Beam Instrumentation
Performance and Plans

Alexander Aleksandrov
Beam Instrumentation Team Leader
January 11, 2012
SNS Beam Instrumentation Systems are Numerous, Diverse and Growing in Number

BCM, BLM, BPM, BSM, WS... 15+ systems

IDump
- 3 Position
- 1 Wire
- 6 Loss
- 2 Current
- 2 Video

RING
- 44 Position
- 54+ Loss
- 1 Current
- 12 Fast Loss
- 5 Electron Detectors
- 2 Electron Profile Scanner
- 2 Transverse BTF

MDump
- 4 Loss
- 2 Current
- 1 Wire

EDump
- 1 Current
- 4 Loss
- 1 Wire

LDump
- 6 Loss
- 6 Position
- 2 Wire

RTBT
- 17 Position
- 26 Loss
- 5 Wires
- 4 Current
- 1 Harp
- 3 Fast Loss
- 1 Target Imaging

MEBT
- 6 Position and Phase
- 2 Current
- 5 Wires
- 1 CHUMPS
- 1 Emittance

CCL
- 10 Position and Phase
- 9 Wires
- 48 Loss
- 1 Faraday Cup
- 4 Bunch Shape
- 10 Neutron Detectors

HEBT
- 29 Position and Phase
- 26+ Loss,
- 3 Fast Loss
- 10 Wires
- 4 Current
- 2 Bunch Shape
- 6 Scapers Charge
- 1 Laser emittance

DTL
- 10 Position and Phase
- 5 Wire
- 4 Loss
- 5 Faraday Cup
- 6 Current
- 18 Neutron Detectors

SCL
- 34 Position and Phase
- 33+ Loss
- 9 Laser Wire
- 24 Neutron Detectors
Outline

• Status and upgrade plans for selected systems:
  – Nominal Operation
    • Beam Loss Monitors
  – Machine Tuning
    • Beam Position and Phase Monitors
  – Beam Power Increase
    • Foil Image and Temperature
    • Ring Transverse Feedback and Beam Transfer Function Measurement
  – Machine Study and Loss Reduction
    • Transverse Profiles and Halo
    • Transverse Emittance
    • Longitudinal Profiles
Beam Loss Monitors (BLMs)

- Major tool for machine protection and tune up
- Ionization Chamber Detectors (307)
- Scintillation Detectors (55)
  - Neutron detectors
  - Fast loss detectors
- Multi-channel analog front-end VME cards
- Digital electronics in VME crate
- VxWorks software
- Very reliable

  - Hardware obsolescence is looming problem
  - Short term solution: stock up on spares
  - Long term solution: new system
New BLM development

• Guiding Principles:
  – Compatible with existing EPICS and MPS infrastructure
  – Less custom, more off-the-shelf components
  – No major functionality changes

• Analog Front End:
  – Single channel Individual cards
  – Provision for analog background subtraction
  – Chassis satisfies “technical transparency”
  – Have had two chassis installed in SCL for testing

• Digital Processing:
  – Have not decided yet on what to use
  – National Instruments Compact RIO chassis is under consideration
  – New Compact RIO FPGA processor for HEBT scrapers is being installed
    • requirements are similar to BLM

Courtesy of A. Zhukov
Beam Position and Phase Monitors (BPMs)

- Main tool for machine tune-up and troubleshooting
  - Phase measurements for linac tune-up
  - Position measurements for trajectory correction, injection set-up and centering beam on dumps and target

- 160 strip-line pick-ups
  - 96 “linac type” operate at 402.5MHz and 805MHz
  - 64 “ring type” operate at low frequency

- Custom made PCI analog front-end and digital cards

- LabView software under embedded Windows XP on individual PCs (one per pick-up), 6Hz trigger rate

- Meets all accuracy specs but reliability is not stellar

- Hardware obsolescence is major problem
  - Parts, cards, PC motherboards, OS upgrades

- Short term solution: stock up on spares

- Long term solution: new system
New BPM development

• Guiding Principles:
  – Compatible with existing EPICS and Reference RF infrastructure
  – Less custom, more off-the-shelf components
  – No major functionality changes but 60Hz capable

• Analog Front End:
  – As similar to SNS LLRF front-end card as possible
  – Investigating need for continuous TDR self-calibration
  – Chassis satisfies “technical transparency”
  – Plan to have 1 chassis for testing by end of FY12

• Digital Processing:
  – Have not decided yet on
  – needs more processing power than BLM
  – National Instruments Flex RIO in PXIe chassis is under consideration
  – Plan to have 1 chassis for testing by end of FY12

Goal: deploy 1 new ‘linac type’ BPM in FY12 summer shutdown for in-the-field performance evaluation
Injection Foil Imaging System

- Analog in-tunnel radiation hard camera has been used for injection foil imaging
  - Expensive maintenance
  - Not suitable for time-resolved optical pyrometry
  - Not optimal for foil shaking observation due to fixed and limited update rate (30Hz)

- New optical transmission line with digital camera outside of tunnel
  - High-End scientific cameras can be used
  - Infrared detectors can be used for temperature measurements
  - No maintenance in radiation areas
Optical transmission line

- Two 8” flat mirrors mounted on the wall in the tunnel
- A commercial off-the-shelf 6” telescope
- Digital scientific camera and/or other detectors
Foil Temperature Measurements

Two-color optical pyrometer

Black body radiation

Foil

Photo diode

Bandpass Filter

Adapter

Filters

Photo diode

Courtesy of W. Blokland
Ring Transverse Feedback System

- Suppressing e-p instability is primary goal
  - 1-300MHz bandwidth
  - 200/400 W/channel peak power
- Have analog LLRF system commissioned
- Digital LLRF is being commissioned

