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FRIB DRIVER LINAC INTEGRATION TO SUPPORT OPERATIONS AND PROTECT SRF CRYOMODULES*

H. Ao†, K. Elliott, D. Jager, S.-H. Kim, L. Popielarski
Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI, USA

Abstract

The driver linac for the Facility for Rare Isotope Beams (FRIB) at Michigan State University includes 324 superconducting radio-frequency (SRF) cavities, and the SRF particle-free beamline spans approximately 300 meters. Protecting the beamlines against contamination is critical to FRIB operations, and thus, various administrative and engineered and controls have been put in place to protect the SRF cryomodules and beamlines. These controls include local vacuum interlocks for cryomodule isolation, accelerator-wide interlocks, and software controls to safeguard the cryomodules and beamlines. Meanwhile, efforts are being made to provide training and development programs with the goal of preventing critical failures during maintenance. This paper discusses the measures and approaches used for both system integration to support operations and SRF beamline protection.

INTRODUCTION

The Rare Isotope Beams (FRIB) at Michigan State University (MSU) is a scientific user facility for the Office of Nuclear Physics in the U.S. Department of Energy Office of Science (DOE-SC) and will provide access to rare isotopes based on a high-power superconducting linac. The FRIB driver linac will accelerate stable ion beams (from protons to uranium) to > 200 MeV/u, and at continuous wave beam power up to 400 kW. The primary beam is introduced to a rotating carbon target, the produced secondary fragments are separated by the Advanced Rare Isotope Separator, and the selected isotope is transported to experimental vaults (see Fig.1). The FRIB construction was complete, and user operations has begun since May 2022 [1].

Protecting the beamlines against contamination is critical to FRIB operations, and thus, various administrative and engineered controls have been put in place to protect the SRF cryomodules and beamlines. The locations of beamline gate valves and fast acting valves were defined at the early design phase. During the construction we detailed a local vacuum interlock configuration, started a beamline management program and trained employees according to the progress of the FRIB beamline installation. We have also integrated accelerator-wide interlocks and software controls with operational requirements in keeping with beam commissioning and user operations. This paper discusses the above-mentioned measures and approaches used for both system integration to support operations and SRF beamline protection.

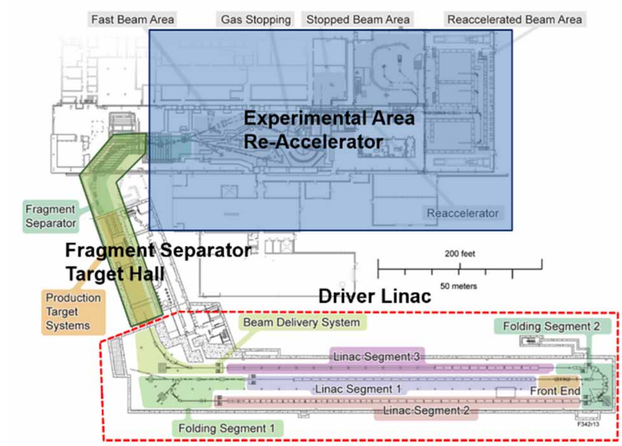

Figure 1: Facility for Rare Isotope Beams at Michigan State University.

ROLES AND RESPONSIBILITIES

In the FRIB laboratory organization, Accelerating Systems Division (ASD) owns and maintains accelerator systems. The ASD Division Director assigns the Segment Manager for each beamline segment (see Fig. 1), and they are responsible for integrated operation. Currently an SRF scientist leads Linac Segments 1, 2 and 3 (LS1, 2, and 3) as the Segment Manager. Two accelerator physics scientists are matrixed and in charge of Front End, Folding Segments 1 and 2 (FS1 and 2), Beam Delivery System taking into preparation for power ramp up.

System Owners and the System Owning Department are assigned to beamline devices. The System Owning Department is responsible to provide operational support. The Linac Vacuum Group within the SRF & Superconducting Magnet Department maintains all the vacuum systems in the driver linac. The group members are experts on SRF particle-free beamline and qualified to operate and maintain all SRF and ultra-high vacuum (UHV) beamlines in the driver linac. Another vacuum group within the Rare Isotope Operations Department separately owns and maintains the beamline vacuum systems downstream in the Target Hall, because the hardware designs and requirements are quite different from the driver linac.

PROTECTION OF SRF CRYOMODULES AND BEAMLINES

Engineered Controls

Cold Cathode Gauges (CCG) monitor vacuum pressures in the cryomodules and the warm boxes. Beamline gate valves are interlocked closed when any CCG reports a pressure higher than 5E-7 Torr by Programmable Logic

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†ao@frib.msu.edu

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Controllers (PLC). Isolation gate valves were programmed to maintain redundant valves around the failure location (see Fig. 2).

