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

October 12, 2022
Working Group #2, TTC 2022 meeting at Aomori-city

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

ADS proposed in JAEA

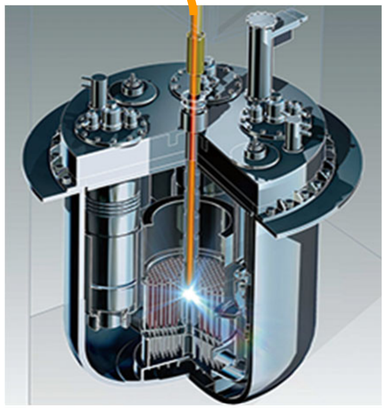
Special Seminar-2: "Japanese ADS program: Current status and future plan", by Fujio Maekawa (Friday, October 14).

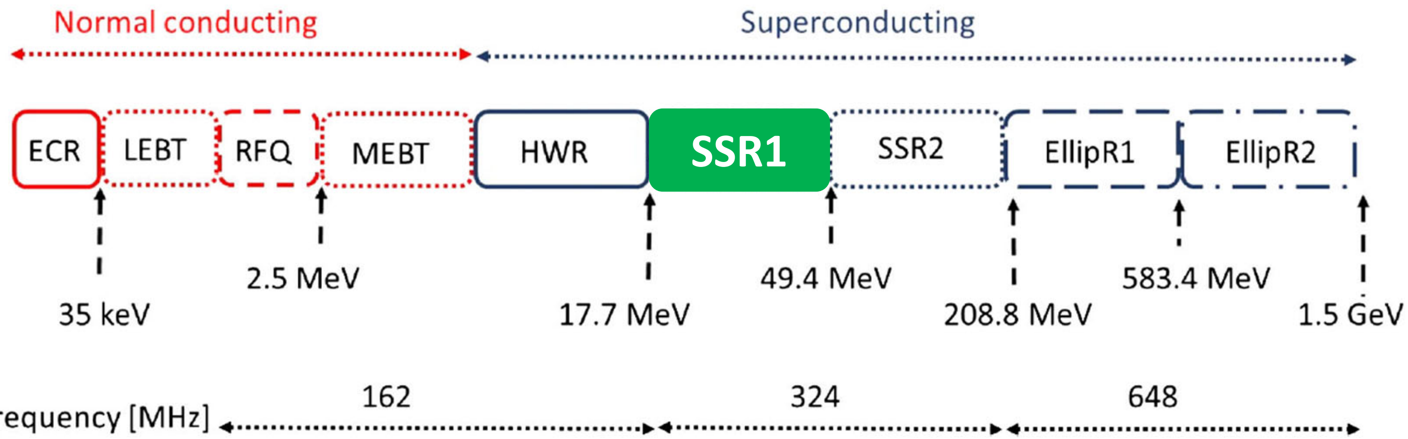
Accelerator driven nuclear transmutation system proposed in JAEA

Super-conducting LINAC

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

Proton beam
Max. 30 MW



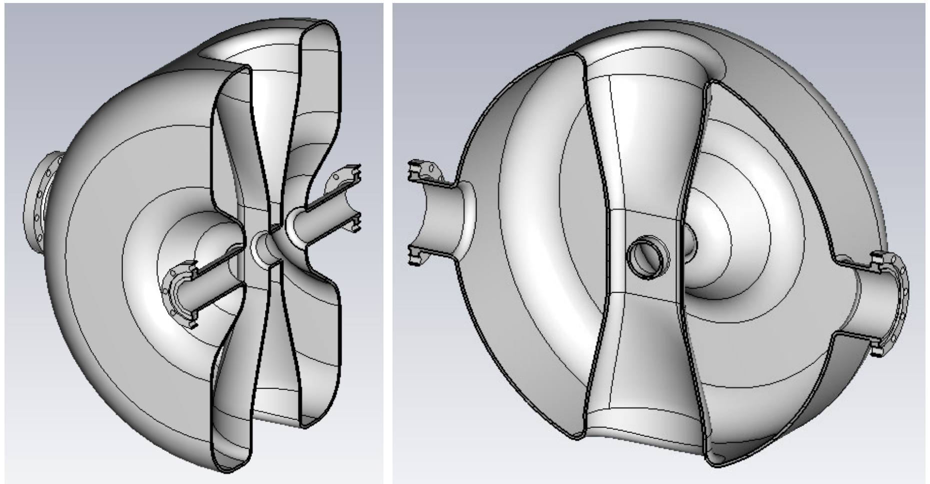


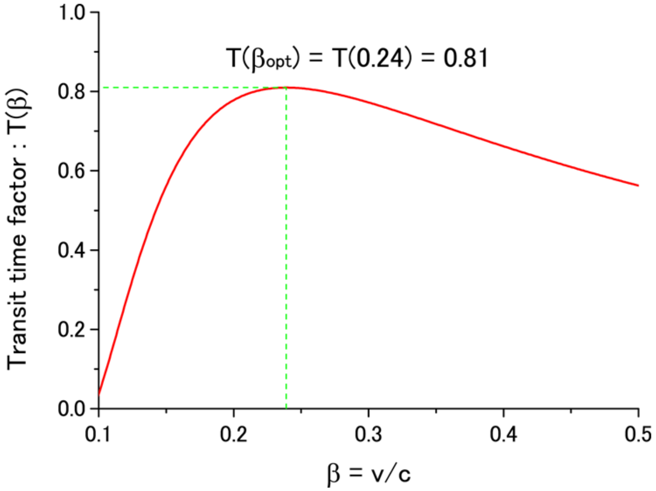
Number of cavities	
HWR	25
SSR1	66
SSR2	72
EllipR1	60
EllipR2	70

B. Yee-Rendon et al., "Design and beam dynamic studies of a 30-MW superconducting linac for an accelerator-driven subcritical system", Phys. Rev. Accel. Beams **24**, 120101 (2021).

