ION CHAMBERS AND HALO RINGS FOR LOSS DETECTION AT FRIB *

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Abstract

Unlike the high energy proton machines, our radiation transport simulation results show that it will be difficult to use traditional BLMs to detect beam losses for FRIB linac, not only due to the low radiation levels from low energy heavy ion beams, but also resulted by the cross talk effect from one part of the machine to another in the folded machine geometry. A device called “Halo Ring” is introduced as a component of the BLM system to substitute the traditional ion chamber in those regions.

INTRODUCTION

FRIB is based on a three-folded superconducting driver linac as shown in Figure 1. It is designed to accelerate all stable ions with a beam power up to 400 kW and energies above 200 MeV/u. Challenges for the protection of such a machine with traditional BLM include low radiation levels outside the cryomodules and cross talk of radiation from one part of the machine to another due to the parallel geometry. To develop an effective machine protection scheme, we study beam loss and its radiation pattern along the linac.

The primary function of the BLM system is machine protection. In addition, BLM diagnostics can be used for beam tuning. FRIB Machine Protection System (MPS) serves the following main functions: (a) radiation safety and residual activation control; (b) superconducting (SC) RF cavity protection; (c) SC magnet and cavity quench protection; and (d) cryogenic heat load control. It imposes two detection requirements on BLM system:

- The BLM system shall be able to detect slow beam losses as low as 1 W/m. Similar to high-energy proton accelerators [1], recent studies indicated that 1 W/m average uncontrolled beam loss is an appropriate limit for an heavy ion accelerator like FRIB [2]. Accumulation of slow losses at higher level may reduce beam availability and degrade SRF cavity; thus loss mitigation is desired.
- The BLM system shall be able to activate beam abort mode when a fast beam loss occurs. Analysis of beam damage to FRIB linac [3] imposed a limit on the MPS response time of 35 µs. As 10 µs is needed to clear the beam in the linac and 10 µs is allocated for the control system response, the BLM response time should be within 15 µs.

As the first step to understand radiation fluxes due to beam loss, we set up two different geometries with two different computer simulation codes: a homogenous geometry for the PHITS code [4] and cryomodule geometry for GEANT4 [5]. The homogeneous geometry is adopted from shielding calculations, which includes three 150m homogeneous linac segments. The cryomodule geometry consists of two 5m cryomodules with more realistic structures of cavities, vacuum vessels, etc. In following section, we present and compare the radiation transport results from both models.

SIMULATION RESULTS

Comparison of Results from Two Models

Although both of the geometry models used uniform line loss, the setup differs from following aspects:

- For the homogeneous geometry, beam is lost simultaneously in the three parallel linac segments with different energies (17 MeV/u, 150 MeV/u, 200 MeV/u).
- For the cryomodule geometry, beam loss is uniformly distributed over just 10 m. This represents more localized loss.

The radiation dose (rad or Gy) in an ion chamber is evaluated per kilogram of matter and is independent of

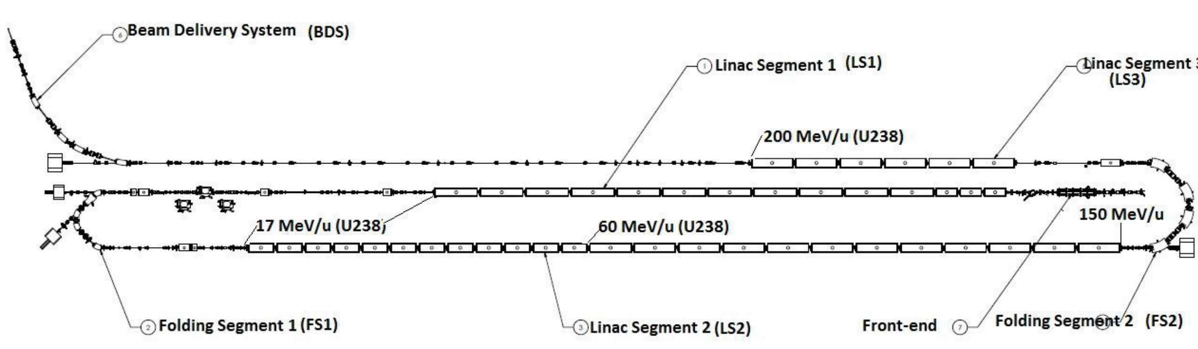

Figure 1: Layout of FRIB driver linac.

* Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661
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the volume of ion chamber.

