Laser Wire Based Parallel Profile Scan of H- Beam at SNS

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OUTLINE

• Motivation
• Principle of laser wire measurement
• System modifications for simultaneous profile scan
• 9-station simultaneous profile measurement results
• Commissioning experience on laser based diagnostics
• Conclusion
Motivation

• Advantages of laser wire profile/emittance monitor:
  – Measurement is non-intrusive and can be conducted on neutron production beam.
  – No moving parts in vacuum and therefore no risk to superconducting cavity.
  – Novel capability: measurement of profile/emittance of individual minipulses.

• Previously laser wire profile measurements have only been performed serially since a single light source is used.

• On the other hand, physics study such as the SCL modeling at SNS requires the measurement of H- beam profiles at different locations along the acceleration path and on different accelerator settings.

• A simultaneous profile measurement would be especially helpful to improve the efficiency and accuracy of the physics studies.
Principle of Laser Wire Measurement

Laser

X-scan

Y-scan

H⁻ beam

H⁻ beam

Deflector

$H^0$

$H^-$

electron

Faraday Cup

Photo-Detachment
SCL Laser Wire Profile Measurement System

SCL Laser Wire Profile Measurement System

Laser Transport Line
## Laser Transport Line

<table>
<thead>
<tr>
<th>Pick-up Mirror #</th>
<th>Individual Mirror Reflectivity (%)</th>
<th>Receiving Power Ratio (calculated)</th>
<th>Receiving Power Ratio (measured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM01</td>
<td>100</td>
<td>11.7</td>
<td>8.9</td>
</tr>
<tr>
<td>CM02</td>
<td>50</td>
<td>11.7</td>
<td>11.4</td>
</tr>
<tr>
<td>CM03</td>
<td>33</td>
<td>11.7</td>
<td>9.3</td>
</tr>
<tr>
<td>CM04</td>
<td>25</td>
<td>11.7</td>
<td>11.6</td>
</tr>
<tr>
<td>CM12</td>
<td>20</td>
<td>11.7</td>
<td>12.7</td>
</tr>
<tr>
<td>CM13</td>
<td>20</td>
<td>14.6</td>
<td>13.8</td>
</tr>
<tr>
<td>CM14</td>
<td>10</td>
<td>8.1</td>
<td>10.2</td>
</tr>
<tr>
<td>CM15</td>
<td>10</td>
<td>9.0</td>
<td>8.7</td>
</tr>
<tr>
<td>CM32</td>
<td>10</td>
<td>10.0</td>
<td>8.2</td>
</tr>
</tbody>
</table>

---

The diagram shows the layout of the laser transport line with various pick-up mirrors indicated by their respective numbers and reflectivities. The receiving power ratios are calculated and measured at different points along the line.
Laser Transport Line

![Diagram showing the Laser Transport Line with labeled points and measurements.](image)

- **Telescope Spacing (mm)**
  - 250 m
  - 160 m
  - 25 m

- **Beam Spot Size (cm^2)**
  - CM27
  - CM17
  - CM05

- **Points:**
  - a
  - b
  - c

---

[Image source](image)
Laser Transport Line

250 m
1 2 3 4 5

160 m
12 13 14 15 17

25 m
27 32

Telescope Spacing (mm)

Beam Spot Size (cm$^2$)
CM27 CM17 CM05

1 cm
Laser Beam Pointing Stabilization

**Position** (220 m from laser)

**Transported laser power**

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**Graph Details**

- **Axes:**
  - X-axis: Time (sec)
  - Y-axis 1: Position (mm)
  - Y-axis 2: Power (W)

- **Lines:**
  - CAM05_PosY
  - Power Meter 01

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**Notes:**

- The graph illustrates the fluctuation in position and power over time.
- The position is measured at 220 m from the laser source.
- The transported laser power is shown below the position graph.
Laser Beam Pointing Stabilization

Diagram:

- Laser
- Piezo-driven mirror
- Beam sampler
- Image sensor
- Controller
- Error signal generation
- Set point
- Driver

Diagram elements connected in a feedback loop.
Laser Beam Pointing Stabilization

Feedback off

Feedback on

±1.25 mm @ 250 m

Laser Beam Pointing Stabilization

Phase Tuning between Laser and H-Pulses

Propagation of Ion Beam and Light Beam

Distance (m)

Time (us)

SCL Cryomodules
Phase Tuning between Laser and H-Pulses

Propagation of Ion Beam and Light Beam

- SCL Cryomodules
- $N + 2\text{nd minipulse}$
- $N + 1\text{st minipulse}$
- $N\text{th minipulse}$
Phase Tuning between Laser and H-Pulses

