The Fermilab HINS Test Facility and Beam Measurements of the Ion Source and 325 MHZ RFQ

V. Scarpine, B. Webber, J. Steimel, B.Hanna, C. Maag, S. Chaurize, S. Hays, D. Wildman
Fermilab

APC Talk
August 11, 2011
Brief History of Meson Detector Building (HINS) Test Facility

• This thrust began in 2006 with initiation of the High Intensity Neutrino Source (HINS) program to demonstrate technology applications new to the low-energy front-end of a pulsed, high-intensity proton/H- Linac

• The plan was to construct a ten’s of MeV Linac to demonstrate:
  – Beam acceleration using spoke-type superconducting RF (SRF) cavity structures starting at a beam energy of 10 MeV
  – High power RF vector modulators controlling multiple RF cavities driven by a single high power klystron for acceleration of a non-relativistic beam
  – Control of beam halo and emittance growth by the use of solenoid focusing optics
  – Fast, 325 MHz bunch-by-bunch, beam chopping

• Now plan is to demonstrate:
  – High power RF vector modulators controlling multiple RF cavities driven by a single high power klystron for acceleration of a non-relativistic beam
  – Test facility for beam diagnostics and fast chopper (?)
MDB Test Facility Layout

325 MHz Spoke Cavity Test Facility

1.3 GHz HTS

1300 CW RF

325 MHz CW RF

Ion Source and RFQ

MDB Linac enclosure for 10 MEV

Source of cryogenics

Scale: Square blocks are 3ft x 3ft
## HINS Beam Parameters

<table>
<thead>
<tr>
<th></th>
<th>Proposed</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particle</strong></td>
<td>H+ then H-</td>
<td>H+ <em>then</em> H-?</td>
</tr>
<tr>
<td><strong>Nominal Bunch</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency/Spacing</td>
<td>325 3.1</td>
<td>325 3.1</td>
</tr>
<tr>
<td><strong>Pulse Length</strong></td>
<td>3 @ 2.5 Hz</td>
<td>1 @ 0.2 Hz</td>
</tr>
<tr>
<td></td>
<td>1 @ 10 Hz</td>
<td>0.1 @ 1 Hz</td>
</tr>
<tr>
<td><strong>Average Pulse</strong></td>
<td>~ 20 (source)</td>
<td>~ 20 (H, 2H+, 3H+)</td>
</tr>
<tr>
<td>Current</td>
<td>~ 8 (RFQ - H)</td>
<td></td>
</tr>
<tr>
<td><strong>Pulse Rep. Rate</strong></td>
<td>2.5/10</td>
<td>0.2/1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hz</td>
</tr>
</tbody>
</table>
HINS Proton Source and LEBT

Proton Source

<table>
<thead>
<tr>
<th>Duo-plasmotron Proton Source</th>
<th>Name</th>
<th>Current [Amp]</th>
<th>B [Gauss]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>SOL-U Upstream solenoid</td>
<td>850</td>
<td>7900</td>
</tr>
<tr>
<td>Peak Current</td>
<td>SOL-D Downstream solenoid</td>
<td>850</td>
<td>7900</td>
</tr>
<tr>
<td>Pulse</td>
<td>DIP-UH Upstream horizontal dipole</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Rep. rate</td>
<td>DIP-UV Upstream vertical dipole</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>DIP-DH Downstream horizontal dipole</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>DIP-DV Downstream vertical dipole</td>
<td>3</td>
<td>100</td>
</tr>
</tbody>
</table>

APC Talk 2011
HINS LEBT Beam Measurement Setup

- Proton Source
- Toroid
- Focusing Solenoids
- Wire Scanner
A Typical Wire Scan

Signal with background subtracted.

The time structure of a 100 µs pulse. The flattop is about 50 µs.
Proton Source Slit-WS Emittance Measurement
Proton Source Slit-WS Emittance Measurement

Other particle species fill the beam pipe.

Proton

Slit motion

Background signal outweighs proton signal.
Source Species

Green – Source Extractor Voltage
Yellow – LEBT Toroid Current
Red – Straight ahead Faraday Cup
Blue – Spectrometer Faraday Cup (bend)

- Downstream solenoid optimized for each species
- Upstream solenoid fixed at 470 A

~ 40% Protons
~ 30% H2+
~ 30% H3+
- As measured by LEBT toroid
Phase Space Signal Cleaning

Source Emittance Slit & Solenoid Scans

Normalized RMS emittance $[\pi \text{mm-mrad}]$ vs. Proton beam current [mA]
Initial RFQ Beam Measurements

