STATUS OF THE BNL ERL INSTRUMENTATION*

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Abstract

The Energy Recovery Linac (ERL) project is currently under construction at the Brookhaven National Laboratory. Energy recovery operations are expected with high intensity beams that have current up to a few hundred milliamps, while preserving the emittance of bunches with a charge of a few nC produced by a high current SRF gun. To successfully accomplish this task the machine will include beam diagnostics that will be used for accurate characterization of the beam phase space at the injection and recirculation energies, transverse and longitudinal beam matching, orbit alignment, beam current measurement, and machine protection [1]. This paper describes the recent progress and present status of the systems that will be used to meet these goals.

INTRODUCTION

The diagnostics requirements have been described in several previously published papers [2,3,4]. There is a progression of ERL facility stages planned in order to advance towards achieving full energy recovery. The diagnostics system configurations vary for each stage. The initial stage for beam testing includes the 2MeV SCRF gun, a straight beam transport to an in-flange ICT, then to an isolated blank CF flange acting as a Faraday Cup. After gun testing with different cathodes we will extend the straight transport to include a pepper pot emittance station. When the beam parameters are acceptable we will connect the transport to the injection zig-zag [5] and deliver beam to a low power dump after the 5-cell Linac. The early commissioning stages are limited to 70W operation by the relatively small temporary beam dumps. The full complement of all of the ERL planned instrumentation subsystems, including devices in the energy recovery loop and high power beam dump, are shown in Figures 1 and 2.

