Present Status of Neutron Source at J-PARC MLF

Katsuhiro Haga
On behalf of MLF team
(Neutron Source Section)
1-MW spallation neutron source at J-PARC

Cryogenic hydrogen system

Moderators

Proton beam
3 GeV, 1MW, 25 Hz

Mercury target system

Neutron beam lines (23)
21: in operation

5m
### History of target operation at J-PARC

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**Improved robust design**

Failure in outer water shroud

Max. 505 kW, 170 MWh

Failure in inner water shroud

300 ~ 525 kW, 1812 MWh

6 times target replacements to date
Work plan in FY2019

• Neutron source operations for 8 run cycles (176 days) with an availability over 90%
• Target operations with a beam power of 500 kW or higher.
• Replacement to the target vessel of new design, termed as constrain-free structure, which has minimum coupling between water shroud and mercury vessel during summer shutdown. -> The replacement work is going on.
• Completion of a new target vessel.
• Completion of the transportation of a used target vessel from MLF building to another storage building (Radio-Activated Materials Building). -> finished on July 22
**Beam Operations with #8 and #9 Targets**

- Stable and long term beam operation of more than 500kW was achieved with high average efficiency of more than 90%.
- **1MW beam study** at the end of user beam operations was successful. 
  
    - Average efficiency in the case of target #9 was over 98%!

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**Average operational efficiency per run#**

**Target #8**

- Beam power:
- Summer shutdown (target replacement)

**Target #9**

- Beam power:
- 1MW study (1 hour)
- 1MW study (10.5 hour)

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**Operational Efficiency [%]**

**Beam Power [kW]**

- 0
- 100
- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000

**Operational Efficiency [%]**

- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
- 90
- 100

**Operational Efficiency [%]**

**Beam Power [kW]**

- 0
- 100
- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000
1MW Target Study of Target #9

- Heat deposition of 50% of beam power into mercury was assumed.
- Temperature riser of mercury showed good agreement with the analytical prediction.
- Temperature rise of mercury vessel at 1 MW was a little bit less than the analytical prediction.
- The effect of beam profile can be one of the reasons.

Facility data of steady state under 1 MW beam condition could be obtained for the first time.
Critical Issues of Target Vessel for High-power Operation

1. Improvement of the target vessel design to have sufficient reliability and robustness.

2. Mitigation of pitting damage at the beam window of the target vessel.
Design improvements of target vessel

1st~7th (previous)

- Hg vessel
- Water shroud
- Bolts

Made with diffusion bonding and many welds which can be the cause of initial defects.

8th, 9th (current)

- Diffusion bonding
- Monolithic structure of water shroud & Hg vessel

Welds were drastically reduced.

High robustness and reliability can be obtained.

10th, 11th, 12th

- Constraint-free
- End plate

- Water shroud
- Hg vessel
- Water channels

- No coupling between vessels.
- Fabrication techniques were improved.

Constraints between vessels cause high thermal stress which limits beam power.
Fabrication of Constraint-free Type Target

- Fabricated with the combination of TIG welding and Electron Beam welding.
- By the high accuracy fabrication and welding techniques with little deformation, the 3 mm gap of helium layer could be maintained.
- By the intensified non-destructive inspection, tiny defects can be detected in the fabrication process to minimize the possibility of target failure during the beam operation.
- The constraint-free type target is ready to be used from this November.

Suppression of welding deformation is the key issue.
Pitting Damage by Pressure Wave

Mercury vessel

Pulsed proton beam

Abrupt heating of mercury

Thermal expansion

Pressure wave

Pitting damage of the wall by the cavitation

Beam window (Thickness: 3 mm)
Most vulnerable to pitting damage

Actual pitting damages

#1 SNS target
3055 MWh
(D. McClintock, JNM 2012)

Max. pit depth: 0.25 mm

#1 J-PARC target
471 MWh

Cavitation bubble inflates by the mercury negative pressure.

Cavitation bubble shrinks rapidly.

Shrink energy concentrates to one point and damage is formed.

