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BEAM INSTRUMENTATION FOR THE NEW LINEAR ACCELERATOR AT THE CANADIAN LIGHT SOURCE

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Abstract

The linear accelerator (LINAC) at the Canadian Light Source (CLS) serves as the injector for the 2.9 GeV synchrotron. The original 2856 MHz LINAC, which made use of components installed in the 1960s, was replaced in 2024 with a new 3000.24 MHz LINAC which was designed and built by RI Research Instruments GmbH. This upgrade has reinforced the importance of having the right diagnostic equipment in place to support visualization and analysis.

OVERVIEW

The new LINAC is made up of a 90 kV-thermionic-source, a 500.04 MHz sub harmonic prebunching cavity (SPB), a 3 GHz single cell cavity acting as a Pre Buncher (PBU), a 3 GHz 14 cell traveling wave structure acting as the Final Buncher (FBU), three 3000.24 MHz 158 cell, 5 m long accelerating structures (ACC1/2/3) and a SLED pulse compression system to accelerate electrons up to 250 MeV.

Early in the project, diagnostic equipment was sacrificed as a result of budgetary constraints. The destructive diagnostic equipment incorporated in the final design included one faraday cup (FC) and five optical monitors (OM). The non-destructive diagnostic equipment included one beam position monitor (BPM), one wall current monitor (WCM) and one integrating current transformer (ICT). Shortly before installation additional non-destructive diagnostic equipment from the original CLS LINAC, was integrated into the new RI LINAC by the CLS, as shown in Fig. 1.

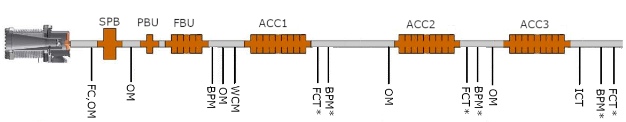

Figure 1: LINAC diagnostic equipment (where * identifies equipment integrated into the design by the CLS).

During RF conditioning additional directional couplers and microphones were added to provide insight into the location of RF breakdowns.

BEAM INSTRUMENTATION

Faraday Cup

A faraday cup was installed on a linear feed through with an optical monitor at the exit of the electron source. The FC is connected to an oscilloscope, has a bandwidth of 3.5 GHz, and is used to measure beam properties like bunch charge and time structure. It was also used to perform dark current scans to ensure proper operation of the electron source.

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Optical Monitors

The optical monitors consist of a YAG:Ce crystal plate, 30 mm in diameter, installed on a black plate engraved with cross hairs, mounted on a linear feed through. When intercepting the beam the YAG fluoresces and the image produced is digitized using a FLIR GigE machine vision camera. This system supports visualization of the transverse profile of the beam at various locations, the camera system also analyzes the image to compute beam parameters [1], including intensity, centroid, ellipticity, eccentricity, orientation, and more. The camera system has also been used for stability and emittance measurements.

Wall Current Monitor

A wall current monitor was installed before the first accelerating section. It has a bandwidth of 2 GHz which allows analysis of the time structure of the 500 MHz bunched beam. This equipment was calibrated against the ICT, to support non-destructive beam current measurements.

Beam Position Monitors

One button BPM was incorporated in the original RI LINAC design. This BPM was installed right after the bunchers. Three cavity BPMs were installed by the CLS, one downstream of each accelerating section, with the intention of eventually using this equipment to automate LINAC setup and steering. The BPMs are monitored using Instrumentation Technology Libera Spark EL units [2]. Instrumentation Technologies DWP-SP down-converters with a 2.5 GHz local oscillator [3], have also been installed, because the Libera Spark EL units are sensitive to the 500 MHz component of the BPM signals.

Fast Current Transformers

Fast current transformers (FCT) were integrated into the new LINAC by the CLS. One FCT was installed downstream of each accelerating section, this equipment does not have enough bandwidth to fully resolve the 3 GHz RF structure of the beam, but does enable additional non-destructive current and charge measurements. The signals are being monitored by Pico Technology oscilloscopes [4]. The 500 MHz bunching of the beam can clearly be resolved on an oscilloscope and the 3 GHz RF structure appears as ripples on the 500 MHz bunches.

