High Power Target Instrumentation at J-PARC for Neutron and Muon Sources

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Outline

- Introduction

- Present mercury target status

- R&D of beam instruments for MLF
  - Beam monitor
  - Beam flattening system
  - 2D profile monitor

- Future plans at J-PARC
  - Facility for R&D of ADS (TEF)
  - 2nd target station for MLF
J-PARC = Japan Proton Accelerator Research Complex

JFY2007 Beam
JFY2008 Beam
JFY2009 Beam

3GeV Synchrotron RCS (25Hz, 1MW)
30GeV Synchrotron MR (0.75MW)

Linac 400MeV (50mA)

Materials & Life Science Facility (MLF)

Transmutation Facility (TEF) (Phase II)

Hadron Experiment Facility

Neutrino Exp. Facility (294km to Super KAMIOKANDE)

JRR-3M 800m to MLF

Bird’s eye photo

Neutron beam lines (23)
Beam transport to MLF

Length of BT: 314m
Partial of 25 Hz beam goes to MR FX: 2.48 s, SX: 5.5 s

Ep: 3GeV
Power: 1MW
Rep.: 25Hz

Material and Life Science Experimental Facility (MLF)

FWHM ~150ns

600ns
Targets placed at MLF

Muon target
- Carbon graphite (IG430)
- 8% beam lost (80 kW loss)
- Highest intensity in the world

Neutron target
- Mercury
- Highest pulse intensity in the world

Rotating target

Thickness: 2 cm
Diameter: 30 cm

Width: 34 cm
Length: 2 m

Safety shroud
Double wall structure

Muon target
collimators
proton beam window
neutron target

NM tunnel
Present status of the mercury target
Efforts to mitigate cavitation damage with gas micro-bubbles

Mercury target vessel

- Beam window (2.5 mm-t)
- Most vulnerable to cavitation damage

Swirl type bubbler

He-gas micro-bubbles injecting into Hg target

Vibration measurement with a Laser Doppler Vibrometer (LDV)

Cavitation bubble

- Bubble inflates by the mercury negative pressure.
- Cavitation bubble shrinks rapidly.
- Shrink energy concentrates to one point

Graph: Velocity amplitude (m/s) vs Time (ms)
Operational history of JSNS

- Earthquake
- Accident at Hadron Facility: 532 kW as of September 30, 2015
- Interruption due to a trouble of Hg-target: 593 kW
- Hg-target replacement: 1 MW test
- ~1 month interruption due to the fire in MLF
- Interruption due to a trouble of Hg-target

As of September 30, 2015
In April 2015, water leak of mercury target was found during 500 kW beam operation. Coolant water in target shroud soaked out through the defect of the welding.

On Nov 2015, similar event happened. Water leaked into inner shroud so that we can not find the leaked point (possibly mirror).

Welding of water channel might be cause of the issue. Since no robust target and no enough space for storage remains, operational beam power is decided as 200-kW.
R&D for high power beam instruments
Beam diagnostics for profile and halo

- Profile monitor and halo monitor (online monitor)
  - Multi Wire Profile Monitors (MWPMs) : SiC wires (15 sets)
  - Stationary MWPM at proton beam window (PBW), separation between vacuum and helium, placed at 1.8 m upstream of the mercury target

- 2D profile: Image of residual dose read out by imaging plate (IP)
  - IP attached to target by remote handling after beam irradiation
Beam profile at mercury target

2-D measurement by IP

0.1 MW (2009 Dec)

Profile result by the IP
- Fitted by two Gaussian
Convolution primary protons and secondary particles

- Fit by Gaussian

MWPM at PBW

0.2 MW (2010 Dec)

Only 6 days cooling after irradiation of 0.2 MW beam, the image was obtained.
⇒ Possible for 1MW with certain cooling time

Result by MWPM
- Fit by Gaussian
- Width and position for each pulse obtained
- Good agreement width result by IP
**Proton beam at the target**

- **Beam operational status**
  - Study with 1 MW beam
  - User operation with 0.5MW

- **Cavitation damage** is critical for high power beam with short pulse
  - Proportional to $4^{th}$ power of the peak current density at target
  - Useless beam scanning to mitigate damage
  - More serious than SNS due to high energy per pulse (JSNS 40 kJ/shot)

- Although helium bubble injection mitigates the damage, peak reduction is essential.
- Required development of beam flattening system

Pin holes at target of SNS by R. Bernie

Damage at JSNS target

Here

Target vessel

5 cm

FWHM ~150ns

600ns
Beam flattening system

Principle: Beam edge folded by non-linear optics

Octupole magnet: 800 T/m³

Phase space

Real space (Horizontal)

Linear

Non-linear

Position

Position

By distribution at horizontal

Horizontal plan

OCT1

OCT2
Beam tuning tool with SAD code

\[ T = R^{-1}M \]