Prototype spoke cavity for the JAEA-ADS linac

RFQ 162MHz → HWR 162MHz → **SSR1 324MHz** → SSR2 324MHz → ELL1 648MHz → ELL2 648MHz

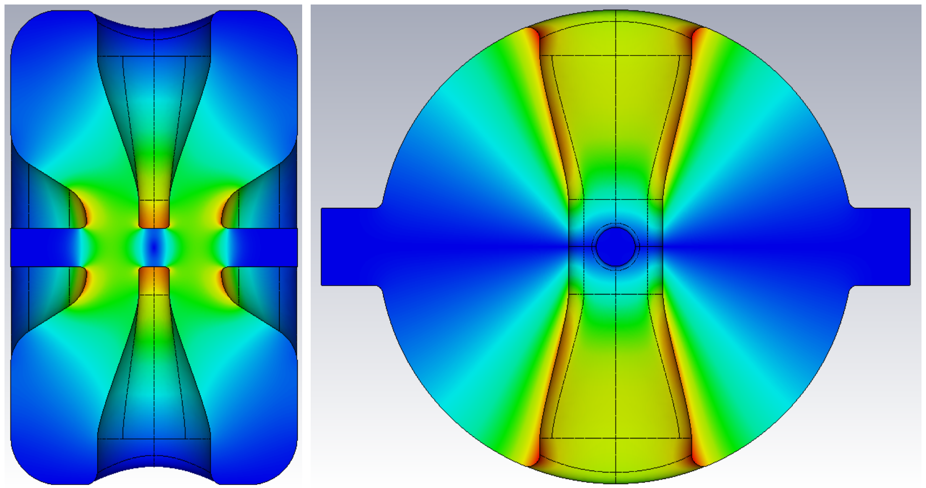


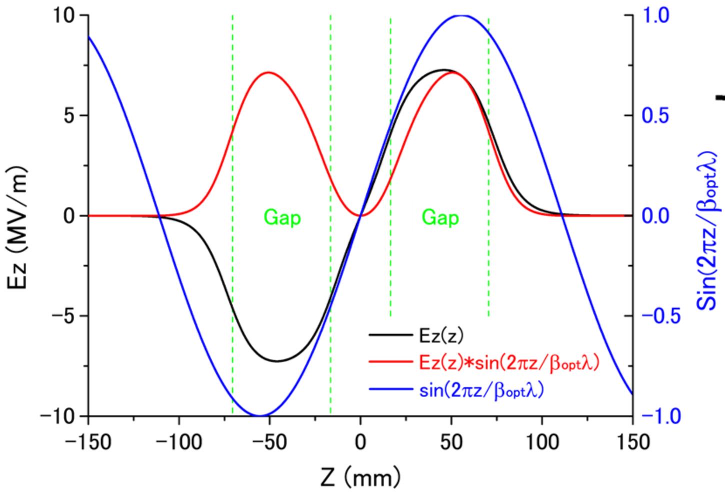


Design parameters

Parameter	Value
f_0	324 MHz
β_g	0.188
β_{opt}	0.24
Beam aperture	40 mm
Cavity diameter	≈ 500 mm
Cavity length	300 mm
$L_{eff} = \beta_{opt}\lambda$	222 mm
$G = Q_0 R_s$	90 Ω
$T(\beta_{opt}) = V_{acc}/V_0$	0.81
$r/Q = V_{acc}^2/\omega W$	240 Ω
E_{peak}/E_{acc}	4.1
B_{peak}/E_{acc}	7.1 mT/(MV/m)