Integrating Current Transformer

A Bergoz in-flange integrating current transformer [5] was installed downstream of ACC3. This signal is digitized using a struck SIS3316 Channel VME Digitizer [6]. The

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calibration provided by Bergoz was confirmed by injecting pulses from a signal generator into the test/calibration winding of the ICT. This equipment is used to monitor the beam charge at the end of the new LINAC.

Directional Couplers

RF pickups, used to measure beam energy and phase, and RF directional couplers, used to measure incident and reflected power levels were included in the original design and installation. Shortly after commissioning began, the RF pickups were removed because of suspicions that these were causing arcing and additional directional couplers were installed before the load, at the end of each accelerating section.

In order to support localization of RF breakdowns, a low power DC direction coupler, that could be used with some tight space constraints, was designed by the CLS, as shown in Fig. 2. These directional couplers allowed us to split the RF power signals and have them run to the RF detector unit, to peak power meters for monitoring and triggering of diagnostic equipment, and to oscilloscopes for visualization and data capture.

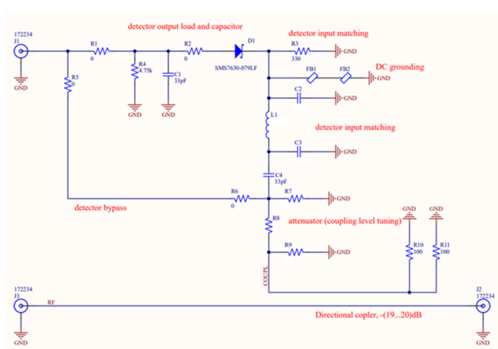

Figure 2: Schematic of CLS built directional coupler.

The incident (INC), transmitted (TRA) and reflected (REF) RF power waveforms are being saved when there is a reflected power event. The data is then analyzed to determine where in the structure, and in the pulse, the breakdown occurred, as illustrated in Fig. 3 [7].

With knowledge of the physical lengths of the waveguides (WG) and accelerator (ACC) sections, along with the RF group velocity profile through each region, the breakdown time and the spatial position is determined using the following relation,

$$T_{\mathrm{BD}} = T_{\mathrm{REF}} - (T_{\mathrm{TRA}} - T_{\mathrm{fill}}) \qquad (1)$$

where, T_{BD} is the breakdown time, T_{REF} is the time at which the reflected wave rises, T_{TRA} is the time at which the transmitted wave falls, and T_{fill} denotes the RF filling time of the structure.

Microphones

Micro-Electro-Mechanical-Systems (MEMS) microphones [8] with a frequency range between 30 Hz and 85 kHz, have been installed along the accelerator sections, on the waveguide and around the directional couplers to detect where breakdown events are occurring [9]. The microphones are monitored at 125 kSa/s using D-tAcq ACQ435ELF ADCs [10], as depicted in Fig. 4. The data collection is triggered by the onset of a reflection seen by the directional couplers. The data acquired is visualized for real time monitoring and also saved for post-processing. Many regular RF pulses were recorded to establish a baseline amplitude. Data associated with breakdown events is then normalized against the baseline to determine which microphone is the loudest and therefore closest to the location of breakdown, as depicted in Fig. 5.

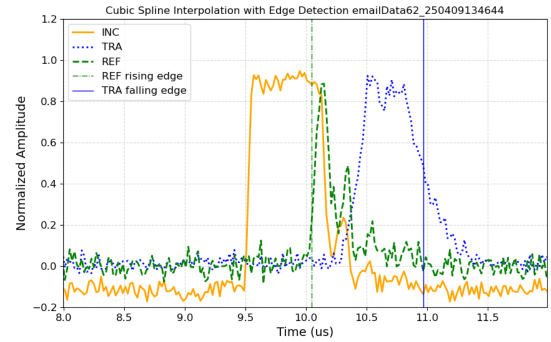

Figure 3: INC (solid orange), REF (dashed green), and TRA (dotted blue). The corresponding detected edges for each waveform are marked using the same colors.

