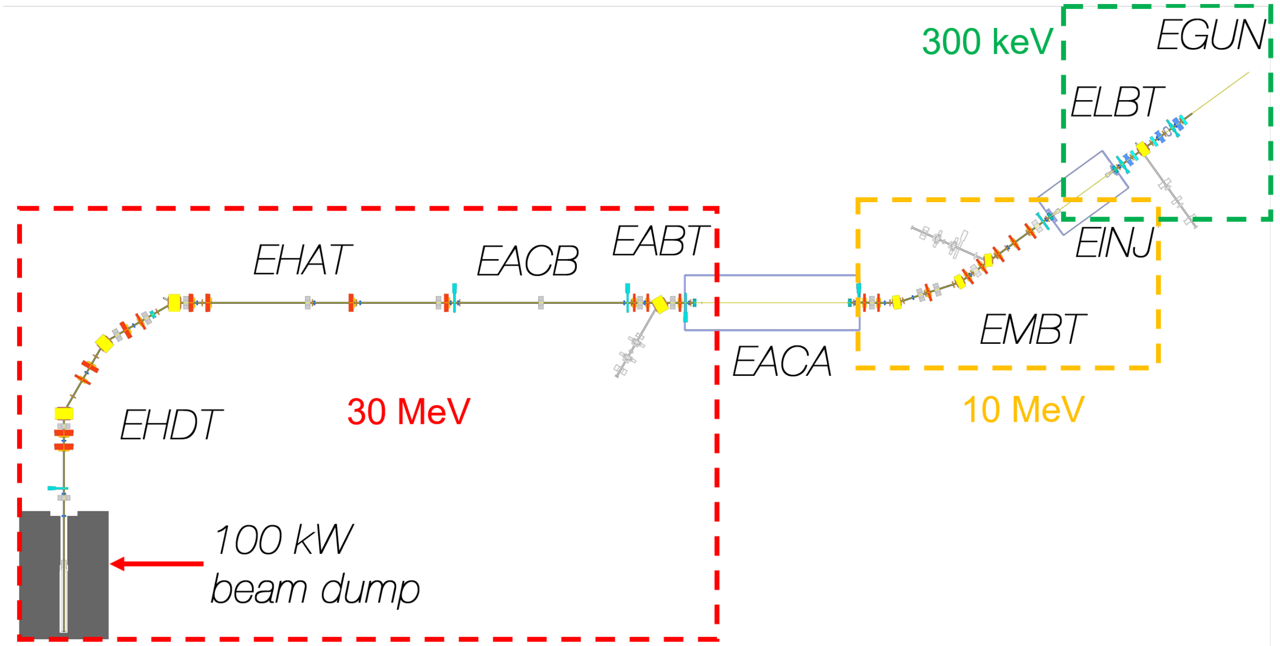

Figure 1: Layout of the electron hall. The low, medium, and high energy sections are highlighted. As discussed in the text, the low and medium sections have been commissioned, and the high energy commissioning is underway. The high power beam dump location is indicated in the bottom left of the figure.

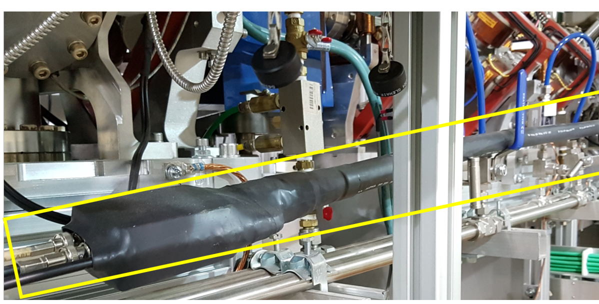

Figure 2: A long ionization chamber (highlighted) located along the beamline in the e-linac. Note the 3 connectors seen coming from the left: an SHV connector to provide −500 V, a BNC signal connector, and a gas fitting to flow Ar.

at TRIUMF which has been successfully commissioned. Each module consists of a carrier board with a VME interface and 8 input channels made up of eight independent daughter cards, each containing the electronics necessary to capture the pulsed signal coming from the two types of BLMs. Several modules have been produced and installed, with one fully outfitted module used in the commissioning of the low and medium energy sections. The beam loss monitors are each connected directly to the TBLM via a long (50 m) cable. Each channel uses dual hardware integrators; while one is integrating the signal from the BLM, the other is discharging the previous integration.