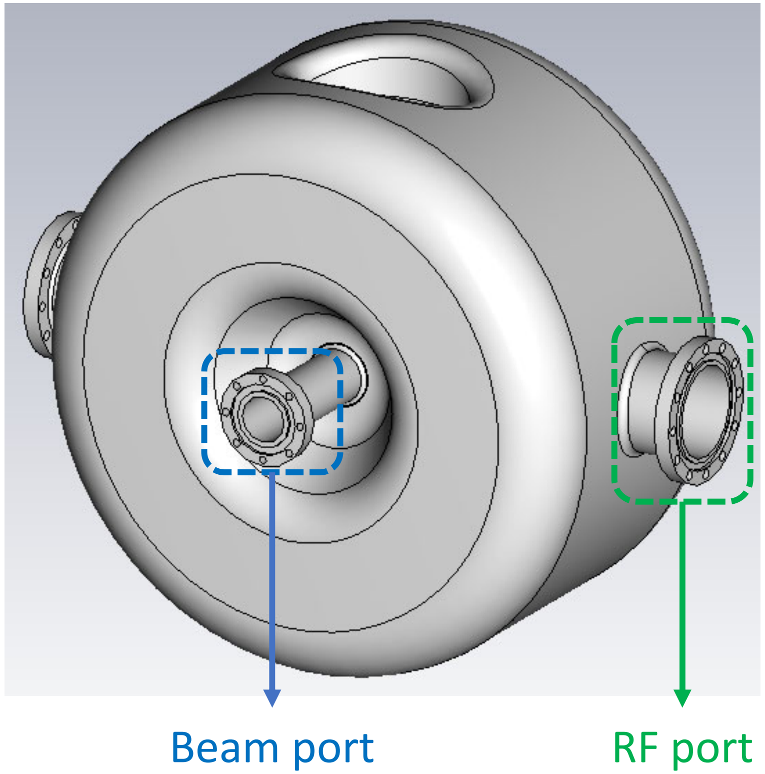
E-field **H-field**



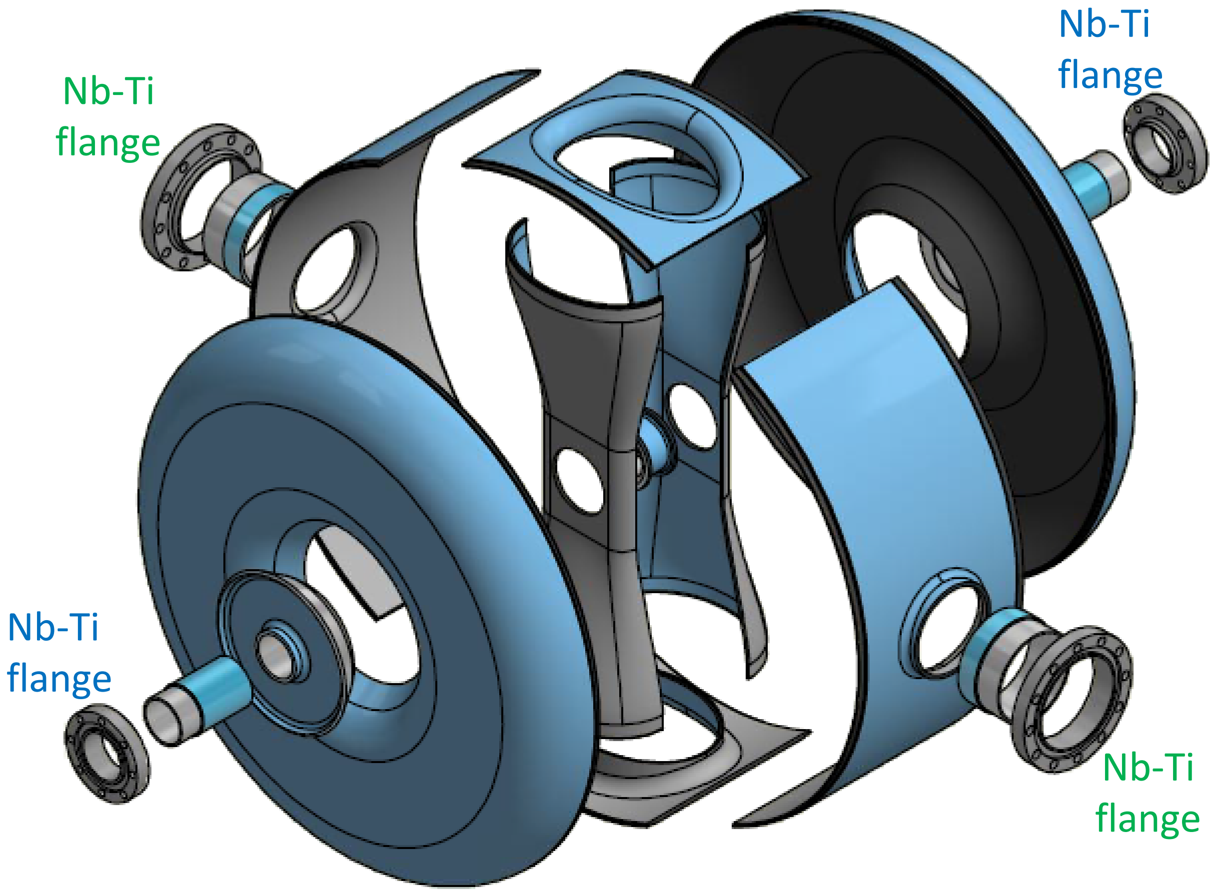


Cavity parts configuration

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



Outside view

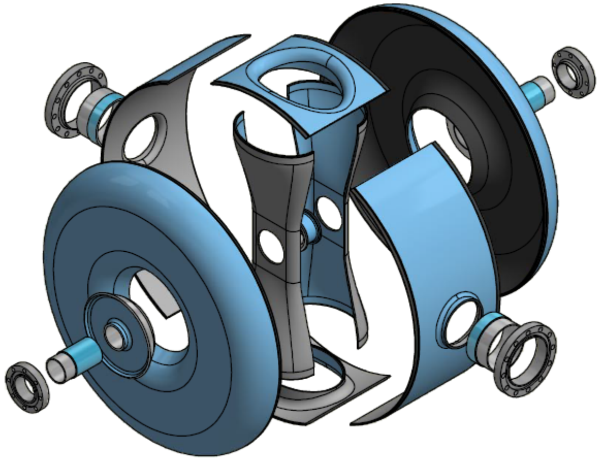


Component parts

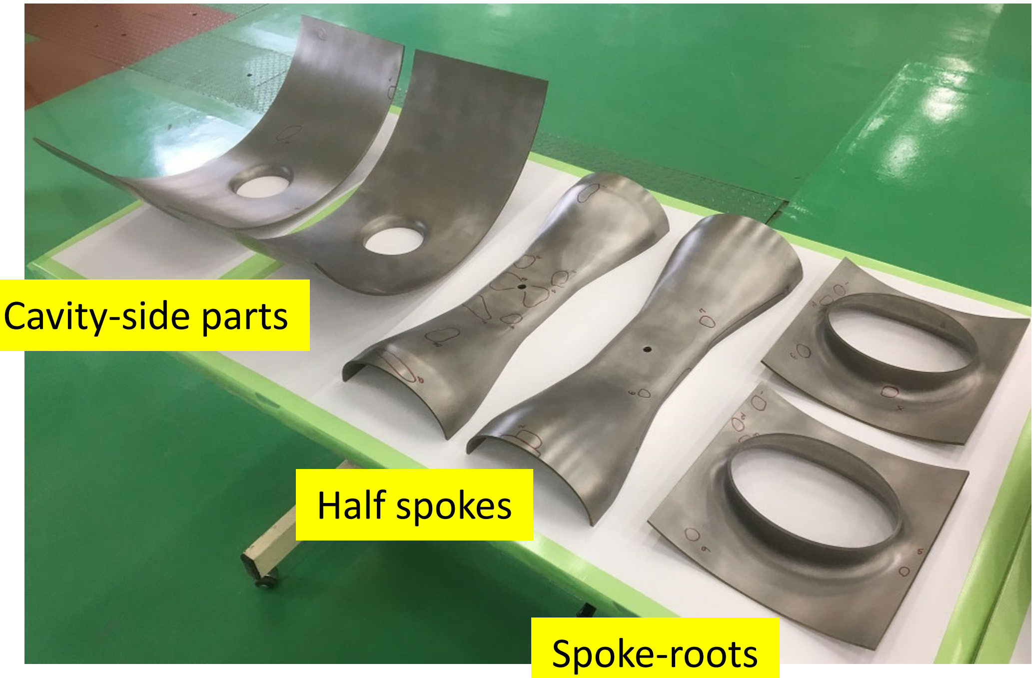
The prototype spoke cavity is made of pure Nb except for the port flanges (Nb-Ti).

