Accelerator Capabilities Enhancement (ACE) Workshop

Main Injector Controls and Instrumentation

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January 30, 2023

Outline

- Criteria
- Upgrades and Enhancements
- Summary

Criteria

- 2 MW MI Fast Ramp Proposal **2MW**
  - Is enhancement or upgrade necessary or desirable for proposal
- PIP-II **PIPII**
  - Is enhancement or upgrade necessary or desirable for PIP-II era
- Reliability **R**
  - Would enhancement or upgrade significantly increase uptime or lower maintenance and upkeep
- Sustainability **S**
  - Would enhancement or upgrade make operations more sustainable (less energy, less waste, smaller environmental impact)
- Performance **P**
  - Would enhancement or upgrade increase operations performance (more beam, more efficiently)
- Criticality **C[0-3]**
  - How critical is this item to present or future operations
- Cost **$[1-3]**
  - Relative estimate of cost
- Labor **L[1-3]**
  - Relative estimate of labor

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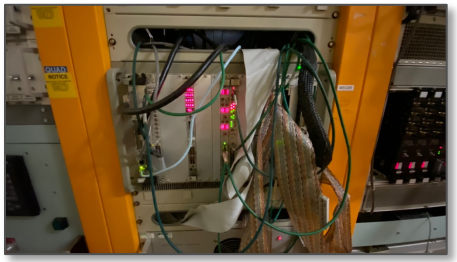
Main Injector Power Supply Controls

Most of the Main Injector main power supply controls are original to 1990's construction

- PS PLCs (**2MW, R, C3, $2, L2**)
  - 50 (24 just for MI quad and bend supplies)
  - $150k, 800 hrs
- PS PLC Control Power (**2MW, R, C3, $1, L2**)
  - 10 (8 remaining)
  - $56k, 320 hrs
- DC PS Control Communications (**2MW, R, C3, $1, L2**)
  - ~$50k, ~100's hrs
- Bus DCCTs (**2MW, R, C3, $2, L?**)
  - 7
  - ~$112k
- PS Data Link (**2MW, R, C3, $1, L?**)
  - CAMAC based
- MECAR (**2MW, R, S, P, C3, $1, L2**)
  - VME based
  - Sustainability opportunity



Water Cooling Controls

Main Injector water cooling controls needs to be replaced

- House PLCs (**2MW, R, C3 , $2, L2**)
  - Magnet, RF, Cavity systems
  - SixTrack system obsolete
- House VMEs (**2MW, R, C3 , $1, L1**)
- Advantage Starter Cards (**2MW, R, S, C3, $2, L2**)
  - ~50 between LCW and pond pumps
  - Obsolete
  - Some pond have been replaced with Variable Frequency Drives (VFD)
    - VFD offer new way to regulate LCW temperature while lowering energy use

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Vacuum Controls

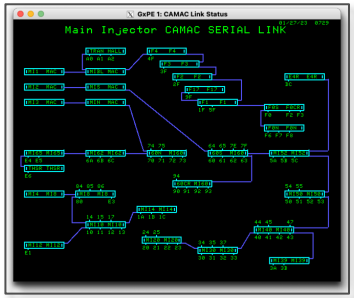
All Main Injector, 8 GeV and 1/3 of Recycler running on obsolete CIA system

- Ion Pump PS (**PIPII**, **R**, **S**, **P, C3 , $3, L3**)
  - ~500
  - ~$500-750k, 1000 hrs
  - Networked Ethernet IPs in use in Recycler
- Beam Valve Control (**PIPII**, **R**, **C3, $1, L2**)
  - ~1-2 per house
  - ~$100k, ~250 hrs
  - Need to replicate CIA crate beam valve control, sector permit
  - Could be used to increase IP vacuum readback frequency

Field Bus

Much of the PS ramp waveforms, timing, clock, signals, ADC, machine protection is handled via CAMAC, a 1970's tech

- CAMAC Cards (**R**, **P, C3, $3, L3**)
  - ~603,
  - ~$2M+, 1000's hrs
- CAMAC Crates (**R**, **P, C3, $3, L3**)
  - `~88
  - ~$1M
- CAMAC VME Front Ends (**R**, **P, C2, $1, L1**)
  - 4
  - ~$50k
- CAMAC ADC (**R**, **P, C1, $2, L2**)
  - Need more channels, less multiplexed
    - We can't currently read adjacent corrector currents in Recycler
  - Greater resolution



