Non-invasive Beam Profile Measurements using an Electron-Beam Scanner

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Willem Blokland for the Spallation Neutron Source
Overview

• SNS Accelerator

• Electron scanner
  – Principle
  – Hardware
  – Software

• Results
  – Images
  – Analysis
  – Comparison

• Conclusion and Plans
Non-invasive Beam Profile Diagnostics at SNS

1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance System
4. Electron Scanners (proton beam)

Wire Scanners
Throughout linac and transfer lines but not in superconducting sections or in the ring
Electron Scanner Principle

Look at the deflected projection by a charged beam of a tilted sheet of electrons onto a screen

- Neglect magnetic field (small displacement of projection)
- Assume path of electrons is straight (they are almost straight)
- Assume net electron energy change is zero (if symmetric).

\[
\frac{d\theta(x)}{dx} = \int \frac{e}{mv^2} \frac{\delta(x,y)}{\varepsilon_0} dy
\]

or, take the derivative to get the profile

Imperfections estimated at 5-10%.

Simulation of electron paths

Deflection of electrons by proton beam
Simulation of electron paths

Deflection of electrons by proton beam
Electron Scanner Layout

Electron Scanner hardware by Budker Institute of Nuclear Physics: Dmitriy Malyutin, Sasha Starostenko, Sasha Tsyganov

Joint design by BINP and SNS.
Hardware: Electron Scanner

Electron scanner now covered with magnetic shield

Electron Gun
Dipoles
Deflector
Quadrupoles
Screen
HV Transformer
Ring Beam Pipe
Hardware: Electron Scanner

Electron Gun

Deflector

Dipoles

Quadrupoles

Electron Scanner parts
Hardware: Transformer

Arcing of HV Transformer
Hardware: Service Building Electronics

Electron scanner Rack in the Service Building

- Magnet power supplies
- HV power supplies
- Breakout boxes
- PXI: Acquisition and Control
- Camera power supply
- Trigger breakout

PXI crate with ADCs and DACs

- GigE Vision
- PS ADC readbacks
- PS DAC settings
- Delay generator (upgraded)
- HV digitizer
- Deflector digitizer
- CPU

PAC2011, March 28 to April 1, 2011 in New York, USA
Software

LabVIEW Application
• Control, acquire, and calculate the profiles
• Interface to EPICS
Control of accelerating voltages, cathode current, deflector voltages, magnets and timing.

Sequencer to support scanning through multiple bunches and adjustments while scanning.
Images

- No proton beam, vertical profile
- Image of horizontal curve
- Image of vertical curve
Analysis

• Find the curve (x,y) points
• Fit a spline to these points
• Take the derivative of this spline -> profile
• Fit a model-based function to profile to remove imperfections
• Correct width to assumed angle of deflectors (20% smaller for horizontal, 20% larger for vertical)
Analysis: Finding the curve

Slicing perpendicular to the curve
Analysis: Fitting a spline

Slicing perpendicular to the curve

Slicing vertical to the image
Analysis: Fitting a spline

Overlay of camera image with peaks and spline fit
Take derivative of peaks
Take derivative of spline fitted to the peaks
Take derivative of spline fitted to the peaks and fit to model-based function
Results

3D plot of Turn 720 at ~11uC
Data

Vertical Profiles (spline derivative)
Data

Horizontal Profiles (spline derivative)
Model-based Function

Goals:
• Reduce noise
• Extrapolate the tails
• Use integral version of model to fit directly to curve

Reject background

Extrapolate tail

Reject “blobs”

Superimposed images of ~19µC beam
Model-based function

The injection painting and space charge effects are the main contributors to the transverse profile in the ring and transfer line to target.

\[ f_{DSG}(x) = a_1 \cdot \exp \left( -\left(\frac{|x - \mu|}{\sigma_1}\right)^{n_1} \right) + a_2 \cdot \exp \left( -\left(\frac{|x - \mu|}{\sigma_2}\right)^{n_2} \right) + sI \cdot x + o \]
Results: Model-based function

- Take out the slope
- Extrapolate tails

Work in progress
- Fitting speed
- Model must be right
Comparison

<table>
<thead>
<tr>
<th></th>
<th>FWHM Hor (mm)</th>
<th>FWHM Ver (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Scanner</td>
<td>37.6</td>
<td>51.5</td>
</tr>
<tr>
<td>ELS Spline</td>
<td>37.8</td>
<td>56.6</td>
</tr>
<tr>
<td>ELS Model</td>
<td>38.8</td>
<td>57.8</td>
</tr>
<tr>
<td>Difference</td>
<td>~3%</td>
<td>~12%</td>
</tr>
</tbody>
</table>

Previous Study:
• Bumping the center of the beam and comparing BPM measurements with ES profile movements agrees to within 20%
Conclusions and Plans

Provides non-intrusive measurement of the transverse and longitudinal profile of the proton beam almost anywhere in the accumulation cycle.

- Open chamber to measure deflector angles
  - Adjust quads if necessary
  - Tilt deflectors even more to increase aperture
- Upgrade HV transformers to 75kV
- Upgrade cameras to increase sensitivity to lower cathode heating to extinguish blobs
- Electron Scanner successful, considering tomography