The TBLM performs a running integration of the current from the BLMs over a period of 100 ms (as determined by the specification requirements) and compares this value to a pre-determined threshold. If the threshold is exceeded, the TBLM stops a 5 MHz fiber-optic signal connected to the Fast Shutdown Module (FSD), which then trips the electron

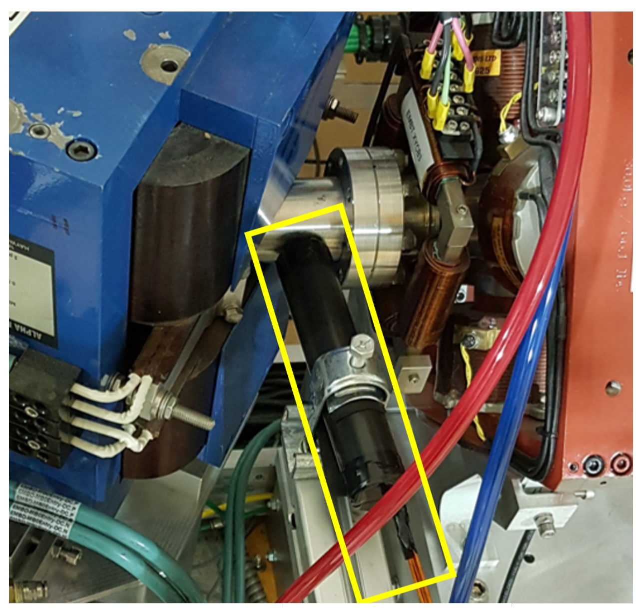

Figure 3: A PMT (highlighted) situated next to the beampipe at the entrance to a dipole in the medium energy section. The three connectors are for HV, signal, and an LED cable. The LED cable provides power to a small LED installed in each PMT used for calibration. Each PMT has three possible gain settings which can be changed via an internal jumper.

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gun by shutting off the RF. The TBLM has two trip conditions, though only the "100 ms" trip has been used during the commissioning phase.

The chronic losses (losses below catastrophic levels but are nevertheless to be minimized to reduce activation) are logged using the TBLM and will also be used for diagnostics during beam tuning. In addition to the chronic loss levels, the TBLM stores up to one second of data in memory from the BLMs which is readout in the event of a beam trip for use in post-mortem analysis.

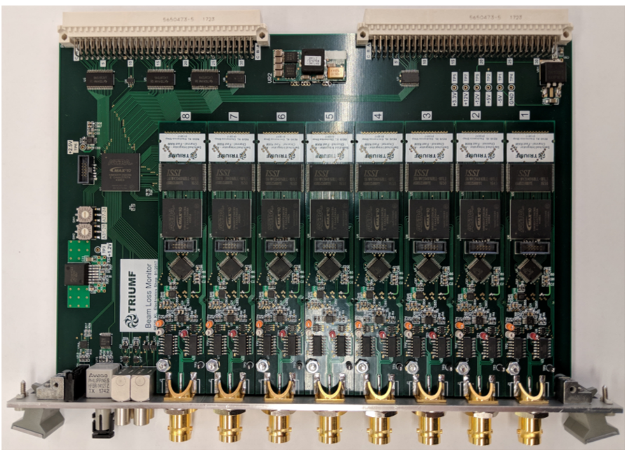

Figure 4: The TRIUMF beam loss monitor front-end board has 8 independent channels to read the current from either a PMT or LIC.

BLM COMMISSIONING

The commissioning procedure is an iterative process. BLMs are placed in each region in an attempt to minimize or eliminate regions which do not see beam spills. A systematic beam spill is then performed, using the various steering and focusing elements. The response of the various BLMs are then compared to the position of the beam spill (as determined by e.g. dipole strength) and if there are deficiencies in coverage, a BLM can be added or moved to maximize coverage. Redundancy in coverage is important as well. The beam spills are performed using low duty factors (typically 0.5%) and low peak intensities on the order of 200 µA.

An example of a plot showing the position (dipole current) versus BLM current from the low-energy section can be seen in Fig. 5. In this plot, the different BLMs are shown in the legend, along with the reading from the Faraday cups. As the position of the beam spill is moved by steering the dipole magnet to cause spills along the beampipe, the different BLMs respond to loss depending on their location with respect to the loss. In this case, the PMTs are quite sensitive to the location of the spill since they are situated very close to the beampipe and the BGO is only 1 cm^3. The LICs, on the other hand, are not quite as sensitive to the position of the spill and are therefore better suited for better coverage.

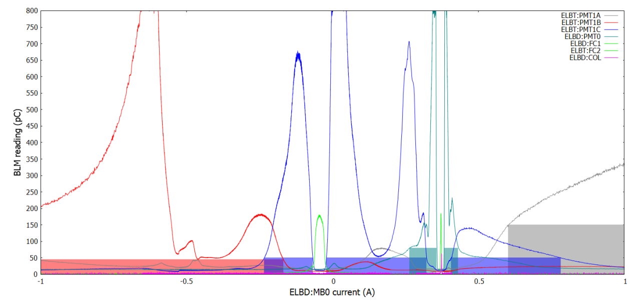

Figure 5: Dipole current (position) versus beam loss in ELBT section. The location of the different BLMs and the Faraday Cups are shown in Fig. 6. For reference, a value of ~0.45 A corresponds to a 90° bend. The Faraday Cup intensity is plotted as well. Note the appearance of signal on the ELBD Faraday Cup at +0.45 A, which is the cup at a 90 degree bend beam left.

ELBT - Low Energy Section

The ELBT section is challenging for the BLM detection due to the very low energy (300 keV) of the electron beam. In this section, only the high gain PMTs were used since the LICs are not sensitive enough to measure the low-energy photons. The ELBT region is outfitted with four different PMTs: three near the dipole, and one along the low energy beam dump section (see Fig. 6). These four PMTs were found to cover the entire low-energy section during the beam spill measurements. See Fig. 5 for the plot of the dipole field versus beam loss.