Micro-jet

Schematic images of pitting damage generation
Technologies for Pitting Damage Mitigation

Micro-bubble injection into mercury

A: Center of thermal shock
- Absorption of thermal expansion of mercury by bubble contraction

B: Propagation path
- Attenuation of pressure waves by thermal dissipation of kinetic energy

Rapid mercury flow in narrow channel

Laboratory experiment in JAEA
- Stagnant
- Flow

Proton beam

Outer wall

2mm

Inner wall

50 mm
Monitoring the Efficacy of Bubble Injection

- Laser Doppler Vibrometer (LDV)
- Target vessel
- Microphone
- Proton beam: 300 kW

Vibration of target vessel #8

- Velocity amplitude, m/s
- Study data in the past
- Analytical prediction
- 1MW study data

Sound signal of target vessel

- Normalized peak value of sound signal
- Data of target #8
- Data of target #9

P: beam power
Q: heat density
α, β: constant

- P, Q and vibration velocity amplitude are related well by the parameter $P^\alpha Q^\beta$.
- The parameter showed good agreement with the analytical prediction.
- Because of inadequate welding, Mirror dropped off the target #9 by pressure wave vibration.
- Efficacy of bubble injection was monitored by sound signal recorded by a microphone.
- The sound data showed good linearity and agreement between #8 and #9 targets.
Cutting Specimens from Beam Window of Target Vessel

**Target No. 8** (Oct. 2017 — Jul. 2018)
- Total energy: 1812 MWh
- Av. beam power: 434 kW@25 Hz
- Total pulses: ca. 3.76×10^8 shots

- Specimens were cut out at the center and off-center locations of the beam window of target #8.
- Quantitative damage data on the bulk side of the inner wall protected by microbubble injection was obtained for the first time.
Cavitation Damage of Target #8

- Damage on the narrow channel side was much less than that on the bulk side, which is advantageous to protect the outer wall, i.e. mercury boundary.
- No-visible damages were observed on the off-center specimens.
- Soundness of the inner wall is also important since damage penetration through the inner wall from the bulk side would hamper the damage mitigation effect in the narrow channel.
# Experimental verification

## Cavitation bubble behaviors in flow and narrow gap

- **Flow velocity and gap width dependency (confirmed)**
  - Damage is reduced as the flow velocity increases.
  - Damage changes depending on gap width.

- **Power dependency of cavitation damage in narrow channel has not clarified yet.**
  - Effect of wall boundary on cavitation growing and collapsing behavior
  - Pressure gradient strongly affects in narrow gap, which should be verified through experiments and numerical simulation

<table>
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<tr>
<th>Stagnant</th>
<th>Flowing 1.7 m/s</th>
<th>Gap: 10 mm</th>
<th>Gap: 3 mm</th>
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<tr>
<td><img src="image1.png" alt="Image" /> 200 kfps</td>
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- **Electrode diameter:** 1 mm

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Influence of a Hole of Inner Wall on Flow Velocity

- Basic water experiments of double flow to understand flow pattern around beam window
- Effects of opening diameter in narrow channel on reduction of downstream velocity
  ---wall curvature on flow pattern
  ---cross flow for bubble distribution, bubble coalescence in narrow channel, etc.
- Basic flow examination -> Simulation -> Mockup model -> Mercury simulation and examination
Analytical Design of a New Target Vessel (Tentative)

**Mercury flow velocity**
- Bubbler position of current target

**Mercury vessel temperature**

**Mercury temperature**

**Helium bubble particle flow trace**: \( \phi 80 \mu m \)
Outlook of operational beam power upgrade

- Beam power will be increased step by step to keep stable operation.
- Observation results of pitting damage will be decisive factor of beam power.

Further development of pitting-damage mitigation-technology will be continued for high power stable target operation.
Summary

- Stable and long term beam operation of more than 500kW was achieved with high average efficiency of more than 90%.
- 1MW beam study at the end of user beam operations was successful.
- Fabrication of the target vessel of constrain-free structure is finished and will be installed next month.
- The pitting damage in narrow channel of target #8 and #9 was much less than that on the bulk side, which is advantageous to protect the mercury boundary, but beam power will be increased step by step to keep stable operation.
- Further development of pitting-damage mitigation-technology will be continued for stable target operation at higher power.