DIAGNOSTICS OF BNL ERL

E. Pozdeyev#, I. Ben-Zvi, P. Cameron, A. Drees, D. Gassner, D. Kayran, V. Litvinenko, G. Mahler, T. Rao, BNL, Upton, NY 11973, U.S.A.

Abstract

The ERL Prototype project is currently under development at the Brookhaven National Laboratory. The ERL is expected to demonstrate energy recovery of high-intensity beams with a current of up to a few hundred milliamps, while preserving the emittance of bunches with a charge of a few nanocoulombs 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 three dimensional beam phase space at the injection and recirculation energies, transverse and longitudinal beam matching, orbit alignment, beam current measurement, and machine protection. This paper outlines requirements on the ERL diagnostics and describes its setup and modes of operation.

INTRODUCTION

The BNL Prototype ERL [1] is an R&D effort aimed at reducing risks and costs associated with the proposed RHIC II electron cooler [2] and eRHIC collider [3]. The ERL will serve as a test bed for developing and testing instrumentation and studying physics and technological issues relevant to very high current ERLs.

The Prototype ERL, mated to a high current SRF gun, is expected to demonstrate production and energy recovery of high intensity, low emittance beams with a current of up to a few hundred milliamps. To successfully accomplish this task the ERL will include beam diagnostics required to characterize and tune beam paremeters, as well as for machine protection. A preliminary diagnostics plan was presented in an earlier publication [4]. In this paper, we describe the diagnostics presently planned to provide the data needed to meet these goals.

BEAM PARAMETERS AND DYAGNOSTICS REQUIREMENTS

Table 1 presents beam parameters of the beam after the gun and in the ERL loop for different operational modes.

Table 1: Expected beam parameters at Prototype ERL

Parameter	High Current	High Charge
Inj. Energy (MeV)	2-3	
Max. Energy (MeV)	16-20	
Bunch freq. (MHz)	10-351.8/703.8	10
Bunch Charge (nC)	1.4 / 0.7	5-10
Beam Current (mA)	14-500 / 500	50-100
$\varepsilon_x/\varepsilon_y$ (μm, norm.)	2	5-10
Bunch length (ps)	40	60
dE/E (rms)	0.01	0.015

Table 2 shows accelerator physics requirements to the beam diagnostics.

DIAGNOSTICS LAYOUT

Figure 1 shows layout of diagnostics planned for the Gun/Injector. Similarly, Figure 2 shows the Ring diagnostics. We present a brief description of each of the diagnostics systems.

- Beam Position Monitors - The pickups are 10mm diameter button electrodes. With the exception of the injection line, they are oriented in the horizontal and vertical planes in the 6cm diameter beampipe. The injection line orientation is 45 degrees due to space limitations. The housings are precisely machined from solid stainless steel blocks. In the Ring, BPM housings will be precisely positioned relatively to the ring dipoles and quadrupoles. Commercial off-the-shelf electronics is under consideration.
- Beam Current Monitors – Bunch-by-bunch current will be measured by a Bergoz in-flange Fast Current Transformer in the injection line. High precision current measurements will be accomplished by two Bergoz DC Current Transformers [5], one in the injection line and one in the dump line. Additionally, the DCCTs can be configured in a nulling mode [6] as shown in Figure 2. Their calibration windings are joined by a single loop, powered by a low-noise current source, driven opposite the beam. Output of dump DCCT is fed back to the current source, to drive its output to zero. The output of the gun DCCT is then a differential current measurement. Drifts (thermal, gain, magnetic field) are removed by periodic nulling without beam. The anticipated sub-microamp resolution may permit using this diagnostic as a second layer of the machine protection system in the case beam loss monitors will fail to detect beam losses.
- Flags – Flags will be driven by multi-position pneumatic actuators, and will have both YAG and OTR capability at each location. Images will be viewed off the ERL plane via mirrors. Radiation resistance of the proposed CCD camera is being evaluated.
- Synchrotron Light – These monitors are planned to be used to monitor the transverse beam profile in the high power/current regime. However, using these monitors can be problematic if the beam energy is below 18 MeV due to the long wavelength of the synchrotron radiation. The present plan is to have CCD cameras available at the locations shown in Figure 2. A dual-scan streak camera will also be available.

