PIP2IT - MPS Summary

Arden Warner on behalf of MPS team
PIP2IT Retreat
May 6th, 2021

A Partnership of:
US/DOE
India/DAE
Italy/INFN
UK/UKRI-STFC
France/CEA, CNRS/IN2P3
Poland/WUST
Acknowledgements

• Contributors to MPS development:
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  J. Wu (PPD)
Outline

Design Elements of MPS - Architecture

• Interaction with Beam Inhibit Devices (BIDs) – Logic, Firmware, Reaction time, etc.
• Beam mode controller
• Beam current and beam loss monitoring – Key element of fast protection scheme
• System interrupts and verification process - System Redundancies
• MPS configuration control – Machine segmentation
• Summary of Path Forward – Some suggestions
All three layers of MPS were tested

- Machine inputs - low level signals from various subsystems and drive permits to beam enabling devices
  - Some system inputs should not be summed if they distribution affect machine configurations (e.g. bunchers)
  - Insertion device position monitoring algorithms worked
  - Differential beam current losses (RPUs, ACCTs) ~ 3% resolution measured but can be improved

- Logic layer
  - Run Permit System worked well but we found one instants where a previously summed input from RFPI was not included after an upgrade. This was caught by operator via interface programs and was corrected
  - Fast Shut down achieved < 1 µs
  - Controls Interface included some startup protection schemes, Controls dependent but more of this is needed going forward as addition layer of protection
PIP2IT High Level Block Diagram

Beam Inhibit Devices

Sensing Devices (Inputs)
Beam Inhibiting Devices (BIDs) arranged into 2 tiers was useful for configuration and mode control development

- Tier 1: LEBT Chopper (Primary BID) performed adequately and added a layer of redundancy
- Tier 2: IS Modulator, LEBT Bend, IS HV
- Decision to remove source HV in response to MPS trips was initially historical, then cautionary and finally unnecessarily annoying operationally. Firmware changes were made but also required a ladder logic (PLC) change which we decided not to pursue.

Input signal interface

- Input signal interface needs to be expanded and standardized
- Test were done with an upgraded option in the form of Abort concentrators units (more on this in summary and path forward)
Fast Beam Interrupts - LEBT Chopper / MPS connection

- Fast interrupts where driven by serial communication between the LEBT chopper and the MPS – This implementation worked well
  - Four signals between chopper driver and MPS
  - Chopper is a normally on device – fail safe design. This works well to add redundancy and robustness to MPS and concept should be implemented going forward

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description / Comments</th>
<th>Signal Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode (Input)</td>
<td>Mode setting command received from the MPS</td>
<td>TTL 50 Ohm term., TTL Serial</td>
</tr>
<tr>
<td>Mode (Output)</td>
<td>Acknowledgement signal sent back to the MPS</td>
<td>TTL, 50 Ohm drive, TTL Serial</td>
</tr>
<tr>
<td>Permit (input)</td>
<td>Logic level high enables &amp; low-level disables beam transmission</td>
<td>TTL 50 Ohm term, 5 MHz AC</td>
</tr>
<tr>
<td>HV_DC_OK (output)</td>
<td>Indicates high voltage integrity, Indication that -5 kV DC PS is greater than -5 kV, rear panel.</td>
<td>TTL, 50 Ohm driver, 5 MHz AC</td>
</tr>
</tbody>
</table>

MPS mode value is a single byte TTL protocol -9600 baud

G. Saewert’s design
MPS High-Level Functional Requirements were Achieved

High-Level Functional Requirements:

• Manage and monitor beam pulse width and set the limits of various MPS-designated devices - within jitter specification < 1 µs
• Beam Mode and Machine Configurations were define and achieved
• Provided post-mortem data to the control system upon detected loss of an MPS permit - future applications will require more subsystem input data
  – Several fast trips were detected in the system and it was not always which channel of the subsystem caused it
• A comprehensive overview of the machine state, readiness and permit status was provided
• Transitions between configurations ran smoothly with design method
• MPS-related trips/alarms where generally managed and displayed – post mortem tool development can be improved
Three machine configurations

- Defined the portion of the beam line where the beam can go using existing scraper instrumentation
  - Dedicated segmentation hardware would be preferable (e.g. faraday cup) but limited space
- Configurations defined which input channels in the MPS were active – worked but required interaction via multiple software applications – integration needed for future implementation
- More operator flexibility was required for some specific MPS channels – specifically those channel not directly related to protection scheme in a given configuration/mode