Shaped cavity parts

End drift-tubes (EDTs)



Lids



Cavity-side parts

Half spokes

Spoke-roots

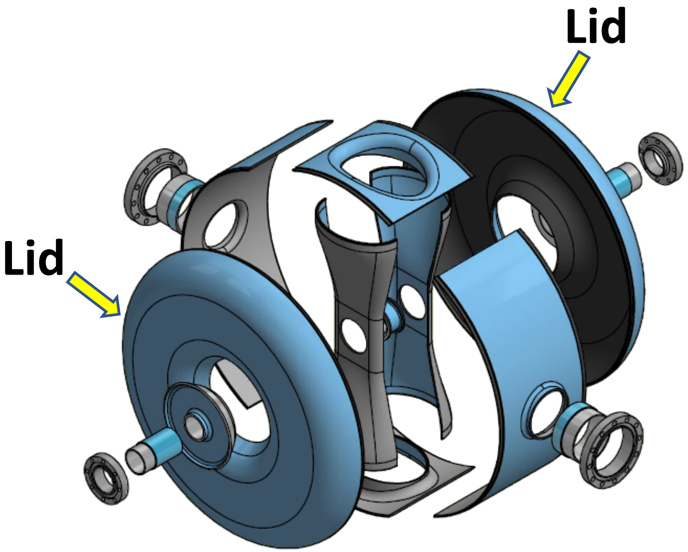
Beam port flanges

RF port flanges

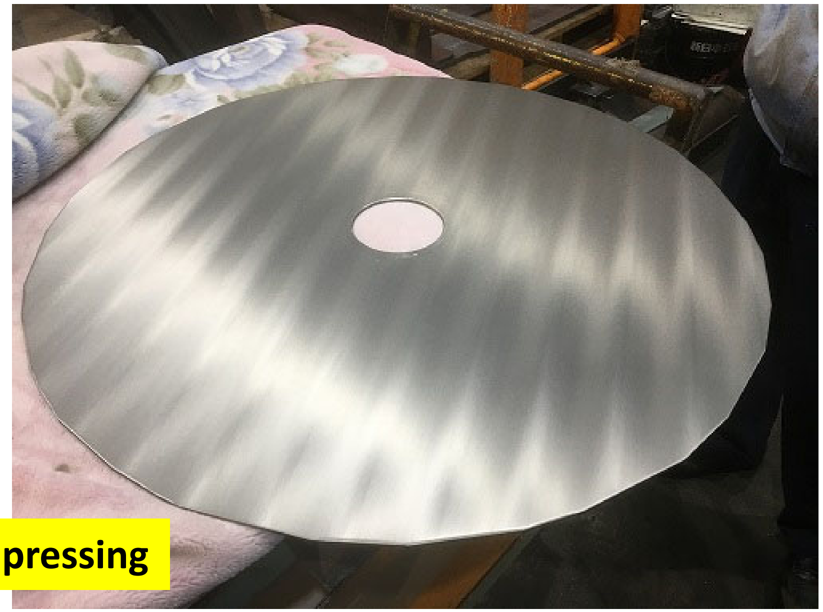
Most of the cavity parts were shaped in fiscal year 2020 by press-forming and machining.

