PLANED DIAGNOSTICS FOR THE FACILITY FOR RARE ISOTOPE BEAMS AT MICHIGAN STATE UNIVERSITY*

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Abstract

The Facility for Rare Isotope Beams (FRIB) at Michigan State University will utilize a high power, heavy-ion linear accelerator to produce rare isotopes in support of a rich program of fundamental research. The linac will consist of a room temperature-based front-end system producing beams of approximately 0.3MeV per nucleon. Three additional superconducting linac segments will produce beams of >200 MeV/u with a beam power of up to 400 kW. Because of the heavy-ion beam intensities, the required diagnostics will be largely based on non-interceptive approaches. The diagnostics suites that will support commissioning and operation are divided into lower energy <0.3 MeV/u front-end, and higher energy <200 MeV/u driver linac systems. The instruments in the driver linac include strip-line beam position and phase monitors (BPM), toroid beam current monitors (BCM), and 3-D electron scanners to measure rms beam size and emittance to match different linac segments.

SCOPE

A desired availability of >90% and an aggressive commissioning schedule lead to some challenges in beam diagnostics requirements that will be addressed in this paper. We are using common architecture for all main diagnostics and share global machine protection system and timing across the accelerator and experimental systems. We briefly discuss interface control system in this paper.

FRIB FACILITY

Introduction

The FRIB facility will be located on the campus of Michigan State University (MSU). The Facility layout is given in Fig. 1 with a list of diagnostics associated to each section. The technical design and construction specifications were driven by the scientific goals discussed in references [1,2].

The superconducting driver linac accelerator system of the FRIB will be instrumented with non-intercepting diagnostics to guide safe operation and the many inputs to the machine protection system. The driver linac is required to provide cw heavy-ions during operations, but can be commissioned with pulsed-chopped beams in order to permit hands-on maintenance. The beam losses in the driver linac must be less than 1W/m of any heavy ion at 30 cm. Instrumentation for the FRIB is highly challenging at high powers because of two major complications; using a high-performance ECR ion source and simultaneously accelerating a multiple charge-state ion beam with low losses.

1. The acceptable beam loss of 1W/m requires diagnostics capable of detecting unwanted particles both in the transverse and longitudinal plane with a sensitivity of down to 10^3 particles per bunch.
2. The high beam power is destructive to all intercepting devices. As such, we intentionally avoid putting any intercepting diagnostic device in the driver linac.

The first issue is being addressed by developing dedicated diagnostic devices capable of measuring a 10^{-3} un-chopped beam, as well as tails in the transverse distribution (beam halo). The second issue requires beam measurements to be done with a dedicated removable diagnostic beam box (for the `commissioning' or `pilot' beam).

Driver Linac

The driver linac is designed to reliably provide intense stable beams that will be used to produce rare isotope beams for world-class experiments. The FRIB linac accelerating systems are housed in a subterranean structure, while the supporting is housed in a surface structure. The linac is folded in three linac segments and concomitant bending sections.

Front End FRIB Front-end diagnostics can also be divided into two main categories, the diagnostics for the commissioning stage and that required for the standard operations. Output from some diagnostics such as beam current monitors and beam loss monitors shall be divided into two parts. These signals will serve dual purposes of machine protection (MPS) and monitoring diagnostics.
The beam chopper will allow the reduction of the average beam current while keeping the nominal bunch intensity. This functionality is crucial for optimal and safe operational and tuning procedures. Additionally, the chopper can be used to switch off the beam as an element of the machine protection system.

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The chopper will include two electrostatic deflecting plates. The voltage on the plates will be controlled by two fast semiconductor switches with the output matched to the capacitive load of the deflector. A working system at MSU-NSCL is an electrostatic pulse switch PVX-4140 manufactured by Directed Energy Inc. to generate the necessary pulse pattern generator. This commercial unit produces an output of either -3.5 or +3.5 kV with a rise/fall time of 25 nano-sec following the input TTL gate signal. Several of these switches have been successfully operated by NSCL for several years without substantial problems. To use phase information between two or three adjacent beam position monitors to infer beam energy and time of flight, we might need a fast chopper rise time to avoid clearly identifying "a give bunch" phase advance. A basic list of diagnostic elements and their locations was established, and distances between components of the accelerating lattice were chosen not only to satisfy the beam dynamics and engineering considerations mentioned reference (1) but also to accommodate the diagnostic elements.