### Machine Configurations and Segmentation

**3 machine configurations:**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Purpose</th>
<th>Beam can propagate no further than</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEBT</td>
<td>Ion source and LEBT tuning</td>
<td>LEBT scraper</td>
</tr>
<tr>
<td>MEBT</td>
<td>MEBT tuning; absorber conditioning</td>
<td>Scraper M62</td>
</tr>
<tr>
<td>Full line</td>
<td>Normal, full machine operation</td>
<td>Full line to beam dump</td>
</tr>
</tbody>
</table>
Beam Modes where defined and implemented

• Beam modes characterized the machine’s state
  – A control program worked well to transition between modes and establish readiness to start the beam (mode controller) – this required interplay with machine sequencers and in the future these can be combined to avoid complexity
  – In each configuration, the machine had to 4 beam modes – operationally only 2 modes where active for PIP2IT commissioning but will be different for PIP-II

• The mode controller program provide machine state to other subsystems

<table>
<thead>
<tr>
<th>Beam mode</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Off</td>
<td>Default mode while starting or the last mode when shutting down.</td>
</tr>
<tr>
<td>No Beam</td>
<td>Default mode for full beam interruptions.</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>Beam operation with short pulses. Pulse length and repetition rate may vary depending on what instrumentation is inserted.</td>
</tr>
<tr>
<td>Operational</td>
<td>Beam operation with average current up to maximum. Insertion devices (apart from the MEBT scrapers) cannot be moved from their ‘parked’ position.</td>
</tr>
</tbody>
</table>
MODE control applications developed

- Mode controller proved useful but the interplay with machine operational setup and configuration requirements were evolving.
- A single dedicated program with the prescribed requirements should have been developed earlier but MPS firmware was also evolving.
Validating & Commissioning PIP2IT MPS – Diagnostic mode

- **LEBT – 30 KeV**
  - MPS Low energy Check
    - ✓ System input polarities
    - ✓ System logic
    - ✓ Permit verification
    - ✓ Interaction signals
    - ✓ 30 KeV test
  - Beam Inhibit Devices/sources (BIDs)
    - ✓ LEBT Dipole
    - ✓ LEBT Chopper (for beam)
    - ✓ Source Modulator
    - ✓ SHV Supply
    - ✓ SHV Crowbar
    - ✓ MPS Limits (comparator)

- **MEBT – 2.1 MeV**
  - MPS Medium energy Check
    - ✓ System input polarities
    - ✓ System logic
    - ✓ Timing verification
    - ✓ Permit verification
    - ✓ Interaction signals
    - ✓ 2.1 MeV test
    - ✓ System input expansion
  - Required Instrumentation/systems
    - ✓ RPUs
    - ✓ Scrapers
    - ✓ PECI
    - ✓ sCVD
    - ✓ Mode Control Software
    - ✓ Response and Verification
    - ✓ Movable device interface
  - Beam Inhibit Devices/sources (BIDs)
    - ✓ LEBT BIDs
    - ❑ LEBT scraper position

- **Cryo**
  - MPS High energy Check
    - ✓ System input polarities
    - ✓ System logic
    - ✓ Permit verification
    - ✓ Interaction signals
    - ✓ 22 MeV test
    - ✓ System input expansion
  - Required Instrumentation/systems
    - ✓ ACCTs
    - ✓ DBCM – Fast DAQ
    - ✓ Beam Inhibit Devices/Sources (BIDs)
    - ✓ DBCM

- **HEBT – 22 MeV**
  - MPS High energy Check
    - ✓ System input polarities
    - ✓ System logic
    - ✓ Permit verification
    - ✓ Interaction signals
    - ✓ 22 MeV test
    - ✓ System input expansion
  - Required Instrumentation/systems
    - ✓ ACCTs
    - ✓ DBCM – Fast DAQ
    - ✓ Beam Inhibit Devices/Sources (BIDs)
    - ✓ DBCM
MPS Beam Commissioning Approach

- Beam intensity (pulse length) is gradually increased as system functions are verified
- Stage 1: Max. pulse length is 10 us, 20 Hz, 2 mA
  - Safe beam even if completely lost
  - Validate instrumentation and MPS response
- Stage 2: Max. pulse length is 100 us, 20 Hz, 2 mA
  - Pulse length gradually increased from 10 us to 100 us
  - Validate functions of MPS and other hardware
- Stage 3: Max. pulse length is 550 us, 20 Hz, 2 mA
  - Pulse length gradually increased from 10 us to 100 us
  - Validate functions of MPS and other hardware
- Max. pulse length is limited by MPS
Configuration Control lessons

• Configuration control required more development time. It was difficult to design around the evolving machine and also incorporate the nuance of all subsystems.

