INSTRUMENTATION DESIGNS FOR BEAM DISTRIBUTION MEASUREMENTS IN THE ERL BEAM DUMP AT BNL *

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Abstract

The R & D Energy Recover LINAC (ERL) at Brookhaven National Laboratory is undergoing continued development in parallel with piece-wise commissioning efforts as installation of each subsystem is completed. While the machine is planned to operate at low intensity with short, low frequency pulses during the commissioning phases, on going design efforts continue to provide a solution to measure the beam distribution inside the high power electron beam dump using several parallel methods. For low power measurements, this includes a new rad-hard version of long 7/8 in. Heliax ion chambers [1,2] that encage the dump both in circular and axial directions. For high power measurements, this includes both "pinhole" like multipoint imaging of the dump with ion chamber beam loss monitors [3] positioned over an array of holes drilled in the shielding around the beam dump as well as an infrared imaging system to peer through an upstream dipole chamber in the extraction line to monitor the temperature distribution on the target surface inside the dump. This paper presents the design details of these three systems that work to ensure the proper distribution of the high power electron beam on the target in an effort to avoid reaching the thermal limit of the water cooled beam dump [4].

INTRODUCTION

The ERL produces an electron beam of short bunches and is designed to operate over a wide range of pulse structures with the ultimate goal of 1MW CW operation. The machine parameters are summarized in Table 1.

Table 1: Machine Parameters

BEAM PARAMETERS	(low charge / high current)
Inj. Energy:	2.0 MeV
Max Energy:	20.0 MeV
Bunch Frequency:	9.383 MHz/ 351, 703 MHz
Bunch Charge:	0.050 – 1.4 nC / 1.4, 0.7 nC
Beam Current:	14 / 500 mA
Bunch Length (rms)	60 – 120 ps / 2 – 40 ps

The ERL has had a long history of R&D efforts at BNL. Its design includes a wide variety of instrumentation [5,6], markedly the three systems described here, to monitor the high power beam dump. Fig. 1 shows the layout and relative size of the machine.

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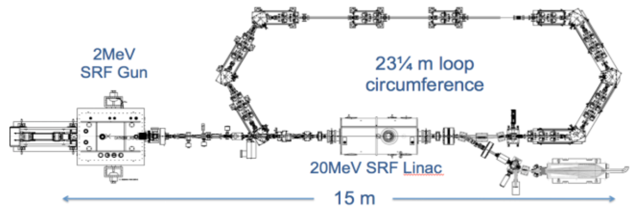

Figure 1: Layout of the ERL.

Electron Beam Distribution

In order to properly fit the beam dump with instrumentation, a simulation of the beam distribution inside the dump was made. Fig. 2 shows the simulated beam function in the X-Z plane. The distribution favors the rear of the dump where most of the energy is deposited on the cone. The predicted beam envelope is outlined in red.

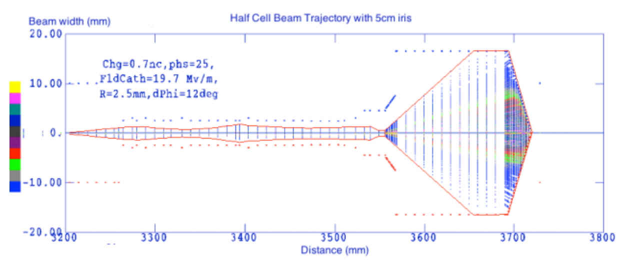

Figure 2: Simulated Beam Trajectory in the extraction line and beam dump.