As an example, the schematic layout of the proposed beam diagnostic elements for the two-ECR Front End is shown in figure 2. Standard beam current transformers will be used to measure the absolute beam intensity. These devices are not only capable of measuring the total beam currents through the front-end linac, but also the part of stripping section efficiency tracking. This requires additional timing signals indicating the sliding time sampling of differential BCMs for the MPS. To measure beam current and split the input signal to the machine protection system, we have chosen Bergoz fast current transformers and Bergoz NPCT (New Parametric Current Transformer) [5]. For the beam current range of 7-700 μA/u, a FCT transformer with 50 turns, providing a trade-off between sensitivity, rise-time and droop. A droop of 0.1%/μs, rise time of <1ns, and sensitivity of 0.5V/A is the target goal. The embedded NPCT made by Bergoz is inside a conflat flange with response DC to 10 kHz and a linearity error of <0.1%.

Driver Linac They meet physics specifications for low average current commissioning and for normal operations a multi-purpose, multi-device beam-boxes are designed (see figure 3). These warm beam boxes are designed to be 38 cm flange to flange and will be installed between cryomodules from segment one to the end of the beam delivery system. As mentioned above, we won't have imperceptible profile monitors in the superconducting linac.

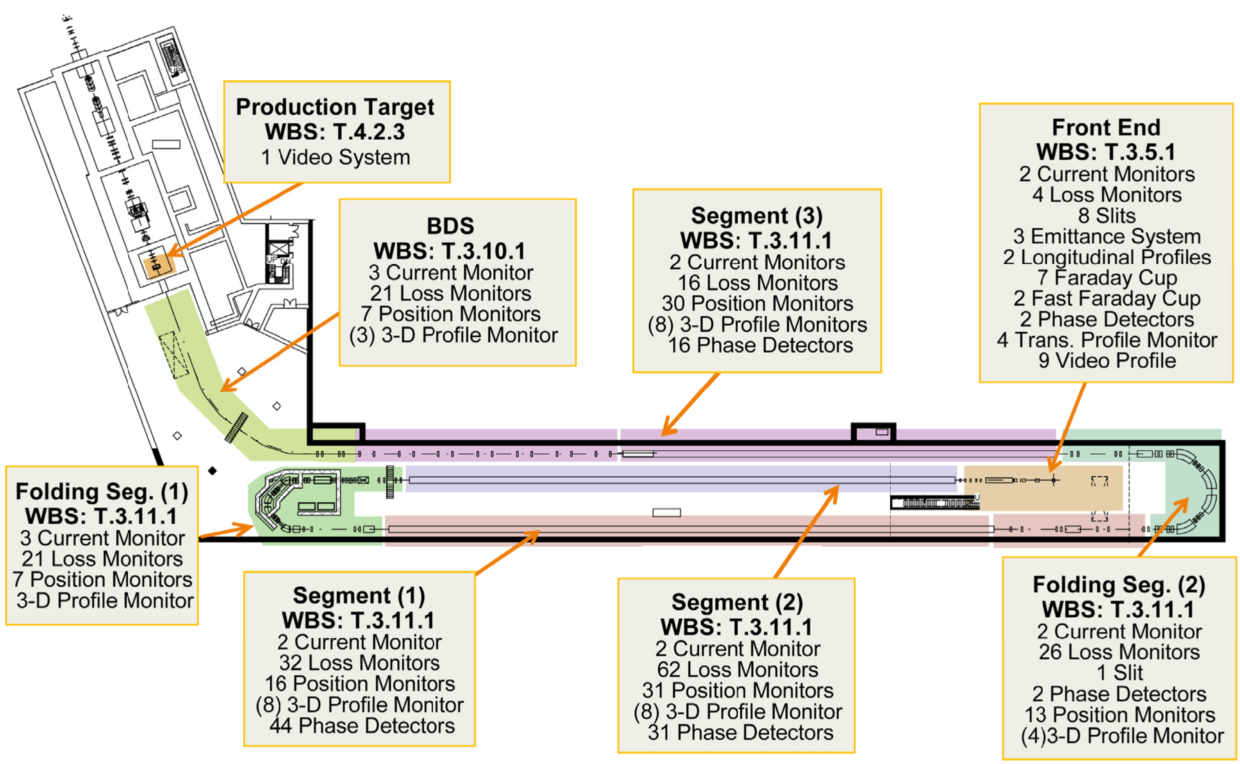

Figure 1: The proposed FRIB facility at MSU shows the diagnostics from the Front End through the superconducting segments 1 to Segment 3. The folding segments have beam dumps to be used for the commissioning and beam tune up as ion species change during operations. Room for the permanent energy measurement stations at the folding sections beyond the start up commissioning are also available. A transport line will deliver the linac beam to the Target where the rare isotope beams will be produced. A video system monitoring properties and beam jitter on target will be the interface separating accelerator beam diagnostics from experimental instruments.