A particular challenge for the BLMs in the ELBT section is the presence of dark current coming from the superconducting cavities (specifically labeled as EINJ in Fig. 1). The current is seen on the view screens both upstream and downstream of the cavity, with energies of up to 4.5 MeV. This can overwhelm the PMT signal if the energy of the cavity is increased to a gradient of ~9.5 MeV or greater. The temporary solution is to lower the gradient, though this unfortunately lowers the accelerating energy. Conditioning of the cavity has proved successful, and these efforts will continue.

EMBT - Medium Energy Section

The EMBT section has energies up to 10 MeV and has been commissioned using 3 LICs and 1 PMT. The PMT is located at the first dipole, with one LIC located beam left and two LICs on beam right (see Fig. 7). The commissioning of EMBT followed the same procedure as that of ELBT. Purposeful beam spills were performed using the two different dipoles, along with quadrupoles and steerers. Both the EMBT and the ELBT BLMs are readout using the same TBLM module. While the dark current is also present in this section, the required sensitivity from the BLMs is much lower than the ELBT section and therefore the gradient from the downstream cavity does not have to be reduced.

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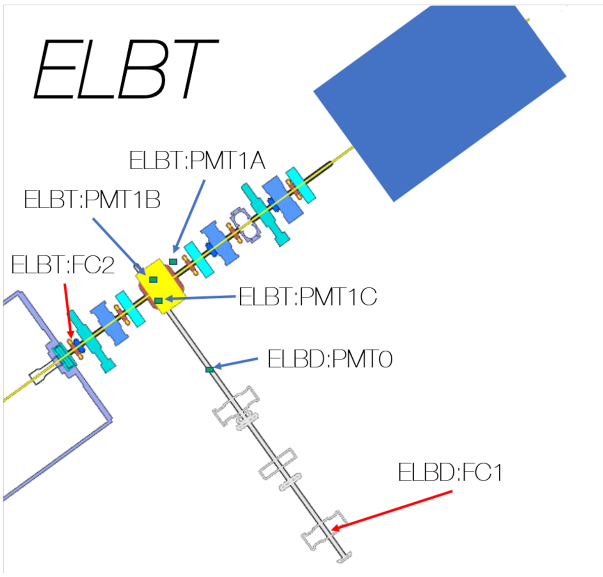

Figure 6: ELBT section showing the position of the PMTs for coverage.

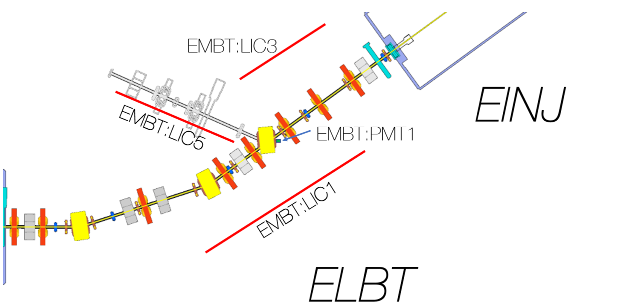

Figure 7: EMBT section showing the position of the BLMs. There are three LICs (each 2 m long) and one low-gain PMT.

EHAT - High Energy Section

The high energy section is designed to transport the 30 MeV electron beam into the 100 kW beam dump or through a long tunnel to impinge on the future ARIEL photo-converter target to produce RIB (not pictured in Fig. 1). This section is currently undergoing commissioning, though tentatively it has been outfitted with 6 LICs for the long straight sections, and two PMTs at the dipole magnets. Initial tests using beam spills have been successful and seem to indicate the coverage is sufficient with these BLMs. However, high power beam has not yet been sent to the high power beam dump so it is difficult to know what the impact of beam-induced radiation is on the BLMs.

There is an additional path, not pictured in Fig. 1, which takes the electron beam slightly to beam right and then into a long tunnel for transport to the final target station. This section is currently in place in the electron hall, though the installation of the beamline in the tunnel is not yet complete. This small section which leads into the tunnel will prove to be a challenge due to its small size restrictions. There is currently one PMT installed in the section, with one small 0.5 m LIC planned, though that section will not be commissioned until the electron hall MPS commissioning is finalized.

OUTLOOK

The goal is to fully commission the MPS BLMs in the electron hall to allow for 1 kW operation at 30 MeV in this calendar year. Once it has been commissioned, the power will slowly be increased to test the various components of the accelerator, including the 100 kW beam dump. During this time, it may be necessary to modify thresholds or change locations/add BLMs as a result of the possible "shine" from the radiation coming off of the high power beam dump.

The next phase of the ARIEL project will be to extend the beam out of the electron hall and transport it to the photo-converter target. This will provide a wealth of challenges since the transport tunnel will be shared with a 500 MeV, 100 µA proton beam line. The BLMs will need to be designed to differentiate spills from the different beamlines to maximize uptime and therefore beam availability.

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