Propagation of Ion Beam and Light Beam
# EDM Screens for Laser Wire System

## Laser Wire Transfer Line

<table>
<thead>
<tr>
<th>Label</th>
<th>Description</th>
<th>Retract</th>
<th>mm</th>
<th>Insert</th>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW_01</td>
<td>Station 01</td>
<td>-0.037</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_02</td>
<td>Station 02</td>
<td>0.042</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_03</td>
<td>Station 03</td>
<td>-0.058</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_04</td>
<td>Station 04</td>
<td>0.138</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_12</td>
<td>Station 12</td>
<td>-0.016</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_13</td>
<td>Station 13</td>
<td>0.069</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_14</td>
<td>Station 14</td>
<td>-0.021</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
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<tr>
<td>LW_15</td>
<td>Station 15</td>
<td>-0.016</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_32</td>
<td>Station 32</td>
<td>0.021</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
<tr>
<td>LW_EMIT</td>
<td>Beam Block</td>
<td>0.000</td>
<td></td>
<td></td>
<td>Rtn Lin Set Pt Ins Lim</td>
</tr>
</tbody>
</table>

*From EPICS, user can select one, multiple, or all scanners*
From EPICS, user can select scan range, step size, average number. Fitting is automatically conducted.
Simultaneous Profile Scan

Horizontal Mean: 22.435
Vertical Mean: 27.611

Horizontal

Vertical

Scan State
- LW01: Done
- LW02: Done
- LW03: Done
- LW04: Done
- LW12: Done
- LW13: Done
- LW14: Done
- LW15: Done
- LW32: Done
## Estimated Beam Parameters (April 15, 2013)

<table>
<thead>
<tr>
<th>Location</th>
<th>Amplitude (mV)</th>
<th>Beam Center (mm)</th>
<th>Beam Size (mm)</th>
<th>Offset (mV)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1H</td>
<td>257±3</td>
<td>22.460±0.019</td>
<td>2.317±0.024</td>
<td>7.3±0.2</td>
<td>0.999</td>
</tr>
<tr>
<td>1V</td>
<td>274±3</td>
<td>27.62±0.016</td>
<td>1.966±0.018</td>
<td>7.6±0.02</td>
<td>0.999</td>
</tr>
<tr>
<td>2H</td>
<td>171±5</td>
<td>11.632±0.027</td>
<td>2.445±0.032</td>
<td>5.0±0.1</td>
<td>0.95</td>
</tr>
<tr>
<td>2V</td>
<td>404±5</td>
<td>25.316±0.010</td>
<td>1.717±0.014</td>
<td>5.8±0.1</td>
<td>0.996</td>
</tr>
<tr>
<td>3H</td>
<td>180±2</td>
<td>23.152±0.031</td>
<td>3.790±0.032</td>
<td>7.9±0.3</td>
<td>0.997</td>
</tr>
<tr>
<td>3V</td>
<td>316±4</td>
<td>32.776±0.017</td>
<td>1.991±0.023</td>
<td>8.7±0.2</td>
<td>0.997</td>
</tr>
<tr>
<td>4H</td>
<td>213±4</td>
<td>28.920±0.026</td>
<td>2.298±0.034</td>
<td>7.4±0.2</td>
<td>0.983</td>
</tr>
<tr>
<td>4V</td>
<td>205±5</td>
<td>22.020±0.025</td>
<td>1.852±0.029</td>
<td>8.4±0.2</td>
<td>0.988</td>
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<tr>
<td>12H</td>
<td>224±2</td>
<td>28.232±0.017</td>
<td>2.226±0.018</td>
<td>8.6±0.2</td>
<td>0.989</td>
</tr>
<tr>
<td>12V</td>
<td>158±2</td>
<td>28.412±0.022</td>
<td>2.4118±0.022</td>
<td>8.0±0.2</td>
<td>0.997</td>
</tr>
<tr>
<td>13H</td>
<td>234±2</td>
<td>21.844±0.018</td>
<td>2.576±0.020</td>
<td>9.5±0.2</td>
<td>0.984</td>
</tr>
<tr>
<td>13V</td>
<td>226±2</td>
<td>27.180±0.019</td>
<td>2.440±0.021</td>
<td>8.4±0.2</td>
<td>0.998</td>
</tr>
<tr>
<td>14H</td>
<td>136±2</td>
<td>30.396±0.028</td>
<td>2.470±0.030</td>
<td>7.3±0.2</td>
<td>0.997</td>
</tr>
<tr>
<td>14V</td>
<td>139±2</td>
<td>23.808±0.024</td>
<td>2.322±0.027</td>
<td>7.0±0.2</td>
<td>0.995</td>
</tr>
<tr>
<td>15H</td>
<td>108±1</td>
<td>22.060±0.034</td>
<td>2.734±0.033</td>
<td>8.2±0.2</td>
<td>0.998</td>
</tr>
<tr>
<td>15V</td>
<td>137±2</td>
<td>22.156±0.027</td>
<td>2.269±0.027</td>
<td>8.5±0.2</td>
<td>0.999</td>
</tr>
<tr>
<td>32H</td>
<td>135±1</td>
<td>25.020±0.013</td>
<td>2.796±0.016</td>
<td>3.6±0.1</td>
<td>0.998</td>
</tr>
<tr>
<td>32V</td>
<td>215±2</td>
<td>19.304±0.009</td>
<td>1.802±0.012</td>
<td>2.9±0.1</td>
<td>0.995</td>
</tr>
</tbody>
</table>
3-D Visualization of Measured Profiles (April 15, 2013)
Profiles on September 13, 2012