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Software

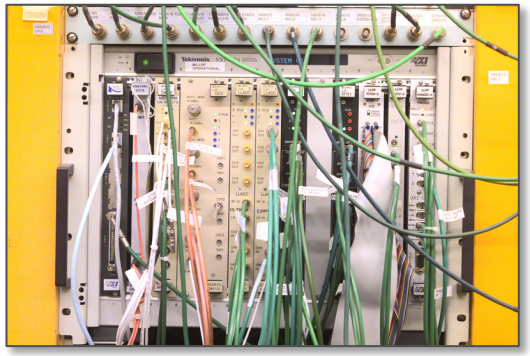
Many client applications were originally written 25+ years ago

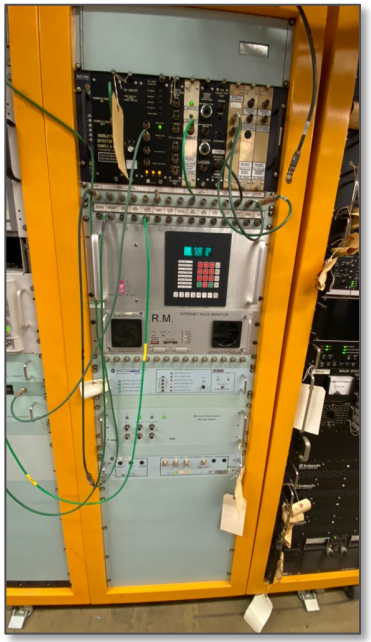
- Client Applications (**R**, **P, C2, $1, L3**)
  - Console Programs, Comfort Displays
  - ~100 for Main Injector, Recycler, 8 GeV
  - 1000's hrs
- More Data (**P, S, C1, $?, L2**)
  - More resolution
  - Better timestamp synchronization
  - More waveform data
- Data Logging (**R**, **P, S, C2, $2, L2**)
  - We save a very small fraction of our machine data
  - ~5 TB per day to save all existing readbacks
- Issue tracking (**R**, **P, S, C1, $1, L1**)
  - Elog is great ☺, but does a poor job of tracking resolution of issues that take longer than a few shifts
- APIs (**R**, **P, S, C1, $1, L1**)
  - Convenient, intuitive, flexible access to machine data and machine settings

RF Controls

Most RF controls are in need of replacement

- LLRF VXI Crates (**2MW, PIPII**, **R**, **P, C3 , $2, L2**)
  - Needed for Main Injector and Recycler
- HLRF IRM Nodes (**2MW, PIPII**, **R**, **P, C3 , $2, L2**)
  - 44
  - Proposed PiRM nodes
- Anode Controls (**2MW, PIPII**, **R**, **P, C3 , $1, L2**)
- Damper Controls (**PIPII**, **R**, **P, C3 , $2, L2**)





Beam Instrumentation

Much of our beam instrumentation is EOL. Most systems were designed for manual tuning and studies

- Beam Position Monitors (**PIPII**, **R**, **P, C3, $3, L2**)
  - 8 GeV, Recycler, MI
  - Digitizers obsolete, few spares
  - VME based
- Beam Loss Monitors (**PIPII**, **R**, **P, C3, $3, L2**)
  - Ionization chambers need refurbishment
  - VME based
- Wire Profile Monitors (**PIPII**, **R**, **P, C3, $2, L2**)
  - Motion controls need refurbishment
  - Better wire frame, can designs desired
    - Bias planes, dual planes, C-channels
  - SWIC scanner + VME FE scheme dated
- Ion Profile Monitors (**PIPII**, **R**, **P, C1, $2, L2**)
  - Fast HV switch to preserve Micro channel plate lifetime

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Beam Instrumentation (Continued)

- Toroids (**PIPII**, **R**, **P, C2, $2, L2**)
  - VME/NIM based
- Beam Intensity DCCT (**PIPII**, **R**, **P, C3, $2, L2**)
  - VME based
  - Hardware is approaching beam intensity limits for PIP-II
- More Non-invasive Measurements (**PIPII**, **R**, **P, C2, $3, L2**)
  - Electron beam profile monitor?
  - Halo profile monitors?
  - Tune measurement?

