PLANNED MACHINE PROTECTION SYSTEM 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. Therefore in the event of operating failures, it is extremely important to shut off the beam in a prompt manner to control the beam losses that may damage the accelerator components such as superconducting cavities. Another duty of the Machine Protection System (MPS) is to protect the accelerator against beam losses set by administrative limits to allow hands-on maintenance. FRIB has adapted the residual beam loss activation limit at 30 cm to be equivalent to 1W/m of operating beam losses. We are designing FRIB MPS to be flexible but redundant in safety to accommodate both commissioning and operations. A Machine Protection System protects the accelerator against failure and excessive beam losses; it is also dependent upon the operational mode of the accelerator and the beam dump in use. The operational mode is distributed via a finite state machine to all critical devices that have multiple hardware checkpoints and comparators. It is important to note that FRIB is a cw machine and MPS status is continuously being monitored by "device mode change" and real time data link. In case of a beam abort, the FRIB Machine Protection System will originate a stop-bit to all relevant data acquisition devices to dump the circular buffer data for post mortem analysis. In this paper, we present FRIB Machine Protection architecture, plans and implementation.

SCOPE

Machine Protection Systems (MPS) for high power accelerators have evolved from a collection of individuals' simple self-protecting of independently operated control monitor devices to the modern centralized interconnected circuit logics. The desired result is availability of >90%. Aggressive commissioning schedule lead to additional challenges in MPS requirements that will be addressed in this paper. Machine protection responds to two beam loss scenarios. (a) Fast losses. (b) Slow beam losses due to the drift in beam trajectory as a result of environmental changes to the hardware. Fast losses are mostly due to equipment failures and machine protection is very well defined to respond in that case. For slow beam losses, we rely on experience gained during commissioning to tightly define the minimum and maximum range of drift we can tolerate. Experiences from large accelerators have shown that a machine protection that is user friendly can be the best remedy during commissioning and operation. Additionally, most new systems involve post mortem analysis tools to help sift through Gigabytes of data stored in MPS database loggers, post process and pinpoint the cause of the drifting beam. FRIB MPS will not be the master data logger but the final recipient of post-processed and time stamped database. The data stored in different data loggers; instrument loggers, diagnostic databases and input devices need to continuously pre-processed and time-stamped before becoming part of MPS post mortem data logger. FRIB timing system will be crucial in synchronizing different data acquisition rates, stored data in circular buffers after stop-beam is issued and compensating for the delay of same-kind systems along the accelerator. We will follow expertise and lessened learned from recently commissioned accelerators in designing our software interface to quickly report only on selectable devices that an operator requires. We are using common architecture for all main diagnostics and share global machine protection system and timing across accelerator system and experimental system. 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 with the conceptual design of redundant switch network and data load balancing is given in Fig. 1. The fibber optics connecting network switches will be in star and loop mode distribution. This configuration will allow to reroute heavy demand from one area to another and at the same time will have a backup network in case of damage to one network connection line. The technical design and construction specifications were driven by the scientific goals discussed in reference [1,2].

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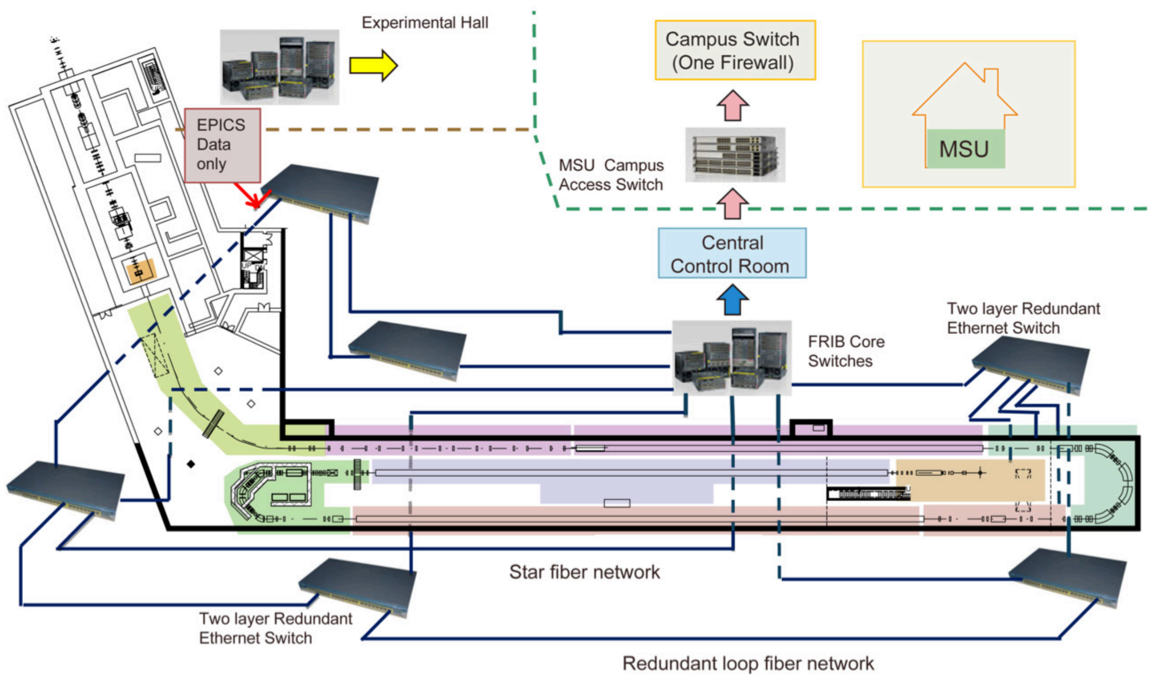