1-4244-0917-9/07/$25.00

Table 2: Accelerator Physics Requirements to ERL Prototype Diagnostics

Parameter	Range / Expected Value	Accuracy	Resolution	Comments
Injection Line				
Beam loss (localized)	0-25 μA / <500 nA	20%	5 nA	Beam Loss Monitors
Beam position	±1.5 cm	200 μm	50 μm	BPMs
Beam Emittance	2-10 μm	30%	0.2 μm	Pepper Pot
Transverse Beam Size	2-5 mm	5%	20 μm	Flags (OTR, YAG)
Beam Halo		20%	1 nA	Scraping
Bunch Charge	0.1-10 nC	5%	1%	1% resolution desirable
Ghost Bunches	10 nA @ 10 MHz	20%	1 nA	
Recirculation Loop				
Beam loss (localized)	0-2500 nA / <50 nA	20%	0.5 nA	Beam Loss Monitors
Beam position	±1.5 cm	100 μm	20 μm	BPMs
Bunch RF phase		1º	0.25º	
Beam Emittance	2-10 μm	40%	0.3 μm	Quad Scan
Transverse Beam Size	0.1-5 mm	10%	5-20 μm	Flags (OTR, YAG)
Bunch length (Full)	50-150 psec	10 psec	2 psec	Streak Cam, Sync laser pulses
Energy spread	1%	1e-3	2e-4	Via transverse size
Beam Current	0-500 mA	1%	0.25μA-1%	
Diff. Current Loss	< 1 μA	1%	0.25μA	2 DCCTs, nulling feedback
Beam Halo			1e-6	
M_{56}	±20 cm / 0.0	10%	0.5 cm	Longitudinal BTF

- Beam Loss Monitoring – Photo-multiplier tubes will be installed at locations where beam loss is considered most likely. The design of PMT BLMs for the ERL will based on the design of PMT BLMs developed at Jefferson Lab [7]. Because of their fast response and a large dynamics range, PMT BLMs can be used for both machine tuning and protection. Additionally to PMT BLMs, we plan to install pin diode detectors manufactured by Bergoz [8]. Because pin diodes are sensitive to small electron losses but practically blind to X-rays, they can be used for machine tuning that might require detection of small beam losses. The third type of BLM detectors is Heliax cable ionization chambers. They will be placed around the recirculation loop and in the dump region. Monitoring beam losses in the injection line with BLMs can be difficult Therefore, additionally, to PMT BLMs we plan to install an IR camera controlling the temperature of the Zigzag merger.
- Electron beam emittance will be measured at the gun extraction energy by a pepper pot. Additionally, we plan to perform a quadrupole scan at the full beam energy using a quadrupole lens and an OTR screen situated after the 5-cell cavity.
- Dump Thermocouples – The temperature distribution in the beam dump will be monitored with a thermocouple array.
- Wire/Halo - Wires will be driven by stepping motors. Each fork will have both a wire for beam core measurement and a block for halo measurement.
- All scrapers are in the Injector. The scraper immediately after the gun is for primary collimation. A second scraper is located in a dispersive region for momentum collimation, and there is a third scraper in the Pepper Pot line.
- A combination of a "laser wire" with a Compton photon counter can be used to measure all three dimensions of electron bunches in the high power regime. We are evaluating a possibility of using laser pulses of either IR or green light produced by the gun driver laser as a byproduct. Correlating the laser pulses with electron bunches we will be able to measure the longitudinal beam profile.

Anticipated quantities of diagnostics are shown in Table 3.