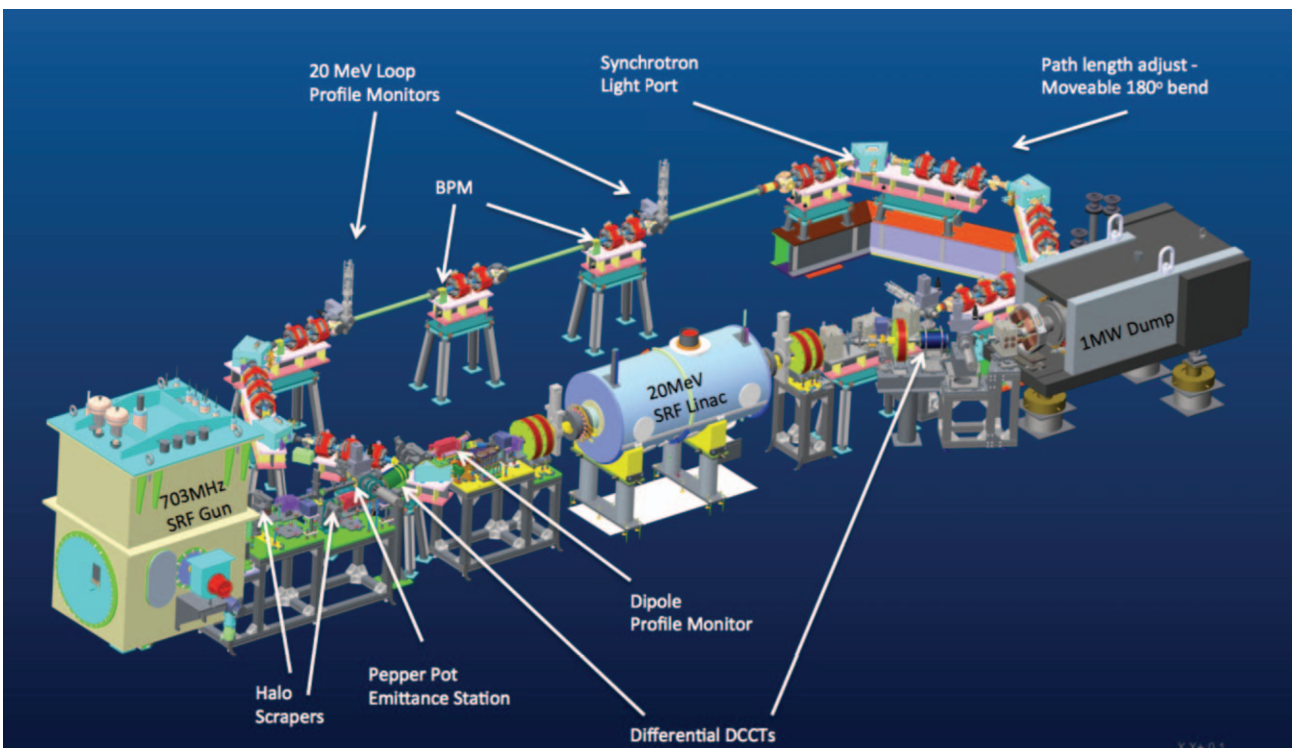

Figure 1: A 3D rendering of the ERL facility showing the SCRF Gun, zig-zag injection transport, 5-cell SCRF Linac, recovery loop, high power dump, and location details of some of the instrumentation detectors.

*Work supported by the auspices of the US Department of Energy
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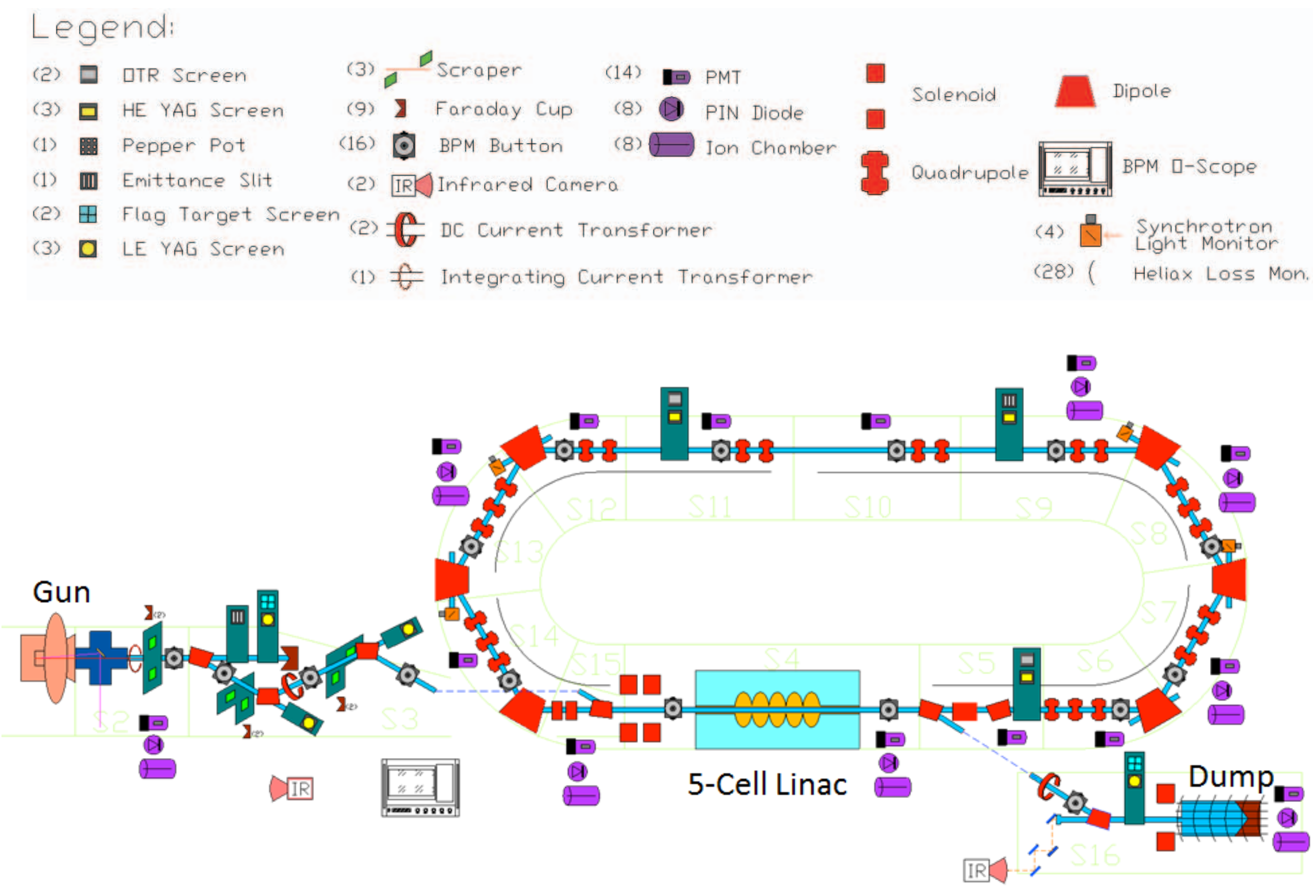

Figure 2: A schematic of the ERL facility showing the distribution of the instrumentation detectors.