- 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 >



Edge cutting (trimming)



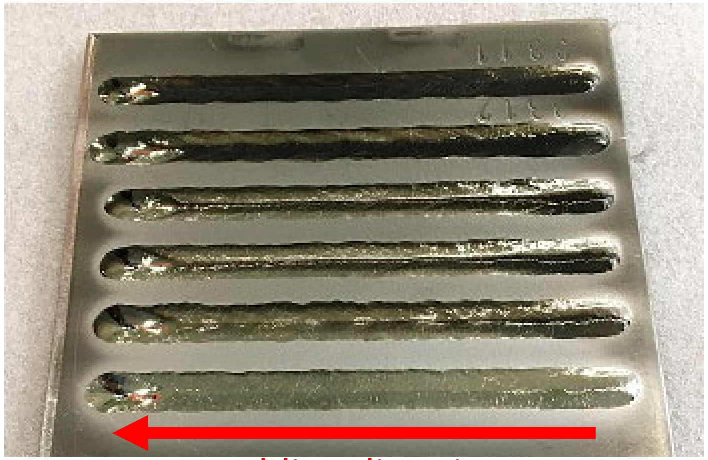
Before pressing

After pressing

Electron beam welding (EBW)

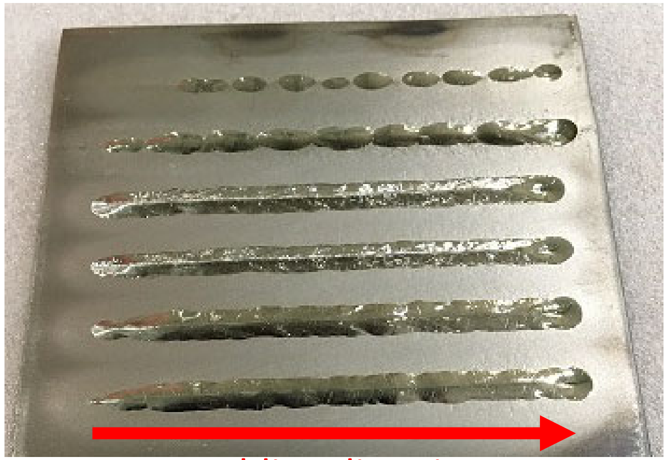
- All the shaped cavity parts are joined together by electron beam welding (EBW).
- We have started welding the cavity parts together in 2021.

Front side to EB



Welding direction

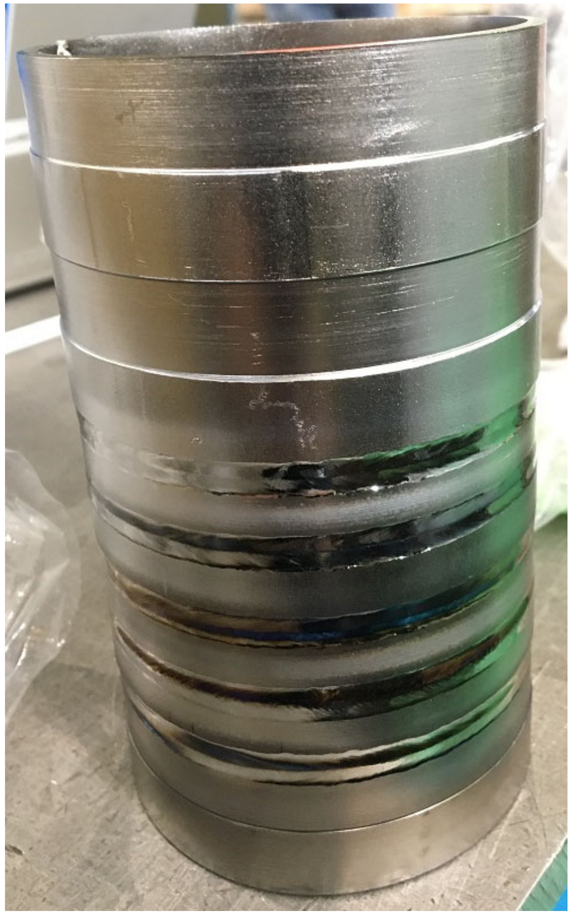
Back side to EB



Welding direction

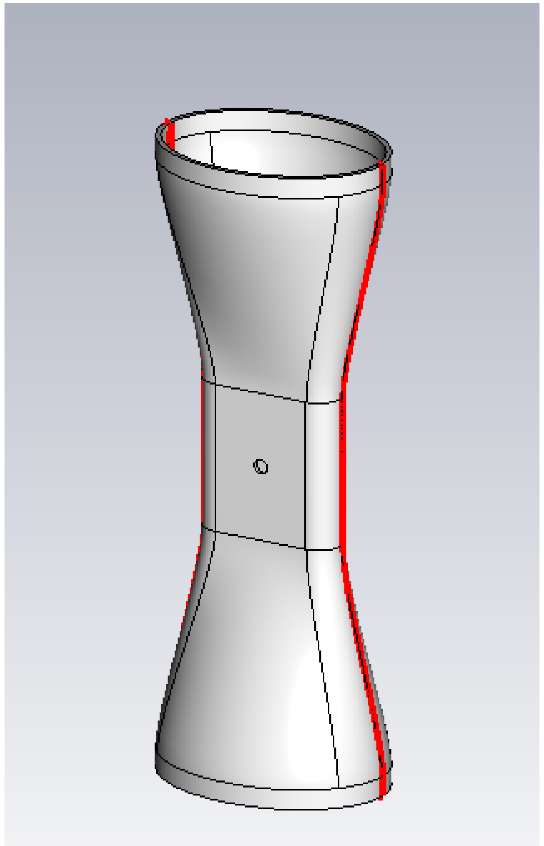
Smooth welding bead (RF surface) is required.
NG : Insufficient EB penetration
NG : welding hole