Table 3: Anticipated quantities of ERL diagnostics

	Gun	Ring	Dump	Total
BPM	4	10	1	15
DCCT	1	-	1	2
FCT	1	-	-	1
Flag	2	2	1	5
Wire	1/1	1/1	1/1	3/3
Scraper	3	-	-	3
Sync. Light	-	4	-	4
Compton	1	1	-	2
Streak Cam	-	1	-	1
PMT BLM	3	9	-	12
Pin D. BLM	-	8	-	8
Heliax BLM	-	4	8	12
Dump TC	-	-	1 array	1

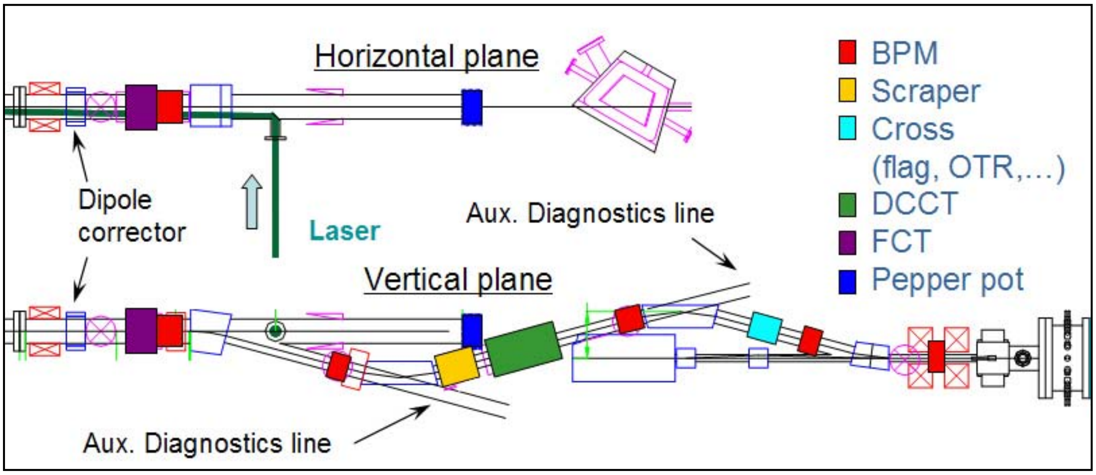

Figure 1: Layout of ERL Injector Diagnostics.

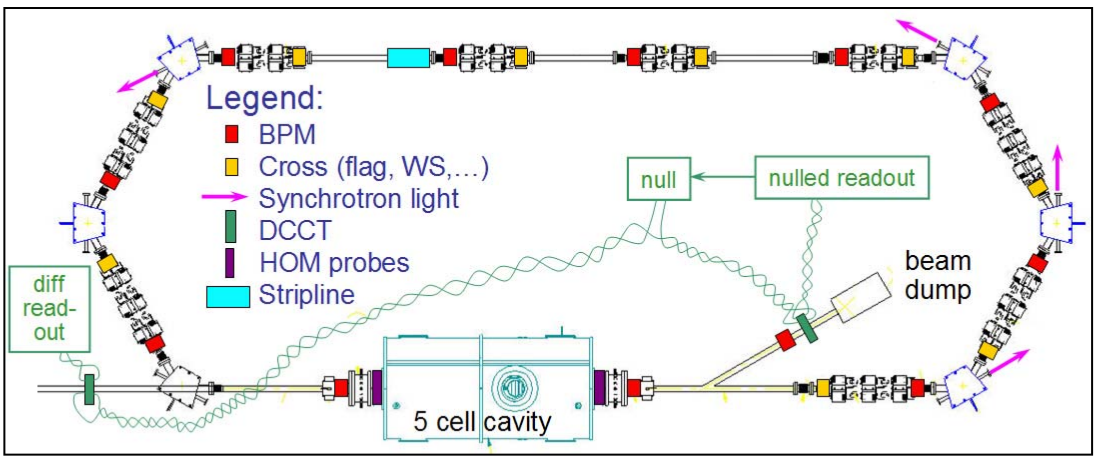

Figure 2: Layout of ERL Recirculation Loop Diagnostics.

CONCLUSIONS

We have presented beam parameters for various beam modes, requirements on measurements capabilities, and briefly described each diagnostics system. Diagnostics described in this paper will allow us to commission the ERL and run it in specified operational modes. It will also allow us to protect the machine from beam losses.

ACKNOWLEDGEMENTS

The authors would like to thank H.C. Hseuh and D. Weiss for designing components of the ERL vacuum chamber and interfacing them to ERL diagnostics. The authors also would like to thank Kin Yip for simulating radiation background produced by beam losses. This work is supported by U.S. DOE under contract No DE-AC02-98CH1-886

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