Extraction Beam line – 2MeV

The design of the 2 MeV extraction beam line transport from the 5-cell Linac to the dump was detailed as shown in Figure 3. The instrumentation includes a BPM, DCCT and a plunging YAG profile monitor.

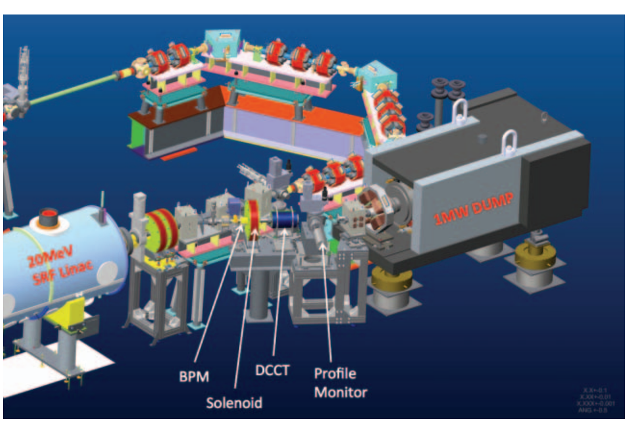

Figure 3: ERL 2MeV extraction line showing instrumentation locations.

DIAGNOSTICS SYSTEMS

Beam Position Monitors

There are 16 dual plane 10mm diameter button style Beam Position Monitors (BPMs), 4 in the injection transport, 11 in the recirculation loop, and 1 in the dump line. The buttons are Times Microwave Systems [6] model SK-59044; they are mounted on stainless cubes that are welded to the adjacent 6 cm diameter beam pipes. The orientations of the installed cubes are either at 45° or 90° depending on their location. A 45° orientation is used if there are space limitations and to avoid beam related energy deposition on a button downstream of bending magnets. The BPMs will be baked to 150C.

Libera Brilliance Single Pass electronics from Instrumentation Technologies [7] will process signals from the BPMs. These modules have been customized with a 700MHz SAW band pass filter that matches the fundamental frequency of the SCRF gun and Linac accelerating cavities. The Libera BPM electronic units have been integrated into the standard RHIC control system. ADO (accelerator device object) software has been written and executes directly on the Linux kernel that is resident in the Libera hardware. The ADO provides on-board communication to the Libera hardware through the CSPI (control system programming interface) library

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provided by I-Tech, and communicates to higher level workstations via Ethernet using standard RHIC control system utilities.

Beam Profile Monitors

Transverse beam profiles will be measured at 7 locations by two methods, depending on the energy and the amount of beam charge in the bunch train. When in low charge operating mode with 1-100pC bunch charge trains, we will use 0.1 X 50mm YAG screens from Crytur [8] (40mm clear aperture). For higher energy and charge modes we will use OTR (optical transition radiation) screens that are comprised of a 250 micron thick silicon wafer coated with ~1000 angstroms of aluminum. The 2 low-energy, and 3 high-energy type profile monitor stations consists of a vacuum cross with a three-position pneumatic actuator allowing selection of a beam impedance matching "squirrel cage," a YAG crystal with its surface normal to the beam direction followed by a 45 degree turning mirror, or an OTR screen also followed by a 45 degree turning mirror. The profile monitor stations were specified by BNL then designed and fabricated by Radiabeam Technologies [9]. They have been delivered and are being tested and prepared for installation.

Optical resolution analysis can be done at any time using a resolution test pattern embedded in the virtual target (attached to the optics box) that is the same distance from the camera as the YAG and OTR screens. Initial test results show optical resolutions of better than 50um.