Circumferential shaped welding lines

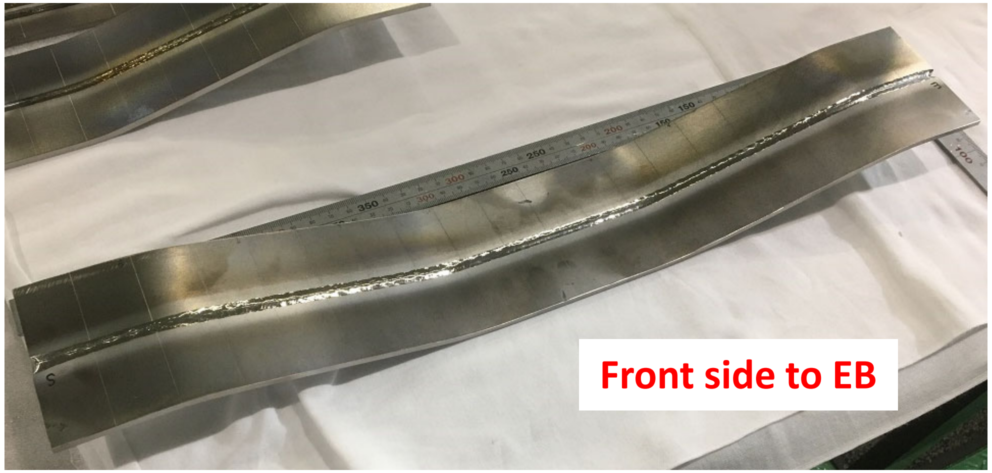


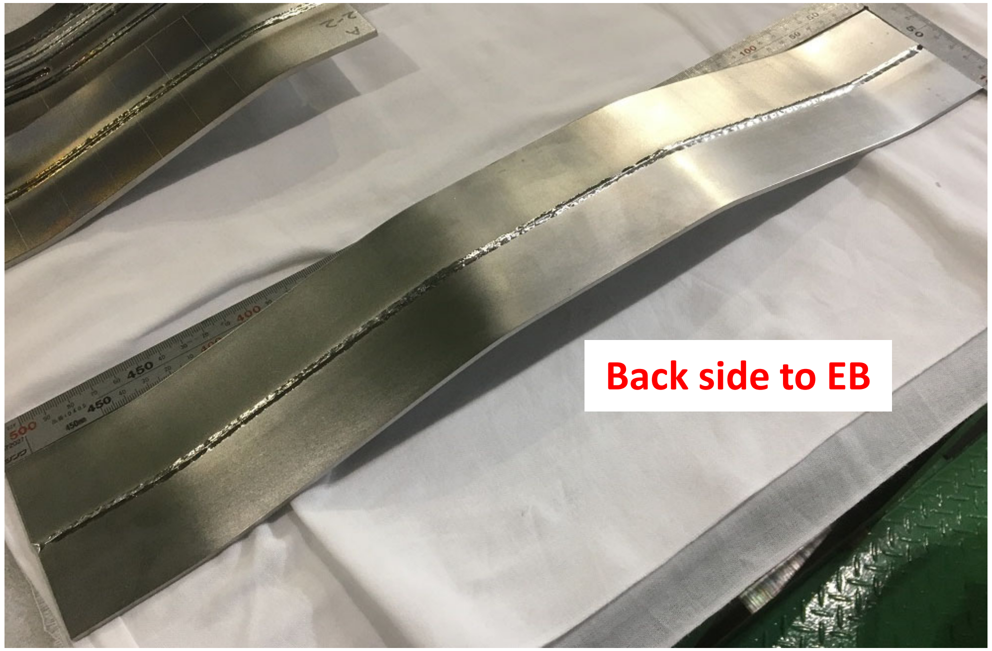
Investigation of the optimal EBW parameters

- 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.