Beam Dump Design

The design of this water-cooled beam dump is an adaptation of a design for a 1 MW klystron and was built to BNL specifications by CPI, a klystron manufacturer in Palo Alto, CA [7]. Figure 3 shows a drawing of the dump with the beam distribution from Fig. 2 scaled to fit. Before the beam enters the dump it is defocused by a quadrupole to have an opening angle of about 18° and drifts just over a meter before contacting the dump's internal surface. It is important to spread the beam over a large area to distribute the power. The goal of these instrumentation efforts is to continuously confirm an even distribution. When operating at full current, the dump will have to absorb nearly 1 MW of energy from the 2.0 MeV extracted decelerated beam. Simulations predict that when properly defocused, the power density of the absorbed beam will be 600 W/cm^2. However, if the defocusing were lost, a power density of 33 kW/cm^2 would destroy the beam dump. In order to take away the heat, a water jacket is formed around the inner copper dump material that channels cooling water at a flow rate

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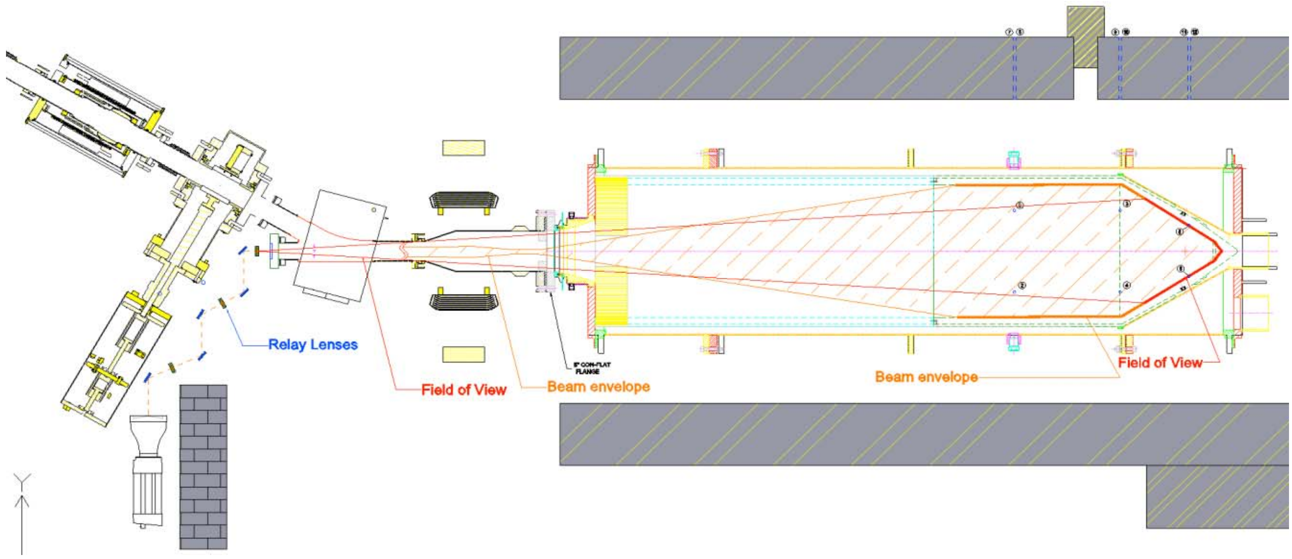

Figure 3: Beam Dump with beam distribution and IR camera field of view.

of 380 gal/min in order to keep the water below its boiling point. The radiation produced during this process is predicted to be 38 Mrad/hr. Although the ERL and beam dump are housed inside a 4 ft. thick concrete blockhouse; additional shielding is required to keep the radiation levels below 0.5 mrem/hr in the controlled area outside the blockhouse. A solid shield made of six inches of steel is placed over the dump like the lid of a butter dish.

LOW POWER BEAM LOSS MEASUREMENTS

As the ERL will be operated in low power for many months of its early commissioning and testing phases, a sensitive beam loss measurement system is installed around the dump under the steel shielding. For this, a matrix of long beam loss monitors (BLM) is created along and encircling the dump to give a cylindrical coordinate system (z,θ) of beam loss intensity. Fig. 4 shows a 3D model of the system layout. These long BLMs are composed of 7/8 in. Heliax cable with specially designed rad-hard fittings on the ends and act as long ion chambers to detect ionizing radiation.

