Fabrication Status of the Prototype Spoke Cavity for the JAEA-ADS Linac

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JAEA/J-PARC

Jun Tamura

on behalf of
J. Tamura, Y. Kondo, B. Yee-Rendon, S. Meigo, F. Maekawa, JAEA/J-PARC
E. Kako, K. Umemori, H. Sakai, T. Dohmae, KEK/iCASA
Special Seminar-2: “Japanese ADS program: Current status and future plan”, by Fujio Maekawa (Friday, October 14).

Accelerator driven nuclear transmutation system proposed in JAEA

Super-conducting LINAC

- Particle: Proton
- Energy: 1.5 GeV
- Current: 20 mA (CW)
- Power: 30 MW

Number of cavities

- HWR: 25
- SSR1: 66
- SSR2: 72
- EllipR1: 60
- EllipR2: 70

Prototype spoke cavity for the JAEA-ADS linac

Design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>324 MHz</td>
</tr>
<tr>
<td>$\beta_g$</td>
<td>0.188</td>
</tr>
<tr>
<td>$\beta_{opt}$</td>
<td>0.24</td>
</tr>
<tr>
<td>Beam aperture</td>
<td>40 mm</td>
</tr>
<tr>
<td>Cavity diameter</td>
<td>$\approx$ 500 mm</td>
</tr>
<tr>
<td>Cavity length</td>
<td>300 mm</td>
</tr>
<tr>
<td>$L_{eff} = \beta_{opt} \lambda$</td>
<td>222 mm</td>
</tr>
<tr>
<td>$G = Q_0 R_s$</td>
<td>90 $\Omega$</td>
</tr>
<tr>
<td>$T(\beta_{opt}) = V_{acc}/V_0$</td>
<td>0.81</td>
</tr>
<tr>
<td>$r/Q = V_{acc}/\omega W$</td>
<td>240 $\Omega$</td>
</tr>
<tr>
<td>$E_{peak}/E_{acc}$</td>
<td>4.1</td>
</tr>
<tr>
<td>$B_{peak}/E_{acc}$</td>
<td>7.1 mT/(MV/m)</td>
</tr>
</tbody>
</table>
Cavity parts configuration

- The fabrication process for the prototype spoke cavity was reviewed in fiscal year 2019.
- The actual cavity fabrication started in 2020.

The prototype spoke cavity is made of pure Nb except for the port flanges (Nb-Ti).
Most of the cavity parts were shaped in fiscal year 2020 by press-forming and machining.

- Major parts were press-formed from Nb sheets with a thickness of 3.5 mm.
- The end drift-tubes (nose-shaped electrodes) were machined from Nb blocks.
- The port flanges were machined from Nb-Ti cylindrical blocks.
Example of cavity parts shaping
< press-forming the cavity lid parts >

Before pressing

After pressing

Edge cutting (trimming)
Electron beam welding (EBW)

- All the shaped cavity parts are joined together by electron beam welding (EBW).
- We have started welding the cavity parts together in 2021.

Smooth welding bead (RF surface) is required.
NG: Insufficient EB penetration
NG: welding hole

Welding direction

Circumferential shaped welding lines
Investigation of the optimal EBW parameters

- Before welding the actual cavity parts, the EBW beam parameters for each welding condition were investigated using mock-up Nb test pieces.
- To remove impurities, all welding grooves were acid cleaned (chemically polished) prior to each EBW.

Sloped EBW lines for joining the two half spokes together

Front side to EB

Back side to EB
Welding the two half spokes together

Sloped EBW lines for joining the two half spokes together

Front side to EB

Back side to EB
**Spatter @ EBW**

**Without acid cleaning the welding groove**

Melting point
Niobium: 2,469 °C
Brass: approx. 800 °C

**Lessens learned:**
Contaminant removal (Chemical polishing of welding grooves) is a very important process for EBW.

**Spatter @ EBW**

**Spoke electrode**

**Wire electric discharge machine**

**The discharge wire is made of brass.**

**Wire-cut cutting cross section**

**Opposite cross section**
Fabrication of the spoke part

Elliptical EBW lines for joining the spoke electrode and the spoke-roots together
To ensure the smoothness of the cavity’s inner surface, any notable edges, including the welding-bead undercut, were removed by machine polishing.

The press-shaping process reduced the thickness of the spoke-root in the elliptical long radial direction.

⇒ Mismatch : Elliptical circumference
Fabrication of the cavity’s body section

- We have fabricated the body section of the prototype spoke cavity.
- By preliminarily examining the optimal EBW conditions, each cavity part was welded together with a smooth welding bead.
- So far, any obvious welding defects such as unpenetrated welds and welding holes have not been found.
Frequency measurement (1/2)

- We performed the frequency measurement for the cavity’s body section to make sure there are no critical issues in the fabrication geometry.
- The body section was temporarily placed between two Al plates.
- A straight antenna was inserted into each of the two RF ports.
Frequency measurement (2/2)

- Measured frequency under atmospheric condition was 377.83 MHz, which was converted to 377.96 MHz in a vacuum taking into account the humidity effect.
- Measured frequency is not too far (-1.2 MHz) from that obtained by simulation (379.15 MHz).
- One of the major contribution to the frequency difference may be the reduced elliptical long radius (design : 80mm) of the spoke electrode roots.
- The difference is well within the range of frequency adjustment in the final fabrication phase by shortening the length of the cavity’s body section.
Summary

- As a first step toward the full-scale design of the CW proton linac for the JAEA-ADS, we are now prototyping a low-β (around 0.2) single spoke cavity.

- The actual cavity fabrication started in 2020.

- By preliminarily investigating the optimum welding conditions, each cavity part was joined with a smooth welding bead.

- Consequently, we have fabricated the cavity’s body section.

- We are now proceeding to the fabrication of the beam ports.
Thank you for your attention

We would like to thank the staff of Mitsubishi Electric Corporation for fabricating the body section of the prototype spoke cavity.

References.