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SOFTWARE AND FIRMWARE-LOGIC DESIGN FOR THE PIP-II MACHINE PROTECTION SYSTEM MODE AND CONFIGURATION CONTROL AT FERMILAB*

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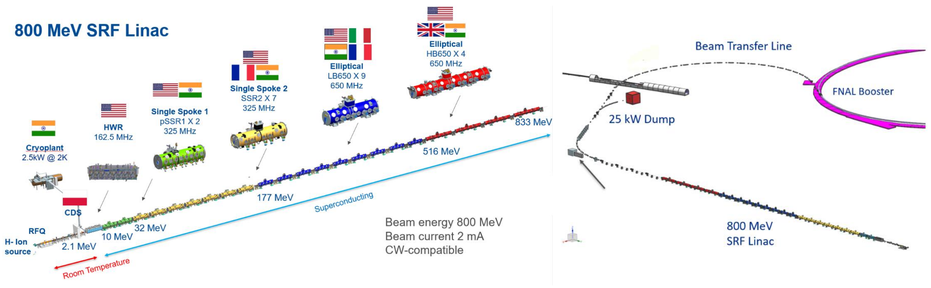
Abstract

The PIP-II Machine Protection System (MPS) requires a dedicated set of tools for configuration control and management of the machine modes and beam modes of the accelerator. The protection system reacts to signals from various elements of the machine according to rules established in a setup database in the form of a Look-Up-Table filtered by the program Mode Controller. This is achieved in accordance with commands from the operator and governed by the firmware logic of the MPS. This paper describes the architecture, firmware logic, and implementation of the program mode controller.

Introduction



PIP-II is the world's highest energy and highest power CW proton linac and first US accelerator project to be built with major international contributions

Figure 1 : Machine Layout of PIP II

The Proton Improvement Plan-II (PIP-II) is an enhancement to the Fermilab accelerator complex [1] that will provide intense high energy neutrino beam to the Deep Underground Neutrino Experiment (DUNE) [2]. PIP-II will consist of a 800 MeV H- Superconducting linac which includes a Warm Front-end (WFE), and a 300-meter-long beam transfer line to the Fermilab Booster. The WFE of the linac plays a critical role in the accelerator. It generates a 30 KeV H- beam, defines the beam parameters, accelerates the beam to an energy of 2.1 MeV with its RFQ for compatibility with downstream accelerating structures, and generates a required bunch pattern. One of the high-level goals of the machine is to deliver a proton beam power to target in excess of 1 MW with sustained high reliability along with multiuser operations of the Fermilab complex

Figure 2 : PIP II Cryo-Plant and Gallery

Protection System Overview

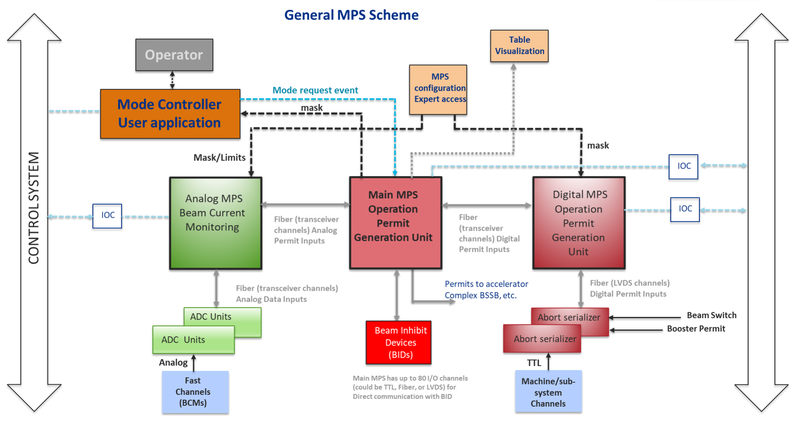


Figure 3 : MPS Architecture

The MPS is FPGA based and consists of a Main MPS (MPSM) which issues the system permits and interfaces with the BIDs, an Analog MPS (MPSA) for post-processing of digitized signals derived from certain beam current measuring devices and a Digital MPS (MPSD) which processes serialized inputs from machine subsystems coming from the field via serializer hardware.

There are four beam inhibit devices (BIDs) in the accelerator located in the Ion Source (IS) and the LEBT Figure 4. There are the LEBT chopper, the Modulator Extractor, the IS High Voltage Supply (ISHV), and the LEBT Dipole. These are divided into two tiers, BID-1 and BID-2. These two tiers are used to prioritize and classify certain types of faults and provide some automatic recovery for system faults such as rf interruptions.