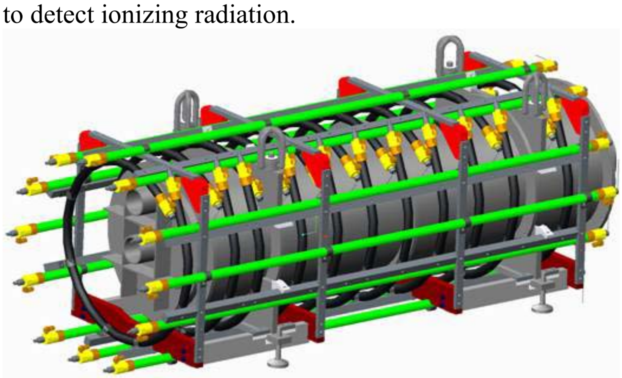

Figure 4: Beam Dump with Heliax BLM matrix.

Heliax BLM System

The Heliax BLM system was chosen for its long track record of beam loss detection in the AGS machine [1,2] at BNL, as well as in the Booster and Slow Extraction Beamlines. Made from 7/8 in. Heliax cable, Andrews [8] model HJ5-50, these BLMs are used as ion chambers to detect ionizing radiation. Argon gas is, either sealed inside, or trickled through the space between the center conductor and the shield in between the spirals of the helical insulating support. A bias voltage of -200V is applied between center conductor and shield and currents are measured in the loop by amplifiers in the bias electronics, located 30m away in the service building.

Here, two sets of 12 BLMs, one at 3.5 m long is installed along side the dump (shown in green in Fig. 4), and the other at 2 m long is bent in a circle and positioned at intervals along the z-axis (shown in black in Fig. 4). This type of BLM exhibits a dynamic range of up to 10^4 (with variable gain electronics) and a sensitivity of ~200 nC/rad/m [13] can be expected with 1 atm of argon. We typically operate near 10 psig of argon, giving a slightly elevated sensitivity.

Although these BLMs will not be used at the full ERL current due to expected saturation, they must withstand the high radiation of the full ERL current without being destroyed. The goal is to reduce the machine current and use these BLMs to map the beam distribution in the dump whenever the distribution comes into question while operating. This requires that all components of these BLMs be rad-hard. Although the center support helix, made of polyethylene (PE), is expected to harden and become inflexible under the effects of the radiation; the shape of the BLM cables is static and does not need to flex. Thus this poses little concern. On the contrary, the connectors that terminate the ends of the cables are typically Andrews model H5PNF, type-N female with a gas barrier to seal the flowing gas. It contains rubber O-

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rings and Teflon insulators. An exploded view is shown in Fig. 5. Here the risk of a leak and HV breakdown are the concerns if the radiation destroys the connector insulators or seals. Table 2 summarizes the radiation sensitivity of the materials of interest [9,10].

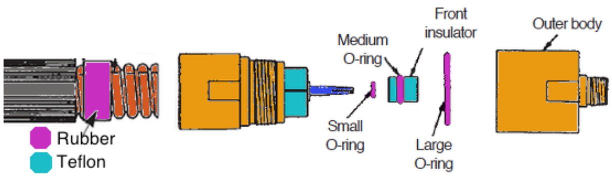

Figure 5: Andrews Heliax H5PNF connector for HJ5-50 Heliax cable.

Radiation Resistance

Efforts were made to develop a rad-hard alternative to the connector. The three rubber seals and the two Teflon insulators in the connector, shown in Fig. 5, had to be eliminated. To eliminate the seal to the corrugated solid shield, a copper body was machined to slip over the shield and joined by soldering. The other two seals that form the N connection to the center conductor were replaced by an off-the-shelf UHV feedthrough with a BNC connector that threads into the copper body and is sealed with Loctite 580 PST nuclear grade pipe sealant (without PTFE).

Table 2: Radiation Tolerance of Materials used

Material	Allowable Gamma Dose [10]
Teflon (PTFE)	0.001 Grad
Rubber (O-rings)	0.1 Grad
PEEK	1.0 Grad [9]
Kapton	>2 Grad

A threaded rod screws into an off-the-shelf banana plug that slides into the hollow center conductor of the Heliax cable. The threaded rod was bored and slit axially to create fingers to grab the electrode on the feedthrough opposite its BNC connector. Fig. 6 shows a cross-section view of the custom connector.