Due to the parallel geometry, LS3 (200 MeV/u) and LS2 (150 MeV/u) beam losses will produce a large cross talk effect in an ion chamber located under the cryomodule of LS1. This is shown in Figure 2. Only 1.5% of the radiation dose in the LS1 ion chamber is due to LS1 losses. This suggests that the ion chambers at LS1 and FS1 can be blinded and that substitute diagnostics should be considered in these regions.

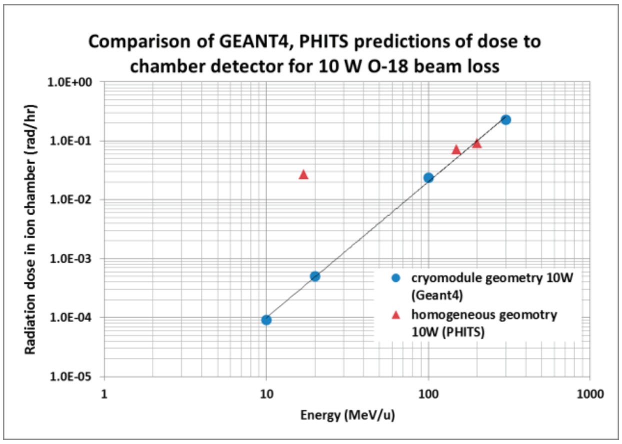

Figure 2: Comparison of radiation dose (rad/hr) simulation with two geometries. The red triangles, in order of LS1, LS2, and LS3, are from homogeneous geometry and are all scaled to the same power of cryomodule geometry (10 W).

Scaling Law for Radiation Dose

Since FRIB linac is designed to accelerate different ion species, it is useful to find scaling laws of radiation for typical ions for a given power loss.

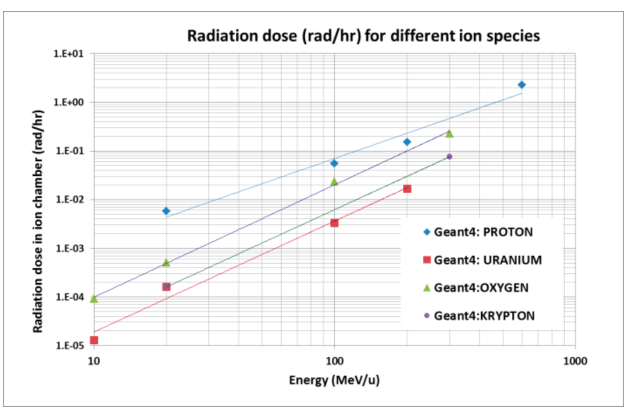

Figure 3: Scaling law for typical ion species for FRIB linac. The dose calculation is based on the 10 W power losses in the Geant4 double cryomodule geometry model.

Figure 3 also gives us an idea of practical scaling from SNS proton beam operating experience. For example, 170 MeV/u oxygen and 350 MeV/u uranium should produce approximately equivalent radiation dose to 100 MeV proton beam.

Estimation of the Cross Talk Effect

The folded parallel lattice structure brings the possibility to blind some FRIB BLMs. Besides LS1 and FS1 as shown in Figure 2, Figure 4 give estimations of the cross talk effect on LS2 BLMs from LS3 radiation produced by uranium beams. The estimations are based on the simple inverse law (1/L) for line loss radiation, where L is the distance between LS2 and LS3.

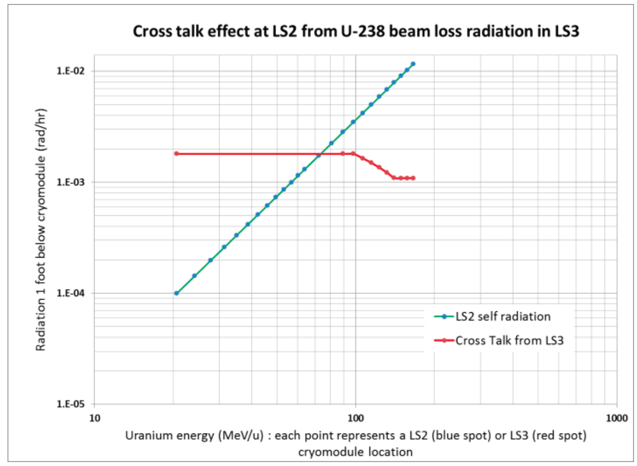

Figure 4: Cross talk effect at LS2 from uranium beam loss radiation in LS3. Green line is the LS2 self - produced radiation obtained by the scaling law. Red line is the LS3 cross talk radiation dose (The flat region represents the beam transport line).

As a result of the cross talk effect, we plan to use the fixed ion chamber only after 60 MeV/u (uranium) as shown in Figure 1. A substitute diagnostics device named “Halo Ring” is proposed in the following section.