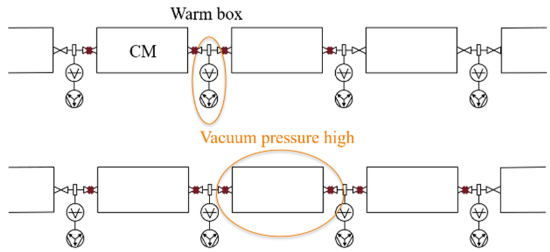

Figure 2: Beamline gate valve interlock with beamline cold cathode gauges.

There are six fast acting valve systems in the driver linac. Fast valves, VAT model 75; 40 mm I.D, located at both ends of LS1, 2, and 3. One fast valve is installed upstream of the FRIB Single Event Effects (FSEE) beamline to protect the driver linac against the failure of the thin vacuum window at the end of the FSEE beamline (see Fig. 3). One fast valve controller operates one or two fast valves and two or three vacuum pressure sensors installed in the beamline. The fast valves can sense and close in < 10 ms. Any one sensor activation trips all fast valves connected to the system. The sensor threshold is set to 1E-5 mbar (7.5E-6 Torr) in operation.

Since fast valves are the primary protection against an air inrush event, we plan to validate the fast valve functions annually during a long maintenance period. The fast valve has a 2000-cycle lifetime before the service, but the validation requires two or three actuations per year and the actuation is quite rare during linac operations. Hence, it still has enough allowable actuation cycles.

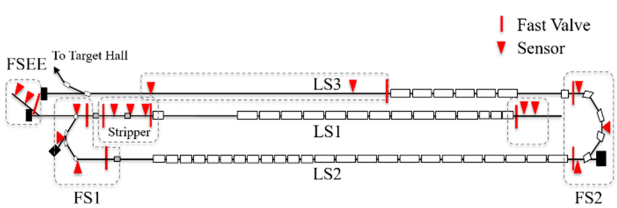

Figure 3: Locations of fast valves and sensors in the FRIB driver linac.

The accelerator-wide interlock, called Beam Inhibit Mode (BIM), is implemented to prevent the high-power primary beam from hitting and damaging beamline gate valves. This PLC-based system is allowing the FRIB operators to select a predefined beam destination from the ion source to the end of the fragment separator (see Fig. 4). The BIM is tied to the Machine Protection System (MPS) and shuts off the beam through the MPS if any gate valve is not at open position along the beamline. The BIM also monitors the devices controlling the beam path and the boundary (e.g. bending magnets, faraday cups) to prevent the beam from going beyond the destination configured by the operators.

The BIM interlocks 'okay' is prerequisites for sending the beam, and thus, adding other preconditions to the BIM can help operators set up the accelerator. For example, we plan to add the degauss completion status of the bending magnet selecting an ion source in the FE area that is required before sending the beam from the second FRIB ion source [2].

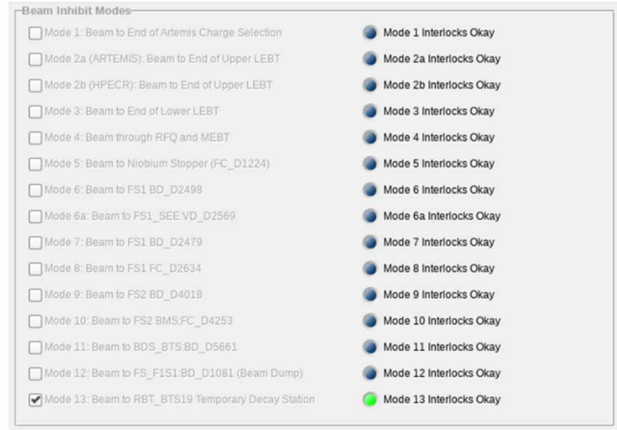

Figure 4: Status screen of Beam Inhibit Mode.

Emergency response is a critical aspect of operations. The laboratory's readiness review program also requires us to implement abnormal/emergency procedures prior to turnover to operations. Thus, the fast shutdown program has been developed and extended to the whole driver linac through the phased beam commissioning [3]. This program shuts off the beam first, followed by turning off ion source, RF cavities, magnets, and closing all beamline gate valves (see Fig. 5). After the shutdown sequence, all cryomodules remain cold, and vacuum pumps keep running. Reference [4] describes the automation of RF and cryomodule operation in detail. This shutdown program is only for emergency situations and not used in normal operations.