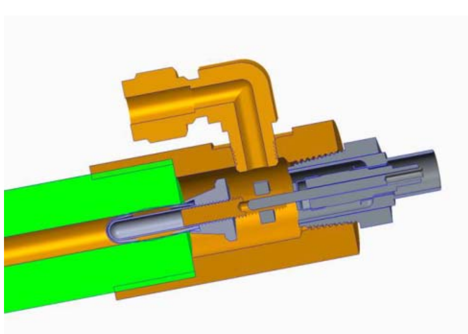

Figure 6: Rad-Hard BNC termination for 7/8 in. Heliax.

The Heliax BLM's are plumbed in series to create a single gas flow circuit. As only one side of the BLM requires electrical connection, the other end is terminated with a simple off-the-shelf copper 1 in. tube adapter & gas tube fitting that is likewise soldered to the copper shield of the Heliax cable.

Rad-hard BNC connectors, Accuglass [11] model 111023, for ultrahigh vacuum with PEEK insulators are used to connect to the Heliax BLMs. These connectors are designed to terminate Kapton coaxial cable, Accuglass model 100720. These cables will carry the signals out of the high radiation area to a patch panel outside of the steel shielding where standard RG58 cables with BNC connectors will make the long run back to the control room.

HIGH POWER BEAM LOSS MEASUREMENTS

Pin-hole Monitors

When operating the ERL at full current, the radiation levels will be their highest at 38 Mrad/hr inside the shielding. To provide a rough map of the beam distribution based on the radiation, ¼ inch "pin-holes" were drilled through the steel shielding for RHIC style BLMs [3] to take a sample of radiation over a small portion of the dump beneath the shield.

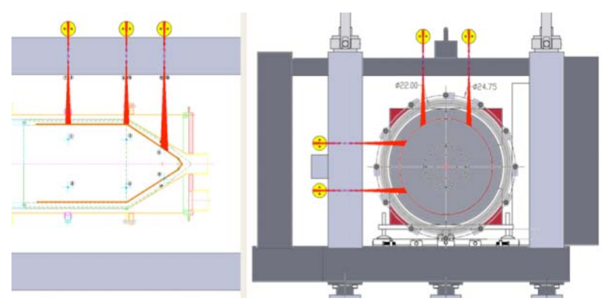

Figure 7: Pinhole radiation measurements: (left) top view, (right) axial view.

A pattern of 6 holes is drilled in the side and top of the "butter-dish" shield. Fig. 7 shows cross-sectional views depicting, in red, the measured areas of the dump.

The RHIC BLM is a "glass bottle" type sealed ionization chamber pressurized to ~1 atm of argon and accompanied by custom VME based amplifier electronics. These have separate connections and cables for their signal & bias voltage of +1400V. These are shown in Fig. 7 as the yellow circles. They benefit from a wider dynamic range than the Heliax BLMs, typically > 10^6, and a sensitivity of about 70 nC/rad [13].

Infrared Imaging of the Dump

Plans are underway to install an infrared camera to image the cone of the dump through an upstream auxiliary viewport in the chamber of the last dipole magnet in the extraction line. The camera is a Flir model A310, with an integrated 25° Germanium lens. It has an uncooled microbolometer sensor with 320 x 240 pixels (25 µm pitch) with a spectral sensitivity over the range of 7 – 13 µm. The viewport is made of ZnSe with a transmission

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spectrum in the range of 0.6 – 16 μm (AR coated for 8 – 12 μm). It is model ZVP38ZNW, made by VG Scienta, with a 38 mm aperture. It is located just over 2m away from the end cone of the dump. The camera was purchased with an add-on 6° Germanium telephoto lens. With the camera located at the viewport, it could image nearly 80 % of the cone's surface. Its view is aperture limited by the downstream flange of the dipole vacuum chamber. This flange could not be enlarged as it would increase the aperture in the lead shield wall planned to limit the radiation to ~2.5 Mrad/hr exiting the dump, back streaming through the extraction line. Due to this high level of radiation, the camera must be moved out of the line of sight of the dump beam aperture and relayed with several mirrors to reduce the total radiation bounce off of the mirror(s). This lengthens the camera's optical path and requires relay lenses to compensate for the increased distance while maintaining the proper field of view. This is shown schematically in Fig. 3 with the "relay lenses" labeled in blue.