A pair of specially designed YAG dipole profile monitors will be provided due to space constraints in the zig-zag transport, they will plunge into the beam path inside of the two injection 30º vertical dipole chambers as shown in Figures 4 & 5.

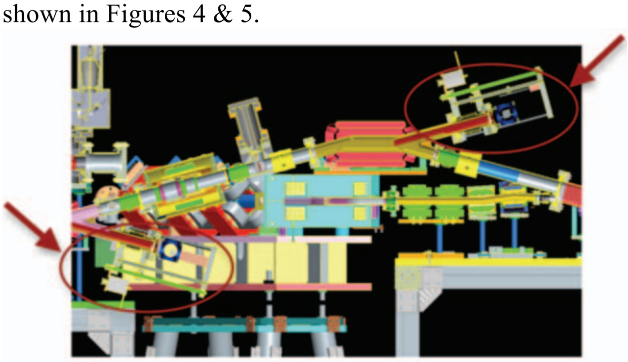

Figure 4: Cross section of injection Zig-Zag showing the locations of the Dipole Profile Monitors.

Precise positioning will be provided by a stepper motor actuated plunging mechanism, with a 4-inch stroke, that has a long YAG screen holder that extends into the dipole magnet chamber through an auxiliary port to intercept the electron beam. The beam can be imaged at different places on the crystal including the edge depending on the plunge depth. This can be useful for semi-destructive beam halo monitoring. A specification and statement of work has been prepared, we hope to receive these devices from a vendor next year. The dipole profile monitor ports will be blanked off during the initial commissioning of the injection zig-zag as the devices will likely not be delivered before first beams.

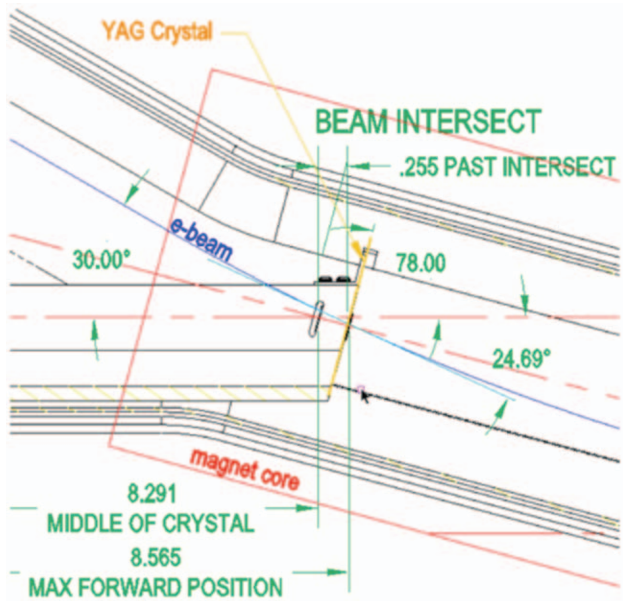

Figure 5: Injection Zig-Zag Dipole Profile monitor details, the electron beam trajectory in this view is right to left.

Images from the YAG or OTR screens are transported through a mirror labyrinth to a 3-motor lens and CCD camera in a local enclosed optics box. Communication cable length requirements and limited support for FireWire 1394 cameras in the WS5 and WS6 RedHat Linux kernels we currently use has prompted a migration to GigE camera technology for digital imaging tasks within our controls subsystems [10]. The Manta G-201B from Allied Vision Technologies [11] is the camera we plan to use for early operations. A software middleware layer is implemented using Aravis, an open-source glib/gobject based library which enables video acquisition from genicam based cameras, which makes the images available to various viewing and image processing applications. Users can control parameters such as image size, bit depth, resolution, exposure, gain, gamma, binning, triggering, etc. The images are used to characterize the beam and can be stored for later examination and calculation of projections, centroids, etc.

Synchrotron Light Monitors

Synchrotron light monitors will be used to measure transverse beam profiles while running with high power beams. Due to the resulting relatively long 14 micron IR synchrotron radiation wavelength (20MeV, 60° bend, 3.3kG dipole), using these monitors productively could be challenging. We plan to install optical transports and CCD cameras at a number of the ERL loop 60° dipole locations sometime after the full ERL has been commissioned and the beam current is high enough to produce enough synchrotron light for a good measurement. Five of the six

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recirculation loop dipole chambers have dedicated synchrotron light output viewing ports.