Fit by observed width and extrapolate to target

Fit region

Extrapolate

Muon target

Fitted parameter

OCT tuning

Beam profile can be estimated by tracking

**Twiss Optics**

- Opt.
- Beta Range (mm): 100.0
- Sigma Range (mm): 40.000

**Fit region**

- Fit zone
- PBW

**Octopus**

- Use measured eps
- Fixed value
  - EPSX for OCT: 10,000
  - EPSV for OCT: 10,000
  - X at OCT1: 0.000
  - X at OCT2: 0.000
  - Y at OCT1: 0.000
  - Y at OCT2: 0.000

**Fit parameters**

- \( x_0 \)
- \( y_0 \)
- \( x_0 \)
- \( y_0 \)
- \( \Delta x \)
- \( \Delta y \)
- \( \Delta x \)
- \( \Delta y \)

**OCT tuning**
- Flat beam was obtained and lower intensity of halo was observed
- Good agreement of calculation even for with muon target
- Peak smaller by 14 % and 20 % at horizontal and vertical. Overall 30~40 % reduced.
Beam profile at neutron target (calculation)

- Ideal shape obtained
Beam loss status

Beam loss was quantitatively observed by mean of activation obtained by dosimeter for 500 kW.

No significant beam loss aroused due to non-linear optics.

To decrease the beam loss at hands on maintenance area (M1) with obtaining more flat shape, star shaped duct following Q mag with large aperture is installing at the present.
Demonstration ~1 MW beam operation

- Demonstrated 0.8 MW (0.9 MWeq) for short duration (70 s x 7times) due to outgas release from foil at RCS for charge exchange
- Radiation dose at target station showed as same as 0.5 MW beam

Beam profile
- Anti-correlated painting makes flat shape
- 30% of peak reduction (11 J/cc/pulse) achievable for 1MW beam operation

<table>
<thead>
<tr>
<th>Beam power (MW)</th>
<th>25Hz equiv. power (MWeq)</th>
<th>Allowable RF rep. (Hz)</th>
<th>RCS inject. paint</th>
<th>Area of paint (π mm mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.52 (SX)</td>
<td>25</td>
<td>Anti</td>
<td>150</td>
</tr>
<tr>
<td>0.8</td>
<td>0.86 (FX)</td>
<td>25</td>
<td>Cor</td>
<td>100</td>
</tr>
<tr>
<td>0.94</td>
<td>1.0 (FX)</td>
<td>0.16</td>
<td>Cor</td>
<td>100</td>
</tr>
</tbody>
</table>

Power [kw] vs Time

- 1 MW

- 0.8 MW w/o OCT
- 0.5 MW w/o OCT
A new profile monitor required to continuously observe 2D profile withstanding high power beam.

- Rad hard fiber scope (Fujikura FIGR-20, 20000 pixels) coupled with near-IR filter
- Applicable for high temperature target (for ADS target)
- Developing luminescent type

Fujikura Fiber

<table>
<thead>
<tr>
<th>Gy</th>
<th>0 Gy</th>
<th>1 MGy</th>
<th>2 MGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>650 °C</td>
<td>980 °C</td>
<td>1300 °C</td>
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Images showing degradation of the fiber over increasing temperatures.
To predict lifetime of the PBW with high accuracy, precious validation of calculation code for nuclear reaction is necessary.

Production cross section measurement was carried out.

Result at SINQ/PSI for 0.6GeV


Obtained good accuracy
Future plans at J-PARC
2nd target station for MLF

1st target ST (TS-1): 24 Hz: 1MW
2nd target ST (TS-2) 1Hz: 42kW (Designed to accept 1 MW)

Rotating tungsten target
Windowless Pb-Bi target
New facility at J-PARC for R&D of ADS

• TEF-T: Lead Bismuth (Pb-Bi) target test facility
  - H⁻ beam, 25Hz, 400 MeV, 250 kW
  - Multi purpose use: High energy neutron beam line and ISOL

• TEF-P: Subcritical assembly (Minor actinide, Am, Np)
  - H⁺ beam, 25Hz, 400 MeV, 10 W
  - Laser charge exchange (LCE) developing
R&D of Laser Charge Exchanger (LCE)

• LCE was examined at RFQ test-stand using 3MeV H\(^+\) beam was conducted last week.
• Demonstrated 5 W equivalent power of beam for TEF-P (0.4 GeV, 25 Hz, peak I=50mA) extraction.

Phototube

Stripping foil

+\( B \) (Q switch)

Nd:YAG laser (25Hz)
Summary

To mitigate cavitation damage on the mercury target vessel, beam flattening system has been developed. Peak intensity will be reduced by ~30% of linear optics.

Present beam operation had started with power of 0.5 MW. After installation of revised mercury target at the welding, the power will be ramped up to the beam power to 1 MW.

For R&D of ADS, TEF facility hopefully will start in a few years.
Thank you for your attention

Be patient for development of the target and instruments