Figure 1: The proposed FRIB facility at MSU showing two layer redundant Ethernet fiber network in star combined with closed loop configuration. This scheme allows data load balancing and protecting the integrity of the machine protection system in case of either damage to a fiber line or one switch failure. 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 an integral part of the machine protection monitoring system.

Protect the Accelerator System

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 machine protection systems roles can be summaries by:

1) Protecting the Machine from beam losses
2) Protecting the cw beam by monitoring finite state status
3) Providing time-stamped correlated evidence
4) High power beam on target jitter and size specification protection
5) Assisting operations

Driver Linac

FRIB machine protection system combines both slow interlocks and fast interlocks to inhibit beam or trigger abort sequences. We envision automatic return to service (normal operation) recovery as a part of BLM diagnostics [3]. BLMS and MPS have to be fully integrated with the global timing system, Control Systems and rf systems as shown to implement auto-sequence and seamless integration of the FRIB loss monitors. Figure 2 shows Beam Loss Monitors (BLMs) block diagram will trip machine operation via fast trip direct analog circuit without software "setting capabilities" combined with slow trends circuit using physics residual activation models and PLC-integrated beam loss electronics. To minimize any EM and RF interference with the BLM-MPS, we will use fiber for any cable travelling outside the local grounding areas. Fiber repeaters will be part of the fanout units connecting all BLM-MPS chassis.

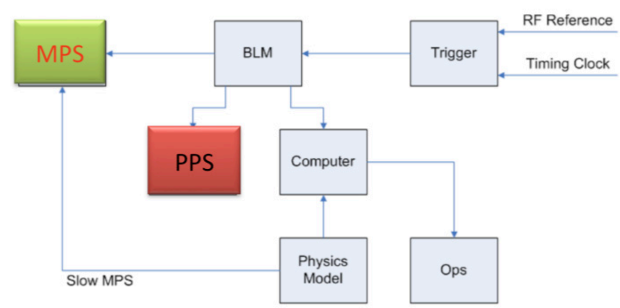

Figure 2: The block diagram of beam loss monitor system connectivity to machine protection, personnel protection and providing information to tune the accelerator.

EXAMPLE OF MACHINE PROTECTION SYSTEM DUTIES

FRIB driver linac is designed to run in cw but it is possible to chop the beam using front-end electrostatic chopper to reduce the power or only to inject short burst of ions into the driver linac. These possibilities are called "beam modes" in FRIB control system. Mode masking, single shot, or short chopped pulses may be required during the commissioning and startup of the FRIB. BLM-MPS can be masked for these special occasions to allow insertion of intrusive diagnostics or pilot beams. Pilot beams will also be used after machine downtimes, see Fig. 3.

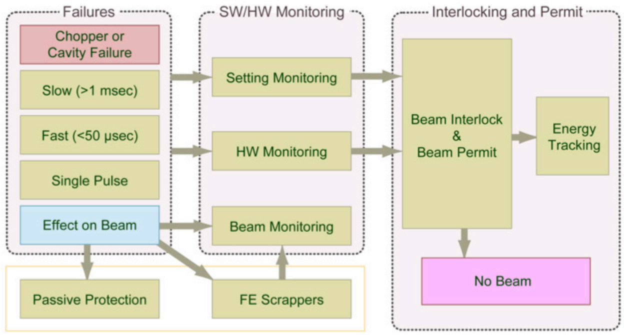

Figure 3: Show for varying pulse length, beam modes are defined. Hardware and software monitoring, setting and beam permit relations can subsequently allow or prevent beam injection as state changes.