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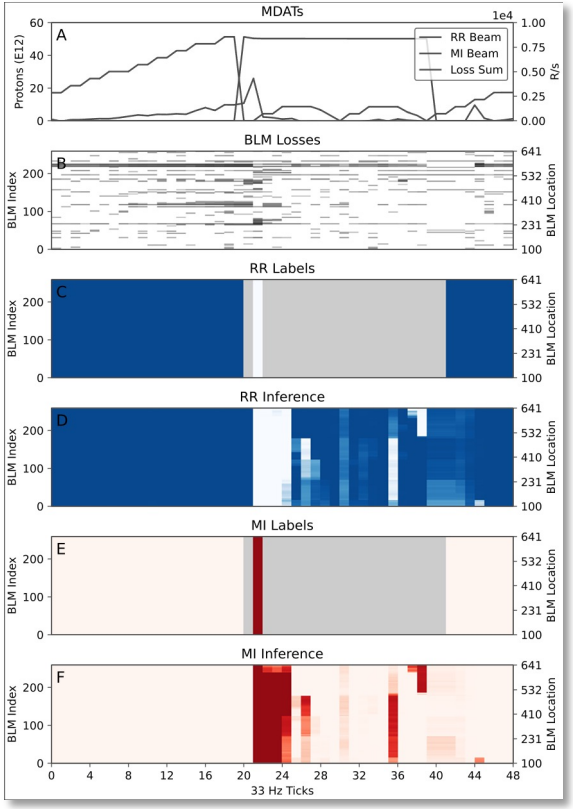
Automation

The vast majority of Main Injector, Recycler and 8 GeV are tuned manually.

- Orbit Control (**2MW, PIPII**, **R**, **P, C3 , $1, L2**)
  - More autotunes
- Tune Control (**2MW, PIPII**, **R**, **P, C3 , $2, L2**)
  - Need active tune readback (Dampers?)
- Artificial Intelligence, Machine Learning (**2MW, PIPII**, **R**, **P, S, C3 , $2, L2**)
  - Anomaly Detection
    - Tuning, studies are often hampered by broke instrumentation only discovered in post
  - Multi-objective Optimization
    - Optimize the machine using multiple sub-systems for multiple objectives
  - Better regulation schemes
    - Slow spill duty factor
    - Main Injector ramp regulation
    - Energy savings
  - Inference, realtime diagnostics
  - Digital Twins (better machine models)
  - Natural Language Processing (Elog searches?)
- Automated Tunnel Surveys, Robotics (**2MW, PIPII**, **R**, **P, S, C3, $2, L2**)



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Miscellaneous

Not every needed upgrade fits into a neat category

- Computer Room (**2MW, PIPII**, **R**, **P, C3 , $3, L2**)
  - Limited cooling
  - At max capacity
  - Generator needed
- Kautz Road Sub-station (KRS) Controls (**2MW, R**, **P, C3 , $2, L2**)
- Building Monitoring/Metering (**R**, **P, S,** **C3 , $2, L2**)
  - Opportunity for sustainability
- Cabling Replacement (**2MW, PIPII**, **R**, **P, S,** **C3 , $3, L3**)
  - Radiation damaged cables, cable liftetimes
  - Investigate other insulation materials
- Motion Controls (**R**, **P, C3 , $2, L2**)
  - Main Injector, Recycler, 8 GeV Collimators
  - Wire Profile Monitors
  - Ion Profile Monitors
  - Septa tanks
  - Crawling Wire
- Total Loss Monitors (**2MW, PIPII**, **R**, **S,** **C2, $2, L2**)

Summary

- **There are no obvious Controls or Instrumentation technological obstacles that would prevent the 2 MW Fast Ramp Upgrade**
  - Just a matter of resources and support
- Increasing reliability should be prioritized the same as any increase in Main Injector duty factor or beam intensity
- Majority of Main Injector controls is EOL, there is much that should be replaced/upgraded
- Much of our instrumentation is oriented towards manual tuning and studies
  - Need more focus on providing streaming readings for future automation
- While both Main Injector and Recycler currently have beam transmission efficiencies of ~98%, this may be insufficient for future machine operations
  - Tunnel activation, personnel exposure
  - Component lifetimes
- More effort and support should be given to machine automation to help improve overall machine efficiencies
  - AI/ML has great promise
- Opportunities exist, and should be explored to increase Main Injector sustainability
- Need to actively rotate out aged systems
  - Attracting and retaining talent is already hard, few want to work on dated systems
- More investigation is needed to adequately scope costs and labor
  - ACORN is doing some of this investigation already
- This amount of work will require significant increases in personnel and funds

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