HALO RING

The so-called “Halo Ring” has two functions:

- It acts as a loss detector for MPS system. It records a current signal from impacting particles and if that current exceeds a certain threshold, the MPS beam abort mode will be activated.
- It acts as a loss scraper to protect the machine. The penetration depth of 100 MeV/u oxygen is 3.6 mm in niobium. We choose 5 mm as the thickness of the Halo Ring.

The halo scraping is preferred in warm transitions other than cold transitions to avoid immediate contamination and to facilitate maintenance. Particle tracking simulations show that a ring scraper with optimized aperture will effectively scrap the beam losses in warm transition caused by cavity failure, solenoid failure, etc. The simulations give optimized aperture with Ø 20~30 mm at different warm transitions. As a preliminary design, Figure 5 shows the mechanical drawing of an Ø 20 mm Halo Ring. Niobium material is preferred for the ring due to the concern of potential contamination.

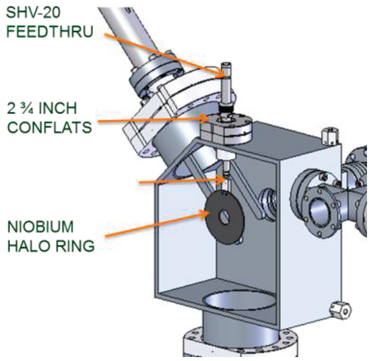

Figure 5: Mechanical drawing of the Halo Ring in the diagnostic box.

The conceptual circuit for the Halo Ring signal is shown in Figure 6.

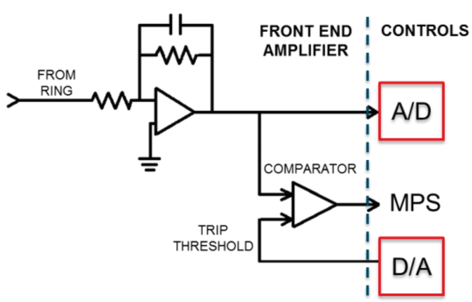

Figure 6 : Conceptual circuit of Halo Ring.

The Halo Ring will also pick up high frequency beam signals (80.5 MHz) when the beam passes through its aperture. A low pass filter is designed to filter out these high frequency signals.

To ensure the capability to filter out induced signals, we use CST Particle Studio [6] to simulate a macro pulse of 100 MeV/u oxygen beam. The induced current from the single pulse is shown in Figure 7.

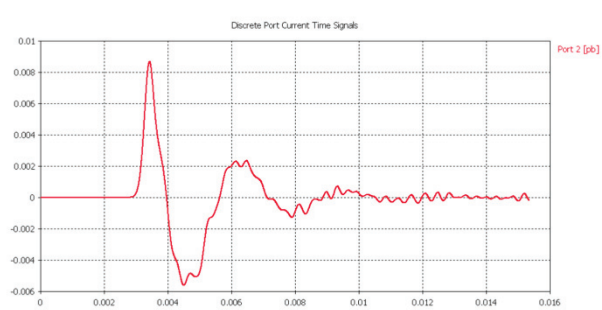

Figure 7 : Induced current signal when a single macro beam pulse (3 deg of 80.5 MHz) passes through the Halo Ring (Ø 20mm). The x axis is time in micro-second and y axis is current in amperes.

As shown in Figure 7, the induced signal damps within 12 ns, less than the gap between pulses (12.54 ns). As a result, two adjacent pulses will not interfere and the charges will not pile up on the electrode.

The Halo Ring detection limit is specified to be 10 nA within an integration time of 10 µs. Particle tracking simulation shows that the current on the Halo Ring due to a cavity failure is ~30 µA, which is easily detected.

Due to practical concerns, an adjustable aperture is preferred for such a device. There are several deign choices for an adjustable aperture: a movable slit with three or four holes in it, a camera-style shutter, etc. Those designs are currently under investigation.

CONCLUSION

Geant4 simulations show that the radiation cross talk effect from LS3 is significant. This leads to the decision to substitute some BLMs with the "Halo Ring" detectors. The current plan is composed of three parts: Halo Rings in warm transitions, several movable BLMs, and traditional ion chamber type BLMs from 60 MeV/u (238U).

The Halo Ring, as an alternative device for traditional ion chamber, will effectively detect and prevent both fast and slow beam losses that an ion chamber cannot effectively detect. At the high energy part (LS3) of FRIB linac, the traditional ion chambers are still used to protect the machine from beam loss damages.

ACKNOWLEDGMENT

The author appreciates A. Zhukov for fruitful discussion on Geant4 model development.

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