After proper beam transport is verified, the beam mode is changed and masks are removed. The configuration file resides in the database, which defines default masks based on the device type. For instance Faraday cups are only allowed in the beam if the pulse width is less than 50 μsec (Fig. 4). Beam is also shut off to protect the Faraday cups if the front-end chopper pattern generator is not working or high voltage to them is set incorrectly. This added protection is to assure the loss fault detection of BLM-MPS has a redundant system at low energies.

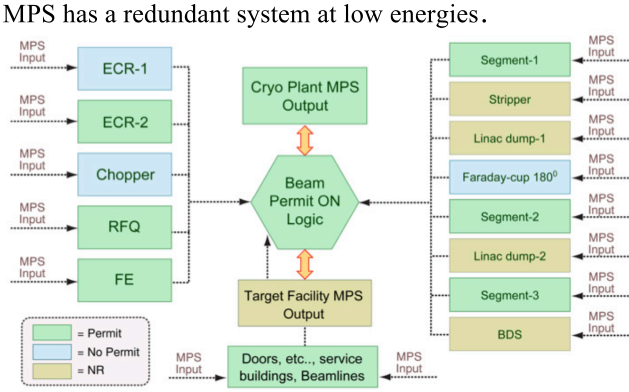

Figure 4: Show the insertion of Faraday Cup will limit the beam power and subsequently the pulse length needs to be adjusted to allow the beam permit be given by the Machine Protection System.

OPERATION ASSISTANCE

There will be four events associated with fault events. These events will be broadcasted by the timing system and all BLM-MPS systems listen to and respond to them per pre-defined algorithm. One is fast protection system. This event will trip the machine in 10 msec. The second is diagnostic event to collect data from all loss monitors IOCs. This event stops triggers to BLM IOCs, downloads all data and reset a bit that data transfer has taken place with timestamp. Third is fast protecting auto-rest trigger. This trigger will automatically reset for a pre-defined number of times before latching takes place. Circulating buffers won't stop but a counter in the BLM IOC will keep track of the number of bit flips/triggers. If the number of fast-protect-auto-triggers is greater than the defined maximum, an operator has to reset the beam switch. This process will dump the circulating BLM buffered data to the server for the future post mortem investigation. Lastly is on-demand trigger. This trigger clears the buffer and starts taking data for a number of super-cycles and stops the trigger to dump the data. The main use is to investigate BLM waveforms. High-level applications are needed to absorb this data and present it to operations in a reasonable fashion. Finally, the relation of all devices that have input and output to the machine protection system is shown in Fig.5.

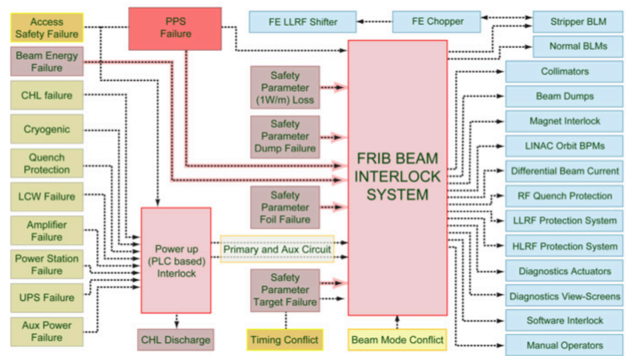

Figure 5: Show the conceptual design of input/output relations of all devices that connect to the machine protection systems in conjunction with the supervisory systems and configuration control system inputs.

SUMMARY

The project has finished Conceptual Design Report and obtained Critical Decision 1 in 2010. Global timing system and Machine Protection System preliminary design has begun and is on schedule. Interface control definitions and specifications are under discussion. FRIB project and MPS are due to become operational in approximately 2019.

REFERENCES

[1] X. Wu et al, "The Overview of the Accelerator System for the Facility for Rare Isotope Beams at Michigan State University", in these proceedings.
[2] R. York, et al, "Status and Plans for the Facility for Rare Isotope Beams at Michigan State University", in these proceedings.
[3] S. Assadi et al.," Planned Diagnostics System for the Facility for Rare Isotope Beams at Michigan State University", in these proceedings.