Halo Scrapers

Halo scrapers fabricated by Radiabeam based on a BNL design will be installed in the low energy injection zig-zag beam line to explore the halo characteristics. A combination of horizontal and vertical stepper motor controlled 2mm thick copper jaws will be located at several locations in the injection transport. After the halo characteristics are determined by measurements with beam, a collimator station will be installed to scrape off the undesired halo at low energy to reduce higher power beam losses downstream.

Beam Current Monitors

High precision DC current measurements will be made using a matched set of Bergoz NPCT-S-115 DC current transformers (DCCT) and standard NPCT electronics [12]. There will be one of each installed in the injection and extraction transport beam lines. These DCCTs are configured in a nulling mode [13] where their calibration windings are joined in a single loop, and driven opposite the beam by a low-noise Khronhite model 523 current source. The output level of the dump DCCT is fed back as a reference to the current source to drive the dump DCCT output to zero. The output of the gun DCCT is then a measurement of the difference of beam current between the two DCCTs.

The DCCT signal processing will be done using a National Instruments PXI-1042 8 slot 3U chassis with a PXI-8115 Core i5-2510E 2.5GHz controller and a set of PXI-6289 625 kS/s, 18-bit digitizers for handling system tasks that include absolute and differential measurements. Drift (magnetic field, thermal, and gain) compensation will be automatically removed by periodic nulling without beam. The anticipated sub-micro-amp resolution may permit using this diagnostic as an additional layer of the machine protection system [14] in the case the beam loss monitors fail to thoroughly detect significant beam losses.

Bunch-by-bunch & bunch train charge will be measured by a Bergoz in-flange Integrating Current Transformer (ICT) part number ICT-CF6-60.4-070-05:1-H-UHV-THERMOE, located in the upstream injection line. This ICT assembly has an internal type E thermocouple for bake-out temperature monitoring; this feature was added by request. ICT signals will be processed by Bergoz BCM-IHR Integrate-Hold-Reset electronics that have the maximum 10 kHz repetition rate feature. A VMIC 3123 16-bit digitizer with a beam synched trigger will be configured using the double-channel digitizing method to increase the acquisition rate to 200 kS/s. The integrating window length range possible in the ICT electronics is from 100ns to 6.9us. The triggering frequency is independent of the integrating window size.

Beam Loss Monitors

Photomultiplier tube (PMT) based loss detectors will be installed at locations where beam loss is most likely. The design of this detector is based on ones developed at Jefferson Lab and used at CEBAF [15]. JLAB uses the Burle 931B PMT. At the BNL ERL we will use the Hamamatsu R11558 PMT that is very similar to the 931B except that it has lower dark current, higher gain, and improved anode and cathode responsivity. The PMT is installed in a light tight ABS plastic housing that includes a green LED for testing with 1uS light pulses, see Figure 6 below.

Figure 6: PMT based beam loss monitor detector, assembled at left, and disassembled.

Beam loss signals from the PMT detectors will be processed using the VME based eight-channel BLM module developed at JLAB. It provides linear, logarithmic, and integrating amplifiers that simultaneously provide the optimal signal processing for each application. Amplified signals are digitized and then further processed through a Field Programmable Gate Array (FPGA). Combining both the diagnostic and machine protection functions in each channel allows the operator to tune-up and monitor beam operations while the machine protection is integrating the same signal. Other features include extensive built-in self-test, fast shutdown interface (FSD), and 16-Mbit buffers for beam loss transient play-back. The new VME BLM board features high sensitivity, high resolution, and low cost per channel [16].

The actual PMT gain at each location will be field adjusted by setting the high voltage bias during beam commissioning. A CAEN HV multi-channel chassis with full remote control will bias the PMTs.

Eight standard RHIC Ion Chamber (IC) loss detectors will be employed at select locations at the ERL. The signals from each IC are transported on 75 ohm cables to the standard RHIC style BLM V119/V118 electronics processing modules. All V119 modules are supervised by a V118 module that monitors integrated signal level data compared to thresholds. The V118 module has a discrete loss output signal that will signal the machine protection system in the event of excessive losses.