• Remote development of the tools was also challenging.

System validation and redundancy needs to be built into MPS at two levels whenever possible for critical channels (firmware/hardware and software layer). This would have reduced or avoided system configuration issue April 11th.
Beam Loss Algorithms successfully implemented

- Integration algorithm applied to all beam current reading devices in the machine
  - LEBT and MEBT scrapers – sub µs response times
  - Kicker Protection Mask (PECI) – proper tripping observed down to 6 µA
- Differential Pumping Port
- Ring pickups – Integration improves stability of loss detection by decreasing the sensitivity to measurement noise which defines the minimum achievable loss threshold

- Differential Beam Current Monitor (DBCM) Algorithm for Cryomodule Protection implemented and tested – better than ~3% resolution observed and can be improved (with noise reduction and calibration improvements)
Low Energy loss monitor tested

- 20- micron Single crystal diamond structure tested at 2.1 MeV
  - A clear loss signal well correlated with beam intensity and position was detected
  - Charge pileup avoided in this setup (thin detector is below the Bragg Peak) Penetration depth for 2.1 Mev protons is > 20µm
  - Charge deposition ~ 35.3 fC
Low Energy Loss Monitor

- Signal Processing required for further MPS application
  - A counting or integrator algorithm can be used for future
  - Enough information obtained to make application design decisions
Potential application - Diamond Detector

SCVD loss/halo/current monitor features specifications.
- 20-micron thickness to avoid charge pile-up
- Full RF shielding
- Customizable so edge of crystal can be close to beam
- Open design detector
- Choose sensors sized to capable to measure current
- 2 GHz, 40 dB broadband Amplifier
- 50 Ohm impedance – can use any length of cable

Kyle Kendziora design

Sensor’s edge
MPS Movable Device Interface

• The MPS movable device interface worked but took some time to implement and integrate into the MPS – I think this is more of a standardization issue with multiple system and segmented interfaces.
  – Serial communication of device position – ok
  – Linear potentiometers on movable devices would be useful for future.
  – MPS side - Some issue with initial conditions, and positions eventually were solve by setting hard limit registers in FPGA.
Modern Interfaces (Rich Neswold & Beau Harrison)

- Part of the lab’s modernization effort is re-imagining our control system interface
- Controls Department is currently investigating web tech
- Current efforts allow rich visualizations which also work on mobile devices.
- Time permitting, we want the MPS application to use these techniques so it’s easy to use, yet informative.
MPS Fast DAQ development

- Firmware Algorithms needed for DAQ system have been tested and is transferable
- Communication protocols tested on two digitizer platforms and decision made to support PIP2IT commissioning goals – hardware delays and shorten time schedule, hampered development time but we have enough information to make technical decisions
- Need to include debugging and development time in addition to test bench
- Some design decisions are being formalized
Summary of Changes Based on Results of PIP2IT Tests

- Consider adding redundancy to the FPGA-based solutions to avoid single-event upset and to assist with configuration comparisons etc. Increased reliability
- Plan to standardize the signal input interface with concentrator units that are already designed in house and use in the accelerator complex this worked well to concentrate some signals at PIP2IT
- Implement loss monitor thresholding to protect the machine at low and high energy based on PIP2IT test results
- Implement an automated checklist procedure
- Plan to Integrate Finite State Machine (FSM) algorithms with configuration and control in the next implementation
- Plan to implement visualization tools for scrapers and machine configuration
- Standardization of input signals
Summary of Path Forward

• The over-all MPS architecture works and can be used for PIP-II
• Algorithms developed will be optimized to newer hardware and platforms
• Develop test bench environment for system development
• Software tool development will be integrated early in the process to keep pace with development