RFQ design:
- 2.5 Mev
- 325 MHz
- Peak power up to 450 KW
- 1 ms pulses at 10 Hz

RFQ suffered from detuning problems and water leaks → 50 µs pulses at 1 Hz

Beam loss after first wire scanner → need focusing

Profile Sigmas and Integrals; I ~ 4 mA

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Diagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner 1</td>
<td>4.5 mm</td>
<td>4.2 mm</td>
<td>4.3 mm</td>
</tr>
<tr>
<td>Scanner 2</td>
<td>7.0 mm</td>
<td>6.8 mm</td>
<td>6.2 mm</td>
</tr>
<tr>
<td>Scanner 3</td>
<td>16.2 mm</td>
<td>13.2 mm</td>
<td>13.4 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Diagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner 1</td>
<td>14.8 V*mm</td>
<td>14.9 V*mm</td>
<td>14.7 V*mm</td>
</tr>
<tr>
<td>Scanner 2</td>
<td>11.8 V*mm</td>
<td>10.5 V*mm</td>
<td>10.2 V*mm</td>
</tr>
<tr>
<td>Scanner 3</td>
<td>11.6 V*mm</td>
<td>10.1 V*mm</td>
<td>10.7 V*mm</td>
</tr>
</tbody>
</table>
Signals from toroid and two BPM buttons, all downstream of the RFQ

Upper display: 2 µsec/div
Lower display: 20 nsec/div

Lower display shows the 44 ns delay expected for transit of 2.5 MeV beam between the BPM two buttons separated by 0.96 meters

Beam current is about 3 mA
RFQ Stability

Phase variation from time-of-flight

Energy Stability

Relative RFQ output beam vs. RF Power

~ 8 keV
Next Iteration of RFQ Beam Measurements

• Initial measurements suffered from RFQ water leak problems
  – RFQ limited to 50 µsec pulses
  – RFQ has been repaired and reinstalled at the Meson test facility

• Initial RFQ measurements suffered many issues
  – No transverse focusing → Quadrupoles added
  – No longitudinal measurements → FFC and BSM
  – No transverse emittance measurements → Quad-Wire, Slit-Wire
  – Energy measurement was not precise → Spectrometer magnet
  – RFQ efficiency not accurately measured → Toroid at RFQ output

• New diagnostics line has been install
  – Reconfigurable, movable
  – *Space available for R&D projects*
Advanced HINS Diagnostics Line

T: Toroid
GV: Gate Value
Q: Quadrupole
BPM: Beam Position Monitor
WS: Wire Scanner
S: Horz and Vert Slits
BSM: Bunch Shape Monitor (Longitudinal)
FFC: Fast Faraday Cup
FD: Faraday Cup/Dump
SM: Spectrometer Magnet

RFQ Beam Diagnostics
April 2011
Transverse Emittance from Quadrupole Scans

Unnormalized emittance
- 6 mA RFQ beam
- 100 usec pulses
H: 1.49 pi mm-mrad
V: 1.88 pi mm-mrad

Horizontal Quad scan and fit

The equation is 
\[ y(x) = 0.5452 - 0.01034x + 0.02791x^2 \]
setting the derivative to zero gives \( x_0 = 10.25 \). Note this is the gradient at minimum.
• X – X’ along beam pulse; arbitrary units
• 6 mA beam
Long Beam Pulse – 500 usec

Vert emittance vs Slice # for 500 usec pulse

Hor Emittance vs Slice # for 500 usec pulse

Emittance from quadrupole scan
Odd Shape Effects

Vertical

Horizontal

Front of pulse

Back of pulse

Halo?

Main beam

Horz Slit
Longitudinal Bunch Shape Monitor

Translate time coordinate into space coordinate using RF deflector cavity
• like a streak camera
Systematics need to be understood

FWHM: (prelim)
~ 40°@325 MHz
~ 340 ps

Preliminary
Longitudinal Bunch Shape – Fast Faraday Cup

Preliminary

FWHM ~400 ps

FFC, 8 mA, 325 KW, 20 Gs/s

FFC, 6 mA, 325 KW, 20 Gs/s
Beam Diagnostic Projects for Project X

Transverse Diagnostics
- Laser Transverse Profile Monitor*
- Ionization Profile Monitors
- Electron Wire Transverse Profile Monitor – with SNS

Longitudinal Diagnostics
- Wire Longitudinal Profile Monitor*
- Laser Longitudinal Profile Monitor* - with LBNL
- Broadband Faraday-cup – with SNS*

Halo Monitoring – transverse and longitudinal
- Vibrating wire* - from Bergoz Instrumentation
- Laser wire* - with LBNL

MEBT Emittance station
- Slit-collector*
- Laser Slit*

* Project X related instrumentation to be tested at HINS

See R. Wilcox Poster TUPD53 “A Low-Power Laser Wire with Fiber Optic Distribution”
Conclusion

• MDB Test Facility (HINS) has taken initial proton source and RFQ beam measurements
• RFQ has been repaired and reinstalled at MDB
• New diagnostics line has been installed
• RFQ Beam measurements have been made – analysis proceeding
• Six cavity being installed now – accelerator and buncher cavities
  – Beam by early Sept
  – $H^{-}$ to be installed later this year?
• The MDB test facility HINS can play a role in Project X front-end testing
  – R&D for beam diagnostics and beam chopper
  – Outside collaborators to participate in diagnostics development
The End