Liu et al, *PRST-AB* 16 (2013) 012801
Beam Status during LW Measurement

Power and Energy on Target
Machine Mode: Target, Max Power: 869 kW, Energy Today: 12.5 MWhr

Average Power (kW)

Energy MWhr (3.6 GJ)

Measurement time window
Laser Based H- Beam Diagnostics at the SNS Accelerator Complex

1. MEBT Longitudinal Profile Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance Scanner
4. Laser Assisted H- Stripping

Injection

Ion Source

MEBT

DTL

CCL

SRF, $\beta=0.61$

SRF, $\beta=0.81$

1 GeV

Liquid Hg Target

Macro-pulse Laser

Extraction

RTBT

Mode-locked Laser

Q-Switch Laser

2.5 MeV

87 MeV

186 MeV

387 MeV
Laser Based H- Beam Diagnostics at the SNS Accelerator Complex

Mode-locked Laser

Q-switch Laser
Laser Based H- Beam Diagnostics at the SNS Accelerator Complex

1. MEBT Longitudinal Profile Monitor
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Ion Source
2.5 MeV 87 MeV 186 MeV 387 MeV 1 GeV

MEBT DTL CCL SRF, $\beta = 0.61$ SRF, $\beta = 0.81$

Injection
Macro-pulse Laser

HEBT RTBT

Liquid Hg Target

Mode-locked Laser
Q-Switch Laser
Laser Based H-Beam Diagnostics at the SNS Accelerator Complex

Ion Source

Mode-locked Laser

MEBT

Liquid Hg Target

RTBT

Injection

Extraction

2.5 MeV

1 GeV

87 MeV

186 MeV

387 MeV

MEBT Longitudinal Profile Monitor

Q-Switch Laser

SCL Laser Wire Profile Monitor

Injection

RTBT

Liquid Hg Target

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Ion Source

- 2.5 MeV
- 87 MeV
- 186 MeV
- 387 MeV

1

Mode-locked Laser

2

Q-Switch Laser

3

HEBT Laser Emittance Scanner

4

Laser Assisted H- Stripping

Injection

1 GeV

RTBT

Liquid Hg Target

Extraction
## Commissioning Experience

<table>
<thead>
<tr>
<th>Item</th>
<th>Findings</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Transport Line</td>
<td>Drift and vibration</td>
<td>Beam stabilization using active feedback</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Optical fiber based transport line (for low power)</td>
</tr>
<tr>
<td>Laser fluence</td>
<td>Over focusing of laser beam caused vacuum window breakdown</td>
<td>Avoid beam collimation optics close to measurement station. Ensure laser fluence below 1 J/cm².</td>
</tr>
<tr>
<td>Influence on beam</td>
<td>Electron collection magnets can cause tiny beam deflection</td>
<td>Correction magnet installed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Orbit correction</td>
</tr>
<tr>
<td>Radiation hardness of laser</td>
<td>Laser driver (&gt; 6 m from beam line) damaged in 1-2 days</td>
<td>Laser should be located outside the beamline for hadron machine</td>
</tr>
<tr>
<td></td>
<td>Unclear about laser head</td>
<td></td>
</tr>
<tr>
<td>Image sensors</td>
<td>Gigabit Ethernet cameras (&gt; 1.5 m from beamline)</td>
<td>Have to replace every 1-2 years</td>
</tr>
<tr>
<td>Motion control</td>
<td>Stepper motor (~ 30 cm from beam line); Picomotor actuators (1.5 m from beamline)</td>
<td>Stepper motors are very robust. Open-loop picomotors have to be used</td>
</tr>
</tbody>
</table>
SUMMARY

• World-first demonstration of simultaneous H- beam profile scan using a single laser source.

• The system has been brought to operation level – a single push-button initiates profile scan at 9 locations of SCL (corresponding to energy levels of 200 MeV -1 GeV).

• A number of laser based instruments have been commissioned/developed at the SNS accelerator complex.

• Laser based beam diagnostics at accelerator facilities is reliable and realistic and provides a useful tool for beam tuning and physics study.