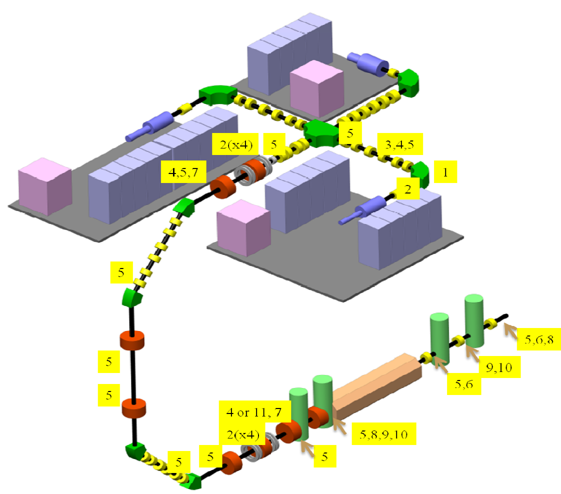

Figure 2: Planned front End diagnostics include insetable profile monitors, scrapers, position monitos, view screens, beam current monitors and emittance devices.

We are planning to install electron scanners as profile measurement devices. The beam position monitor consists of four stripline electrodes connected with low loss cables to a BPM processor. The bunch length in FRIB is comparable to or smaller than the size of the BPM electrodes. The electrode length is set based on a commissioning scenario that relies on a phase and amplitude scan. Simulation shows that the bunch-length on the second BPM, which is located at the output of cryomodule two in the FRIB driver linac, is 30 mm when only one cavity in cryomodule one is on. This is the case during the commissioning of cryomodules one, and while setting the phases and amplitudes of the cavities of the first two cryomodules. Deformation of the signal is minimal during commissioning due to phase scans and low intensities with the proper choice of cabling and electronics. These striplines are well suited for short bunch observation during normal operation. The expected bunch length from simulations during commissioning is about 3-5 centimeters at the first BPM located in the cryomodule one vs. less than 3 cm during normal operation. The slow monitor system currently specifies an ion chamber similar to the FNAL design complemented with an array of scintillating material and fast PMTs to measure low energy neutrons in segment 1 [< 16.9 MeV/u].

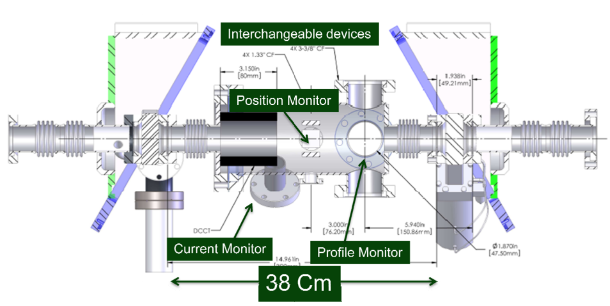

Figure 3: The warm diagnostics beam box can accommodate three devices such as a beam position. monitor, a current monitor and a 2-D profile monitor.

Temporary Diagnostics A movable diagnostics station will be constructed to Commission the FRIB superconducting linac from segment one to the end of the beam delivery system. The conceptual review of this system is complete and the preliminary engineering design is in progress. Nominal devices are to measure transverse and longitudinal beam sizes and a temporary 100 Watt Beam Dump Type of the emittance scanners to measure transverse RMS beam size of multi-charge ions are limited to either the pepper-pot similar to GSI or modify an Alison Scanner designed by SNS Ref. [3-4]. We also plan to install scrapers and a bending magnet prior to the installation of the emittance scanner installation, which identifies the ion species. Once again, to avoid melting the material within a few pulses, the inline chopper will be used to limit the average beam power on insertable diagnostics in the front end. The accelerating frequency of FRIB is 80.5 MHz and the expected bunch length is far shorter than the resolution of beam position monitors. We plan to install fast Faraday Cup with a bandwidth of ~10GHz to measure RMS bunch length.

Driver Linac Diagnostics An ionization profile monitor similar to the one developed for INR will be deployed in designated warm beam boxes between cryomodules. One serious problem must be overcome. The space charge fields of the circulating beam leads to a large energy spread of the collected electrons. Because the microchannel plate has an energy dependent efficiency, this energy spread can lead to distortions of the measured profile. R&D is underway to quantify this effect and to possibly develop alternative detection methods.

FRIB PROJECT

The project has a finished Conceptual Design Report, and has obtained Critical Decision 1. Diagnostics preliminary engineering design has begun. Subject to the availability of funds, the FRIB project could become operational in approximately 2019.

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