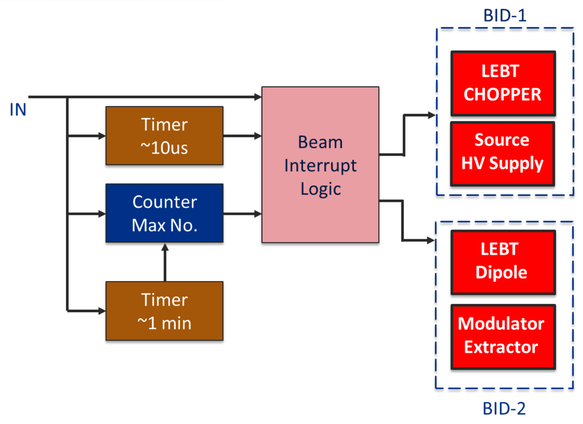


Figure 4: Primary and Secondary Device Diagram

MPS User Interface

The user interface under development for the MPS will allow operators and domain experts to interact with the MPS via a set of applications. These applications include Phoebus displays for viewing faults, java application for configuration control and flutter applications for post-mortem analysis.

The underlying controls framework is EPICS with IOCs handling the readback and control of the MPS FPGA boards. Additionally, a middle tier is being used which consists of a set of services called Data Pool Managers (DPM). These services interact not only with the EPICS IOCs, but also with legacy front ends. Also, these services provide interfaces to Java, Python and Web frameworks being used by several of the user interface applications.

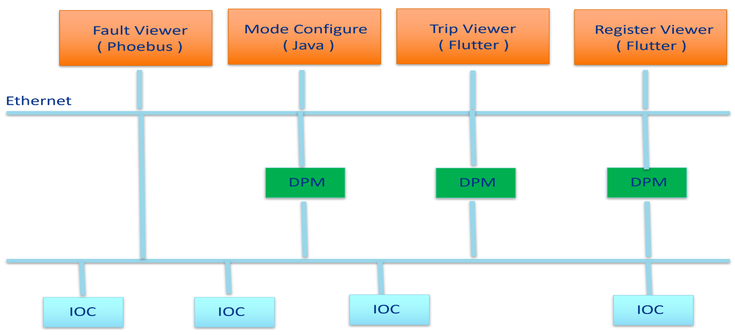


Figure 5 : Control System Overview

Hierarchical Fault Viewer

One of the main MPS applications is the Fault Viewer Phoebus display. This display provides users with operator and expert views of faults. This view provides some coarse granularity in identifying faulted channels and tripped BIDs. The user can then drill down to a specific BID to view the channels that are producing a fault.

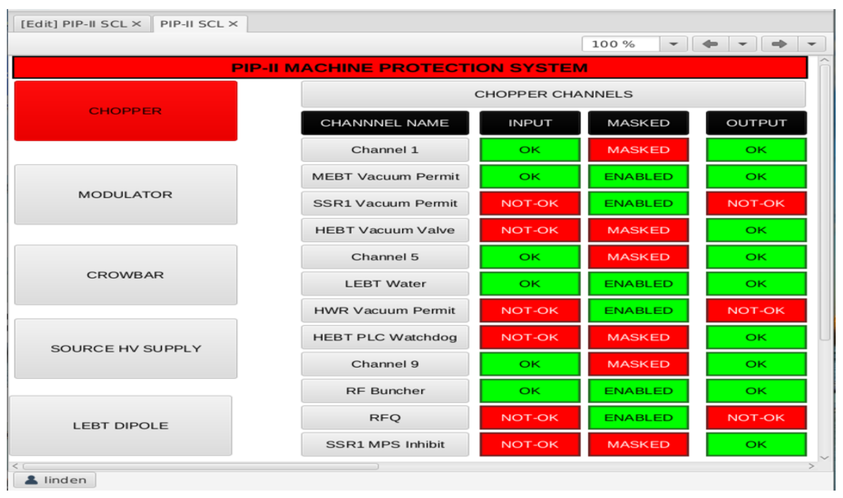


Figure 6 : Fault Viewer (Phoebus)

Post-Mortem Analysis

Post-mortem analysis is a key component of the MPS workflow. The Trip viewer flutter app displays the channels logged per trip . Users can trace the first faulted channel and any other channels which are faulted. The Register viewer flutter app provides users with a snapshot of the MPS FPGA registers. Trip and register information is logged and retrieved via the apps to view trends.