BPM and kicker tuning

Feedback electronics

Measured system bandwidth

Courtesy of C. Deibele
Ring Transverse Feedback / BTF Measurement System Performance

- Have demonstrated e-p instability suppression, but results are not repeatable and consistent
- Have implemented Beam Transfer Function (BTF) measuring technique
- Have observed unexpected, and so far unexplained beam response
  - Can be a key to successful e-p damping
- Digital LLRF promises more flexibility in system tuning

Effect of feedback on e-p instability

Low intensity beam BTF

High intensity beam BTF

Courtesy of R. Hardin
Beam Study Diagnostics

• Improve performance through machine knowledge
  – Understand initial 6-d beam distribution
  – Understand beam dynamics in real machine
  – Tune / validate beam model
  – Optimize beam transport

• Demands to diagnostics
  – Complex beam pulse structure requires fine time resolution
  – Small beam loss requires large dynamic range
  – As many measured projections as possible: transverse profiles, longitudinal profiles, 2-d projections
    • Direct measurement of 6-d distribution is not practical
  – As many measurement locations as possible

• We can not meet all demands in one diagnostic – use variety of complimentary measurements
Transverse 1-D Profile Measurements

- Wire scanners in warm linac and transport lines (41)
  - Interceptive: max pulse width = 50us
  - 10us time resolution
  - Dynamic range = 10,000

- Laser Wire in super-conducting linac (9+1)
  - Non-interceptive
  - 10ns time resolution
  - Dynamic range = 100

- Electron beam scanner in accumulator ring (1)
  - Non-interceptive
  - 20ns time resolution
  - Dynamic range = 10
Status and Plans

• Wire scanners status
  – Updated computers (PCs)
  – Upgraded LabView to 2009
  – Developed new software

• Wire scanners plans
  – Increase scan speed
  – Investigate and mitigate dynamic range limitations

• Electron profile scanner status
  – Expert run system
  – Limited scan aperture
  – Limited measured beam maximum intensity due to limited electron gun voltage

• Electron profile scanners plans
  – Improve electron beam optics
  – Develop user friendly software
  – Increase maximum electron gun voltage
  – Increase scan aperture
Transverse 2-D Emittance Measurements

- Slit – harp emittance station in MEBT
  - Interceptive: max pulse width = 50us
  - 10us time resolution
  - Dynamic range = 1,000

- Laser emittance station in HEBT
  - Non-interceptive
  - 10ns time resolution
  - Dynamic range = 100

- Tomographic reconstruction using wire scanners
  - Interceptive: max pulse width = 50us
  - 10 us time resolution
  - Dynamic range = ?
Emittance Measurements Status and Plans

• MEBT emittance status
  – Updated computer (PC)
  – Upgraded LabView to 2009
  – Developed new software

• MEBT emittance plans
  – Increase dynamic range to ~ 10,000
  – Reduce integration time to < 1us

• HEBT laser emittance status
  – Recently commissioned
  – Details in next presentation

• HEBT laser emittance plans
  – Finalize EPICS GUI
  – Unify data analysis software with MEBT
  – Investigate and mitigate dynamic range limitations
MEANT Tomographic Reconstruction of 2-D Emittance from 1-D Profiles

- Reconstruction seems to work very well in HEBT
  - Need to verify using laser emittance measurements
  - High resolution of wire scan data helps in algorithm convergence
- Plan to extend to SCL, Warm Linac, MEBT
  - Requires a good transport model
  - Problem of space charge

Comparison of measured and reconstructed profiles
Longitudinal 1-D Bunch Profile Measurements

- **Beam Shape Monitors (aka Feschenko monitor) in CCL and HEBT (4+3)**
  - Interceptive: max pulse width = 50us
  - ~1° @805 MHz (3.5 ps) intra-bunch resolution
  - 10us averaging time
  - Dynamic range = 10,000

- **Mode-lock-laser monitor in MEBT (1)**
  - Non-interceptive
  - ~ 3° @402.5 MHz (20ps) intra-bunch resolution
  - 10us averaging time
  - Dynamic range = 100
  - Non-operational currently
  - Status and plans in next talk
BSM Status and Plans

- Beam Shape Monitor status
  - Upgraded computer hardware (PC)
  - Upgraded LabView to 2009
  - New software
  - Upgraded BSM hardware on 2 CCL BSMs to improve resolution to ~.5°

- Beam Shape Monitor plans
  - Upgrade remaining BSMs hardware
  - Study and mitigate resolution limitations
  - Collaborate with INR (Feschenko) on laser BSM development
New BSM EPICS GUI

- Fully independent parallel scans
- Extensive set of troubleshooting and tuning tools

Courtesy of R. Dickson
A near-term wish list

• MEBT vertical scrapers
  – Not funded in FY12

• Ring Ionization Profile Monitor (IPM)
  – Design 90% complete
  – Not funded in FY12

• Ring electron scanner aperture increase
  – Not funded in FY12

• Laser stripping experiment set-up
  – Not funded in FY12

• Laser based BSM
  – Not funded in FY12

• New Ring pinger electrode
  – Not funded in FY12

• RFQ test stand diagnostics
  – Not funded in FY12
Summary

- Existing Beam Instrumentation is capable to support machine tuning and production runs
- Downtime associated with beam diagnostics is low
- Moving steadily toward increasing dynamic range of measurements and implementing more non-perturbing diagnostics to support beam study
- Working on improving GUIs and speeding up data collection
- Approaching state-of-the-art for many systems
  - working closely together with AP team to ensure trustworthiness of data