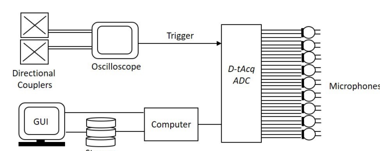

Figure 4: Microphone hardware schematic.

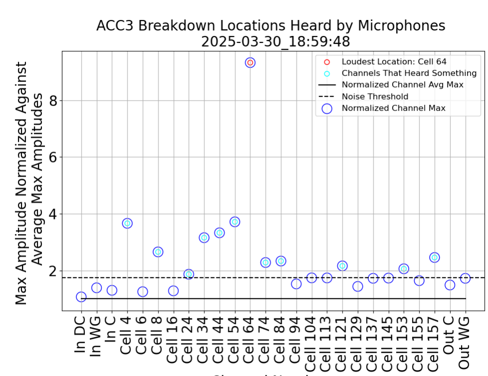

Figure 5: Amplitude plot of sample microphone data.

CONCLUSION

The data from the microphones and the directional couplers is actively being used to determine where in the pulse,

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see Fig. 6, and where in the structure, see Fig. 7, breakdowns are occurring.

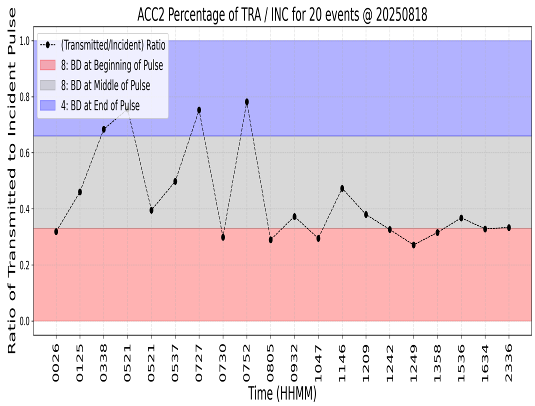

Figure 6: Location of reflection in pulse for ACC2 events.

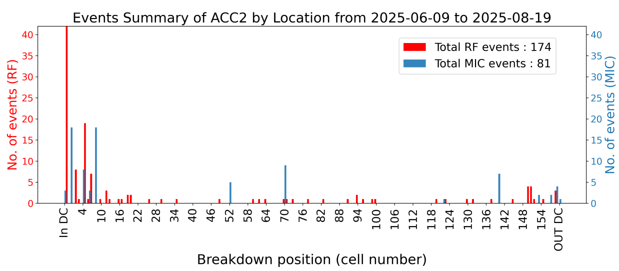

Figure 7: ACC2 breakdown summary.

The analysis of data from these two complementary systems has enabled identification of hot spots in the structure, with most events occurring at the beginning of ACC2, between cell one and cell twenty, shown in Fig. 8. The microphones produced complementary results, and supported detection of breakdowns at the input coupler, which could not be detected using the directional couplers. This study demonstrates that the availability of multiple diagnostic systems is essential for accurate breakdown localization.

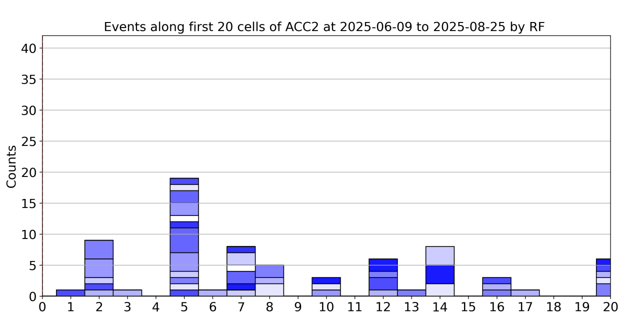

Figure 8: Breakdowns detected by directional couplers.

The importance of having the appropriate equipment available to both provide insight into what is happening and to diagnose issues is often overlooked or sacrificed as a result of schedule or budgetary constraints, being defined as nice to have and not need to have. If nothing goes wrong, this is true. However, when things go wrong the more tools available directly impacts the probability of resolution in a timely manner. If these tools are installed after the fact, both the cost and timeline is considerably greater than it would have been if these tools had been included in the original design and installation process.

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