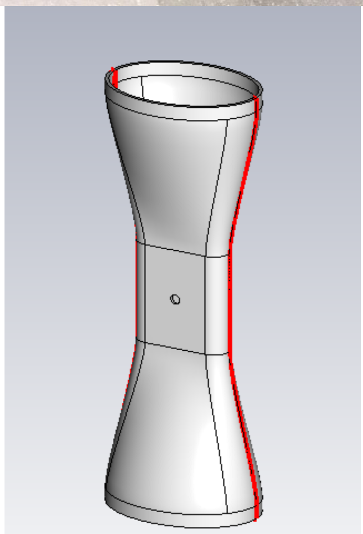


Sloped EBW lines for joining the two half spokes together



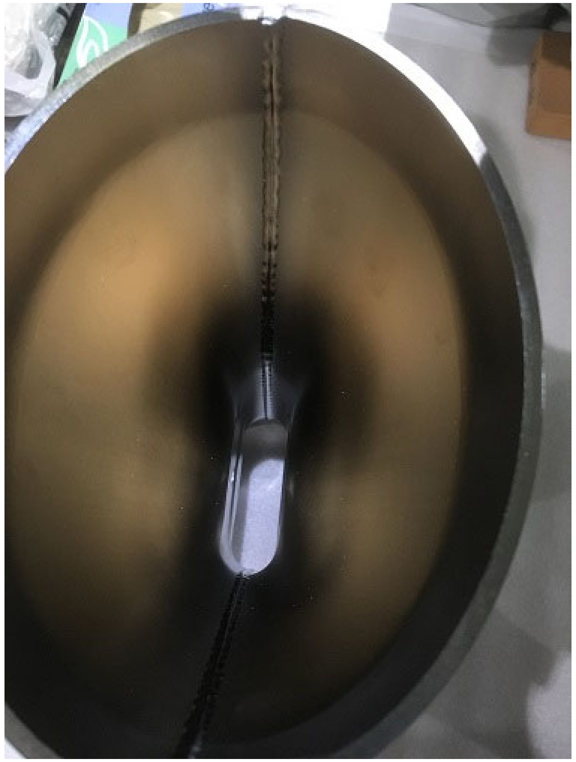


Welding the two half spokes together



Sloped EBW lines for joining the two half spokes together

Front side to EB

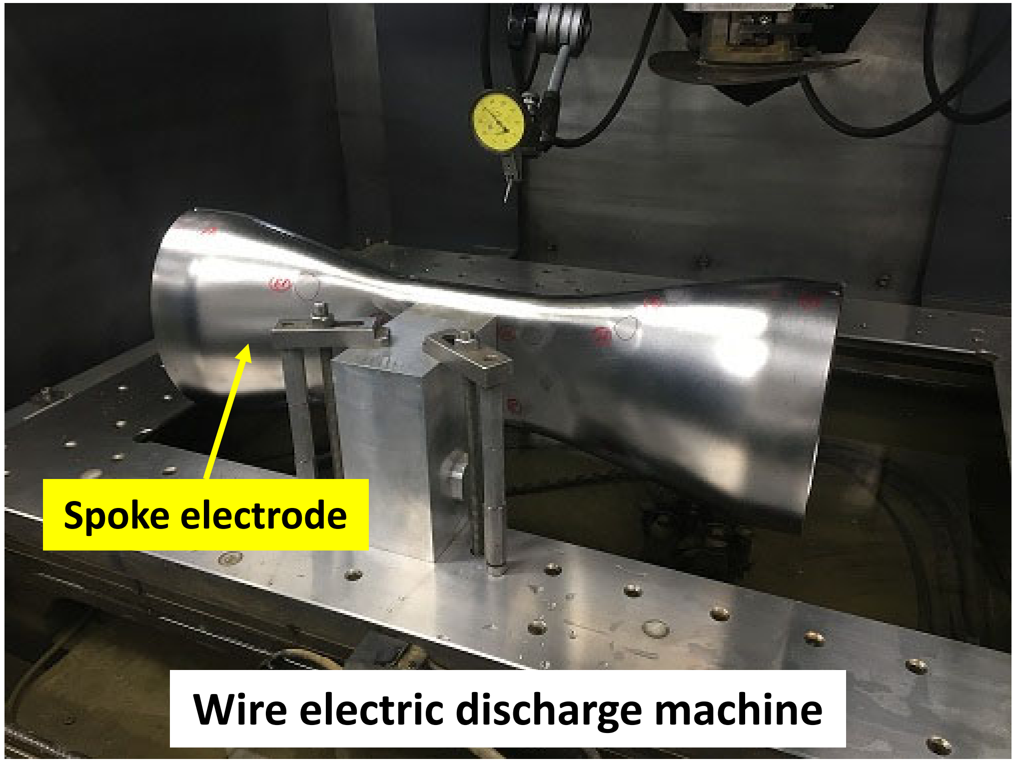


Back side to EB

Spatter @ EBW

Melting point
Niobium : 2,469 ℃
Brass : approx. 800 ℃

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



The discharge wire is made of brass.