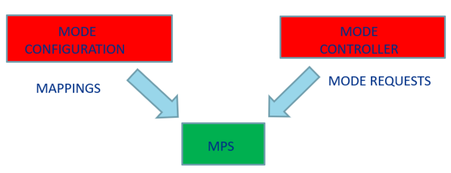
Figure 7 :MPS Post-Mortem Analysis

Mode Configuration and Control

A distinct group of channels is monitored to generate a permit for each BID. The decision to monitor a channel can change depending on the beam type and path of the beam. A set of Beam modes and Machine modes were defined that capture this dependency.

BEAM MODE	DEFINITION
Mode 1	DIAGNOSTICS LOW DUTY
Mode 2	DIAGNOSTICS
Mode 3	LONG PULSE LOW DUTY
Mode 4	OPERATIONAL

MACHINE MODE	DEFINITION
Mode 1	LEBT
Mode 2	MEBT
Mode 3	SSR1
Mode 4	SSR2
Mode 5	FULL LINAC
Mode 6	BEAM TO BTL ABSORBER
Mode 7	BEAM TO BOOSTER



ID	CHANNEL	PANEL	POLARITY	TYPE	ENABLED
1	LEBT VACUUM	C3L	NORMAL	STATUS	YES
2	MEBT VACUUM	B3	NORMAL	STATUS	YES
3	SSR1 VACUUM	A3	NORMAL	STATUS	YES
4	HEBT VACUUM	A2	INVERTED	STATUS	NO

Figure 8 : MPS Beam and Machine Modes

The Mode Configuration Application is a java application interfaced to the Data Pool Manager middleware developed at Fermilab. This application allows experts to save mappings between modes and MPS parameters (masks, limits) on the MPS

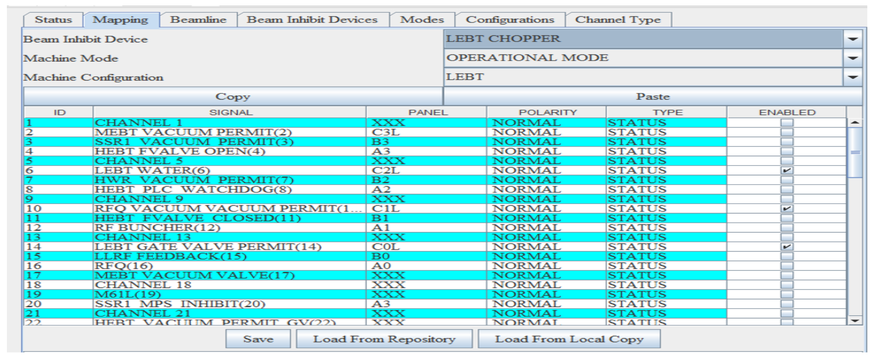


Figure 9 : Mode Configuration Application

The mode Controller Application is a Phoebus display which allows operators to send a mode change request to the MPS which will then switch to the desired masks and limits.

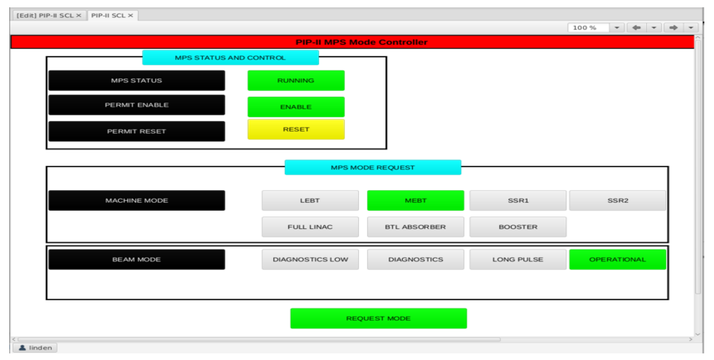


Figure 10 : Mode Controller Display

Summary

A MPS for the PIP-II machine is being developed. In addition to studying various schemes to protect the machine in the LEBT and MEBT where the damage potential is at its minimum, a user interface is being designed which will leverage the power of EPICS and web frameworks.

References

[1] "The Proton Improvement Plan-II (PIP-II) Final Design Report", 2021 (unpublished).
[2] Fermilab, https://lbnf-dune.fnal.gov

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