Although a location for the camera has been chosen with a place for four turning mirrors and the proper lead shielding, efforts continue to model a proper relay lens system to provide an acceptable limit of distortion. Fig. 8 shows the camera, vertical optics table and four mirrors. The relay lenses and lead shielding are not shown.

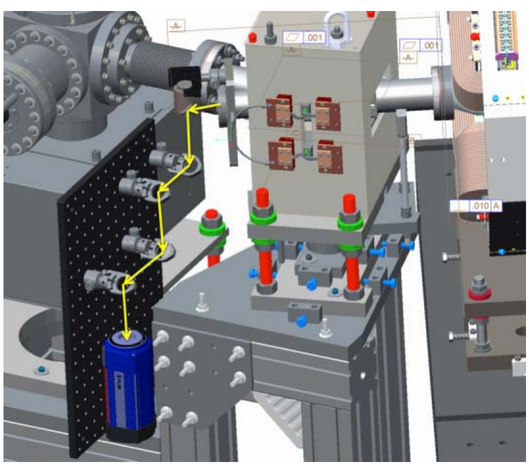

Figure 8: IR camera & turning mirrors (relay lenses not shown).

Optical components made of ZnSe are readily available; although in a diameter of only 1 inch. Preliminary models, with three lenses using the free software Oslo [12], have been made thus far with promising results. Once a satisfactory lens design is achieved, the lenses will located at their proper positions on the vertical optics board in between the four turning mirrors and the camera.

STATUS & FUTURE PLANS

With first beam tests planned for the ERL Gun next month, and low power beam around the loop to follow next year, the dump is expected to see high power beam near mid 2014. The dump is in house and is being assembled with the Heliax BLMs off of the ERL site. It will be lowered into the blockhouse by an overhead building crane and set on its steel support table while encaged by the Heliax BLM assembly. Once the cooling water is plumbed and the BLM signal & HV cables are routed, the steel "butter-dish" shield will be lowered onto the assembly. Then the ion chambers can be mounted over the "pin-holes" in the shield. In parallel to these efforts, the IR optics will be installed on the upstream beam line.

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REFERENCES

[1] E.R Beadle, et al, "The AGS Booster Beam Loss Monitor System", PAC 1991
[2] J. Balsamo, et al, "Long Radiation Detector system for Beam Loss Monitoring" IEEE Transactions on Nuclear Science, vol. NS-24, No. 3, June 1977
[3] R. Witkover, et al, "RHIC Beam Loss monitor System Design", PAC 1997, Vancouver, Canada
[4] A. Hershcovitch, "R&D ERL" Beam Dump", C-A/AP/#378, Upton, NY 2010
[5] D. Gassner, et al, "BNL Energy Recovery Linac Instrumentation", ERL 2011, Tsukuba, Japan
[6] D. Gassner, et al, "Status of the BNL ERL Instrumentation", ERL Workshop 2013, Novosibirsk
[7] Communication & Power Industries, 607 Hansen Way, Palo Alto, CA 94304, www.cpii.com
[8] CommScope, Inc., 1100 CommScope Place SE Hickory, NC 28602, http://www.commscope.com/ catalog/ andrew/product_details.aspx?id=1458
[9] M. Tavlet, et al, "Radiation resistance and other safety aspects of high-performance plastics by ERTA", Workshop on Advanced Materials for High Precision Detectors, CERN 1994, Geneva
[10] M. H. Van de Voorde, "Effects of Radiation on Materials and Components", CERN 70-5, 1970, Geneva
[11] Accu-glass Products, 25047 Anza Drive, Valencia, CA 91355, www.accuglassproducts.com
[12] Optics Software for Layout and Optimization, Lambda Research Corp., 25 Porter Rd. Littleton, MA 01460, http://www.lambdares.com/additional-software/oslo
[13] K. Wittenburg, "Beam Loss Monitors", DESY, Hamburg, Germany, http://cds.cern.ch/record/ 1213279/ files/p249.pdf

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