Bunch Shape Measurement in the Fermilab Linac

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Outline

- The Fermilab Accelerator Complex
  - The Fermilab Linear Accelerator

- Introduction to Bunch Shape Monitors (BSM)

- The Fermilab Bunch Shape Monitors
  - The Radio Frequency (RF) Cavity (RFC)
  - Controlling the BSM
  - Data Acquisition

- Testing and Calibrating Hardware Devices
  - Testing Stepper Motors
  - Signal Testing
  - Calibrating the Focusing Lens Plates

- BSM R&D
  - X-ray based BSM’s
A simple model of the Fermilab Accelerator Complex for the current run. Energies:

- Linac: 400 MeV
- Booster: 8 GeV
- Main Injector: 120 GeV
- Tevatron (RIP):
  \[ \sqrt{s} = 1.96 \text{ TeV} \]
The Fermilab Linac

- The Linac has two main sections.
- First section: Drift tube linac operating at a bunching frequency of 201.25 MHz. Accelerates $H^-$ beam to 116 MeV.
- Second section: Side-couple cavity linac operating at 805 MHz bunching frequency. Accelerates beam to 400 MeV.
- The BSM is installed in the transition area (between the two main sections) where the bunching frequency is 805 MHz.
Method developed in the late ‘80s at INR in Russia.

BSM built at Fermilab in early ‘90s.

Place thin filament at -HV in beam; secondary electrons ejected from the wire with same time structure as the beam.

$e^-$ propagate through slit and into radio frequency cavity.

$e^-$ structure in time transformed to a spacial structure.

$e^-$ impinge on an electron multiplier tube (EMT).

RF cavity phase shift to sample entire beam structure.
BSM Diagram

Beam pipe

Radio Frequency Deflector

Signal Pickup

Center at 0 RF

Radio Frequency Field

Negative HV

$e^-$ bunch from ion beam

$e^-$ bunch

$e^-$
Radio Frequency Cavity

The RFC is the most important part of the BSM
Time distribution ⇒ Spacial distribution.

1. Resonant Cavity Forming Arms
2. RF Power Coupling Loop
3. RF Readback Loop
4. Endcaps (tuning)
5. Plate Size Trimming (tuning)
6. Slug Tuners
7. 0 RF – DC Voltage applied here
8. 1 MΩ Resistor
9. Focussing area
10. Nylon Support
Controlling the BSM

A simple block/flow diagram for the Linac BSM system:

- **ACNET** - RF Shifter $\nu = 805$ MHz
- **gate** - Gate & Attenuation
- **manual** - Cavity RF HV
- **ACNET** - Plate DC HV
- **Wire HV & Current**
- **Wire Motion** - ACNET
- **Bunch Shape Monitor**
- **e^- signal**
- **Preamp**
- **Sample & Hold**

*Note: D. Davis Fermilab BSM 8/7/2013*
We use ACNET and ACL for setting and reading back BSM parameters. ACL scripting language used for DAQ

- Set RF phase limit
- Set Starting RF starting phase
- Step RF phase
- Wait for a Linac pulse
- Readback phase value and EMT signal (10x)
- Step RF phase...
How the Shape is Determined

- Each Linac pulse (15 Hz) gives signal to the EMT. Many pulses contribute to one measurement.
- As the phase is shifted, different segments of the spatial profile propagate through the second slit.
- The measurement is then a function of the shift in phase.
- A theoretical bunch shape measurement, as a function of phase difference $\delta\phi$; real measurements would not be as perfectly Gaussian.
Stepper Motor Testing

**L:DDMOT3 Motor Linearity**

- **Slope:** 0.01231 Deg/Step

**L:DDMOT3 Motor Linearity at 805 MHz**

- **Slope:** 0.0489 Deg/Step

**Point to Fit Distance [L:DDMOT3]**

- **RMS:** 0.02553

**Point to Fit Distance [L:DDMOT3] at 805 MHz**

- **RMS:** 0.4101

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Successful Signal

Very recently we have been able to generate a successful signal of electrons from the filament on the EMT. Applying approximately 1 A to the filament:

![Signal Testing Graph]

- **Voltage (V)**: 1400, 1600, 1800, 2000, 2200, 2400, 2600
- **Signal Current (nA)**: 1, 10, 1, 10

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Calibrating the Focussing Plates

The tungsten wire can emit electrons when not impinged on by beam by applying a current to the wire; we can calibrate how to apply voltage to the lenses in the RF Cavity without beam running.

- Good focussing ⇒ Good signal
- Over focussed ⇒ Bad signal
X-ray based BSM

- X-ray based BSM has been commissioned at ANL by Peter Ostroumov.
- Place foil in the beam line (or gas) as target. Beam-Target collisions create inner shell vacancies in target atoms. Allows for emission of X-ray photons.
- Photocathode converts X-rays into low energy electrons.
- Like the secondary electron based BSM, the X-rays and electrons in the X-ray version have the same time structure as the bunched ion beam.
- Better time resolution (10 ps vs. 5 ps) & no effect from $2\, e^{-}$ from the $H^{-}$ beam.
Summary and Conclusions

- Secondary electron based BSM has existed at Fermilab since the 400 MeV upgrade.
- Recommissioning of this detector has begun this summer and will continue.
  - Components of the Fermilab BSM have been tested and more will be tested.
  - New data acquisition method has been developed.
  - Unfortunately, we were not able to access the Linac to diagnose problems until very recently – but we have been able to diagnose some problems outside of the tunnel, and we have now identified some issues in the tunnel.
- An X-ray based BSM has been commissioned at ANL and Fermilab will begin R&D on an X-ray based BSM for the PXIE effort.
- After successful measurements with the current BSM, it will be removed to install the X-ray based BSM into the Linac to prepare for one in PXIE.
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Backup
The original developer of the Fermilab BSM, Elliott McCrory, has made measurements in the past.