Ion chamber type loss monitors based on gas filled heliax cables with ~10^4 dynamic range and sensitivity of >200nC/rad/m will also be employed at ERL [17]. The cable is 7/8 inch Heliax, Andrew type RG318, filled with Argon to 10 psig. A series of four long loss monitor cables will continuously run along the inside of the recirculation loop in order to have full beam loss monitor

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coverage and a way to determine integrated losses in each loop quadrant as shown in Figure 2. The cable loss monitors are biased to ~150V by custom floating bias supplies (used in the AGS), mounted in NIM modules. The loss signal returns on the bias cable and is integrated by custom integrating amplifier modules (also used in the AGS) whose analog outputs are digitized by standard VME DAC modules.

In addition to amplitude proportional beam loss detection, as provided by the PMT, IC & Heliax detectors, event count based detectors will be employed. PIN Diode loss detector modules, Bergoz model BLM, will be installed at eight select locations in ERL. The TTL data output of each detector is counted by a Struck model SIS3808 scalar VME module [18].

It is important to ensure the hi-power dumped electron beam is distributed as designed inside the dump chamber. A variety of diagnostics are planned to help ensure dump performance and protection [19]. It is impractical with this dump design to install thermocouples to directly map temperature variations due to the two concentric layers of cooling water flow.

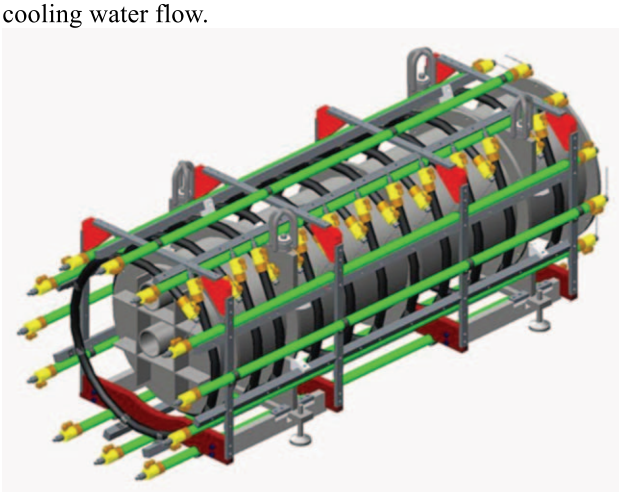

Figure 7: ERL Dump drawing showing the heliax cable type beam loss monitors shown in green and black.

A configuration of heliax loss monitor cables as shown in Figure 6 will be installed inside the outer shielding vessel of the beam dump to map losses at low power. An IR camera is planned to be used in an attempt to image the downstream portion of the inside of the dump while operating at reduced power using an optical labyrinth for camera protection, and a ZnSe viewport.

Thermal imagers will be used at several locations to measure beam pipe temperature gradients to ensure beam losses not seen by other loss detectors are monitored. We chose the FLIR A310 camera [20]. It offers image transfer and control via Ethernet, and configurable location specific temperature thresholds on the image can be programmed and used to provide a machine protection alarm or interlock signal from a digital output port on the camera assembly.

FUTURE INSTRUMENTATION

We plan to eventually add more instrumentation systems as the progress with the ERL facility moves forward. These systems include a streak camera, M_{56} measurement using a longitudinal BTF technique, and several techniques to measure high power transverse beam profiles. There is beam transport space available in the ERL loop far from the SCRF cavities. We are considering using conventional wire scanners, vibrating wire scanners, and laser wire scanner techniques. A combination laser wire with Compton photon counter can be used to measure all three dimensions of the electron bunches in the high power regime [21].

ACKNOWLEDGEMENTS

The authors acknowledge the contributions of I. Ben-Zvi and other members of the Accelerator R&D Division, Instrumentation Systems Group, Accelerator Components & Instrumentation Group, the Controls Group especially B. Olsen, J. Jamilkowski and L. Hoff, the Vacuum Group, and Jesse Fite and Sal Picataggio.

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