MULTI-LASER-WIRE DIAGNOSTIC FOR THE BEAM PROFILE MEASUREMENT OF NEGATIVE HYDROGEN ION BEAM IN THE J-PARC LINAC

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1. Introduction / Objective

Laser-wire profile monitor

- Beam profile monitor plays a significant role in the high-current and high-brilliance accelerators.
- To avoid the thermal damage of the metallic wire scanner monitor and to reduce the radiation during an operation, the laser-wire method is the possible candidate for the profile measurement.
- The photon energy with only 0.75 eV is required for the photo detachment to generate $H^0$ from $H^{-}$.

Multi-laser-wire

- A simple optical design with only a pair of concave mirrors brings the multi-laser paths.
- No scanning device and no multiple-shots of the accelerated beams are required for the system.

Objective of the study

- To design the system for the J-PARC linac, the feasibility check and the demonstration of the multi-laser-wire formation are key missions of our study.
2. Beam specification of J-PARC linac

Beam-line layout of J-PARC linac

- Linac accelerates the H⁻ beam up to 400 MeV.
- There are 8 matching sections where the transverse matching is conducted using the wire scanner monitors.

Time structure of pulsed beam

- H⁻ beam is accelerated by 324 MHz RF which is the smallest time structure (3.01 ns).
- Intermediate bunch with 560 ns is for the injection to the downstream RCS.
- The longest pulse duration is 500 μs.
3. Design of the multi-laser-wire

Asymmetrical confocal cavity

A pair of concave mirrors with different diameters to make multi-paths of laser beam, and the beam waists of the laser paths are aligned in principle.

- The distance from axis is defined as $x_0, x_1, \ldots, x_n$.

$$x_1 = \left(\frac{f_2}{f_1}\right)x_0$$

$$x_2 = \left(\frac{f_2}{f_1}\right)x_1 = \left(\frac{f_2}{f_1}\right)^2 x_0$$

$$x_n = \left(\frac{f_2}{f_1}\right)^n x_0$$

- The $1/e^2$ radius at $c_0, c_1, \ldots, c_n$ as $w_0, w_1, \ldots, w_n$ using a wavelength ($\lambda$).

$$w_0 w_1 = \frac{\lambda f_1}{\pi}$$

$$w_1 w_2 = \frac{\lambda f_2}{\pi} \Rightarrow w_2 = \left(\frac{f_2}{f_1}\right) w_0$$

$$w_n = \left(\frac{f_2}{f_1}\right)^{n-1} w_0$$
4. Demonstration of the multi-laser-wire formation

Optical set-up of asymmetrical confocal cavity.

He-Ne Laser (515 nm, 2.4 eV, 300 mJ, M^2 < 1.2)

- A pair of mirrors with focus length of $f_1$ (435 mm) and $f_2$ (417 mm) are used.
- Distance between the mirrors are set to 852 mm ($L = f_1 + f_2$).
- We cut an edge of 2.0 mm of mirror 2, and set an offset of 25 mm from the centre axis ($x_0$).
4. Demonstration of the multi-laser-wire formation

Laser beam spots on film plane
4. Demonstration of the multi-laser-wire formation

Laser beam spots on film plane

Injecting Beam

Focal Lens

Mirror 2

Mirror 1
4. Demonstration of the multi-laser-wire formation

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Thin film plane

- A thin film plane is inserted to observe the laser paths.
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The relation \( w_n = (f_2/f_1)^{n-1} w_0 \) suggests the spot size decreases at \( f_2 > f_1 \).
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4. Demonstration of the multi-laser-wire formation

laser intensity measurement using a micro-mirror

- A micro mirror is produced by φ30um gold-wire with optical flat surface.
- A photodiode is used for the quantitative measurement.

- We could count 24-laser spots at the top-half of the center axis clearly.
- Spots are overlapped around the center axis.
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[Diagram showing laser intensity measurement setup with photodiode and micro-mirror.]
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![Diagram](image)
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![Diagram of laser setup and photodiode measurement](image)
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5. Design of the multi-laser-wire profile monitor

Horizontal resolution and dynamic range

- Minimum beam size is 2.0 RMS. Less than 0.2-mm intervals are required.
- The beam halo appears around 1/10 magnitude of the beam core. Over \(10^2\) dynamic range is required.

![Transverse profile taken by WSM](image)

Time intervals

- Accelerated beam duration is 3.01 ns intervals due to 324 MHz RF.
- Time of the laser beam round trip is \(4L/c\) (\(L = f_1 + f_2\)).
- Laser beam flight time should be in the RF repetition timing, i.e.,
  \[
  \frac{4L}{c} = \frac{n}{324 \times 10^6}.
  \]
5. Design of the multi-laser-wire profile monitor

**Wavelength of laser beam**

- Wavelength should be matched the cross section of the photo detachment of H⁻ to H⁰.
- Visible light (λ = 380-800 nm) is included in the large cross sectional region.
- When we chose the longer or shorter wavelength, we can take a match to the largest cross section with incident angle described by following eq.

\[ \lambda_{PRF} = \frac{\lambda_{LF}}{\gamma(1 + \beta \cos \alpha)} \]

**Requirements of the laser profile monitor**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>400 – 1200 nm</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>&lt; 0.2 mm</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>&gt; 10²</td>
</tr>
<tr>
<td>Measurement time</td>
<td>2.5 mins / profile</td>
</tr>
</tbody>
</table>
6. Conclusion

Advancement of the multi-laser profile monitor
- No scanning device is required.
- It is non-destructive to the accelerated beam.
- Fast data taking.

Summary
- Demonstration of the multi-laser-wire formation was conducted.
- We set the specification of the laser profile measurement.

Future works / Discussions
- Noise reduction due to electrons come from physical process.
- Need to decide the electron detector.
- Design, fabrication and test at 3-MeV beam line.
- Application to the 400-MeV beam line.