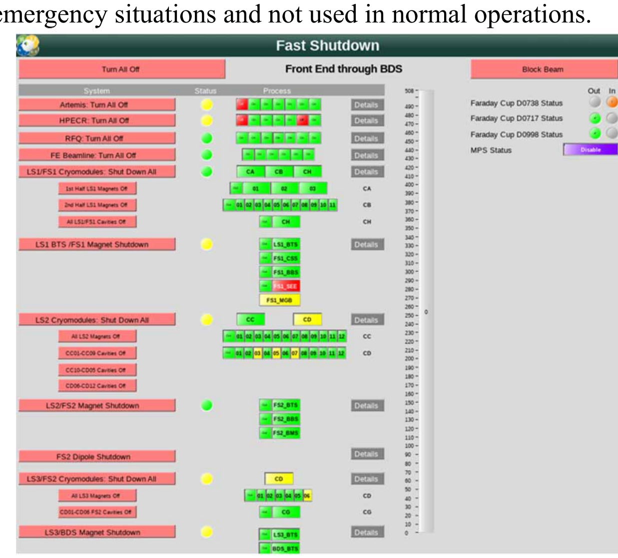

Figure 5: Fast shutdown screen. (This screen is only for emergency situations and not used in normal operations.)

Management Programs and Administrative Controls

The Linac Beamline Management Committee is formed within ASD to lead all efforts to provide training and develop programs with the goal of preventing critical vacuum

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failures during maintenance. The committee includes SRF experts, Segment Managers, and System Owners of the beamline devices. It currently covers the whole FRIB driver linac and a part of the MSU re-accelerator for rare isotope beams, which is also owned by the ASD and includes SRF cryomodules.

The committee started at the beginning of the FRIB construction phase. At that time, many other groups worked around the cryomodules in the linac tunnel, but they were not necessarily familiar with the SRF cryomodules. We limited access around the cryomodules with tape barriers – Beamline Limited Access Area, provided trainings to all employees who needed access inside the barriers, and created a rule that they must wear a pink vest when working in the Beamline Limited Access Area, which allow us to see trained workers at a glance (see Fig. 6).

Figure 6: (Top) White tape barriers around the cryomodules in the Linac Tunnel during the installation. Only trained and authorized workers have access inside the white tape barriers – Beamline Limited Access Area. (Bottom) Workers must wear a pink vest when working in the Limited Access Area.

The Beamline Limited Access Area expanded according to the progress of the beamline installation. Currently, the tape barriers were removed due to starting beam operations, but the concept of the Beamline Limited Access Area still exists, and we continue to train new employees who work around the cryomodules and beamlines. All work that may impact the beamline vacuum space requires a written approval under the linac beamline management program. Some recurring maintenance work (e.g. carbon stripper foil exchange) has been well established and smoothly performed.

Since the actuation of a beamline gate valve is a source of particulates, it has to be optimized between cryomodule protection and potential particle generation, i.e. frequent valve actuation to isolate cryomodules potentially contaminates them instead. Thus, the committee developed the beamline gate valve position for each BIM mode, off shift, and maintenance period and it is configured by the operators. For example, the gate valves upstream and downstream of LS1, 2, 3 are closed during an off-shift period. All cryomodule gate valves are closed during maintenance. The control cables of the gate valves would be disconnected during a long maintenance period as an additional measure.

SUMMARY

This paper described our measures and approaches to protect the SRF cryomodules and beamlines during operation and maintenance. The FRIB driver linac has operated without critical vacuum failures since the initial installation. The breakdown hours of the linac vacuum system were 7.2 hours (2.3% of the total hours) from Oct. 1st, 2022 to Mar. 31st, 2023.

The FRIB facility is in the transition from construction to user operations. We continue to improve the measures and programs based on operational experiences to support stable operations and protect SRF cryomodules.

REFERENCES

[1] J. Wei *et al.*, "FRIB Transition to User Operations, Power Ramp Up, and Upgrade Perspectives" presented at SRF2023, Grand Rapids, MI, USA, Jun. 2023, paper MOIAA01, this conference.

[2] H. Ren *et al.*, "Development and status of the FRIB 28 GHz SC ECRIS," *J. Phys.: Conf. Ser.* vol. 2244, p. 012008, 2021. doi:10.1088/1742-6596/2244/1/012008

[3] H. Ao *et al.*, "FRIB Driver Linac Integration to be Ready for Phased Beam Commissioning," in *Proc. NAPAC2019*, East Lansing, MI, USA, Sep. 2019, pp. 823-826. doi:10.18429/JACoW-NAPAC2019-WEPLH09

[4] S. Zhao *et al.*, "Automation of RF and Cryomodule Operation at FRIB," in *Proc. HIAT2022*, Darmstadt, Germany, Jun.-Jul. 2022, pp. 136-139. doi:10.18429/JACoW-HIAT2022-TH1C3