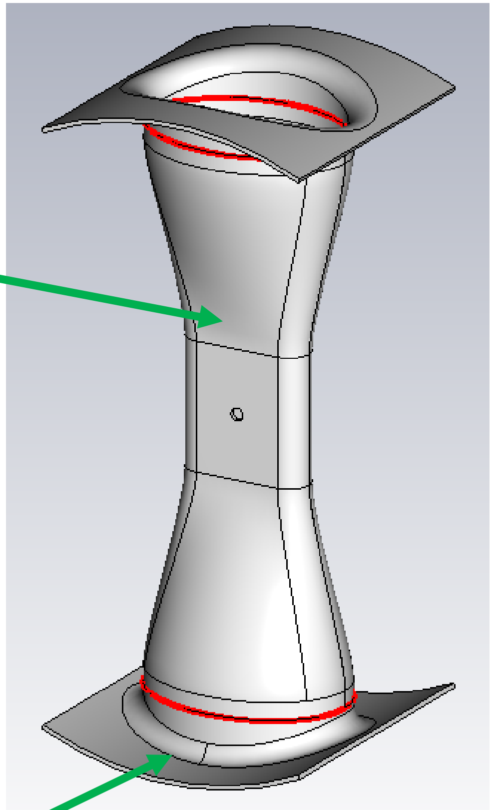
Wire-cut cutting cross section

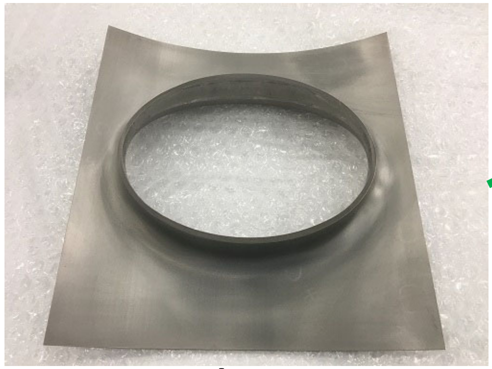
Opposite cross section

Fabrication of the spoke part

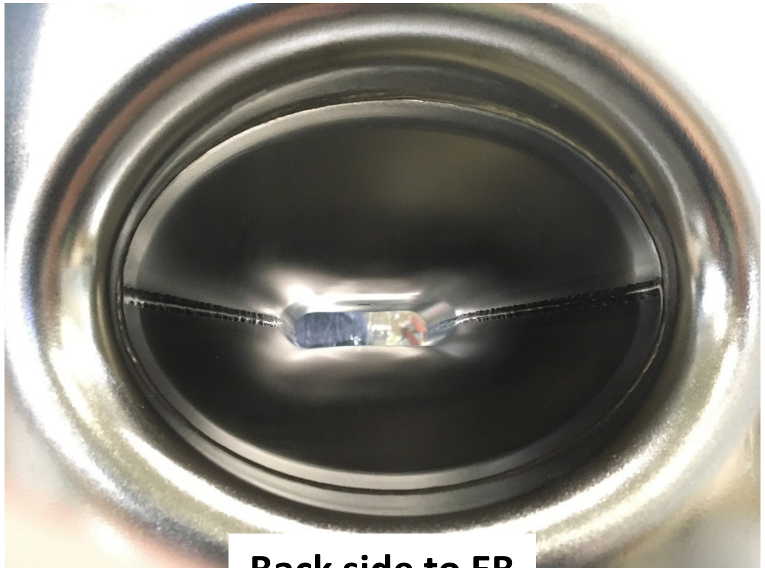
Elliptical EBW lines for joining the spoke electrode and the spoke-roots together

Spoke electrode





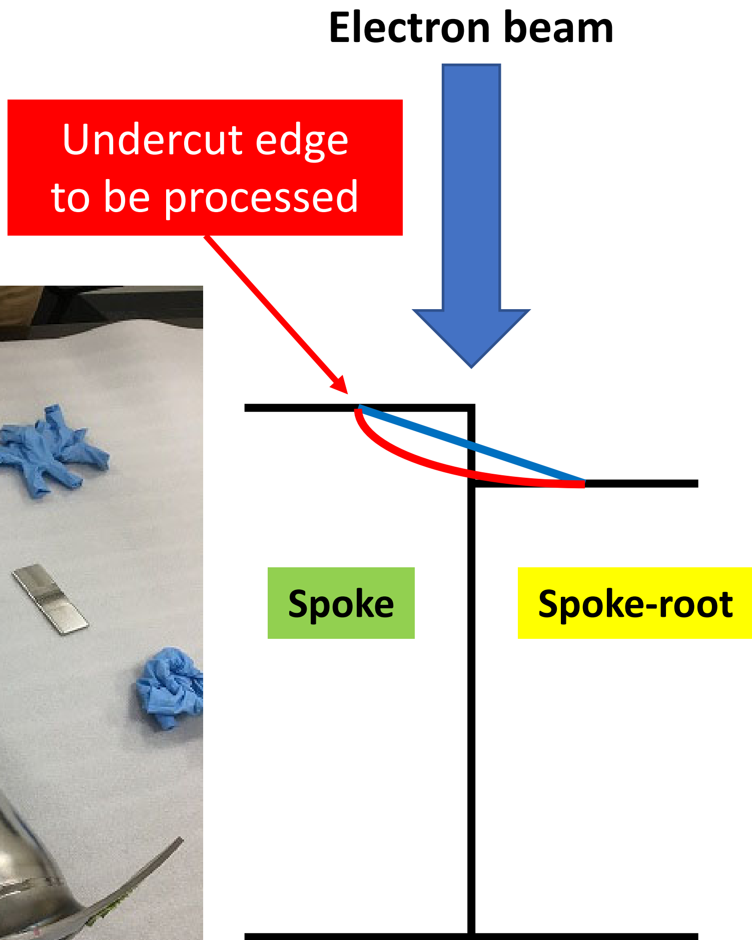
Spoke root



Back side to EB

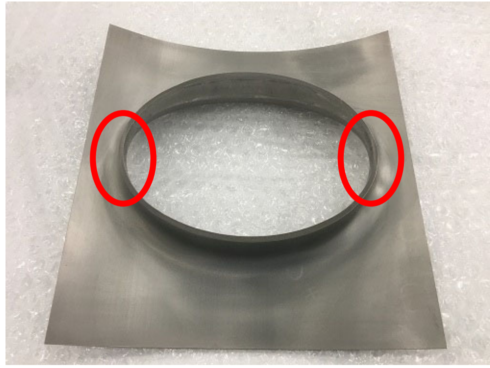
Machine polishing

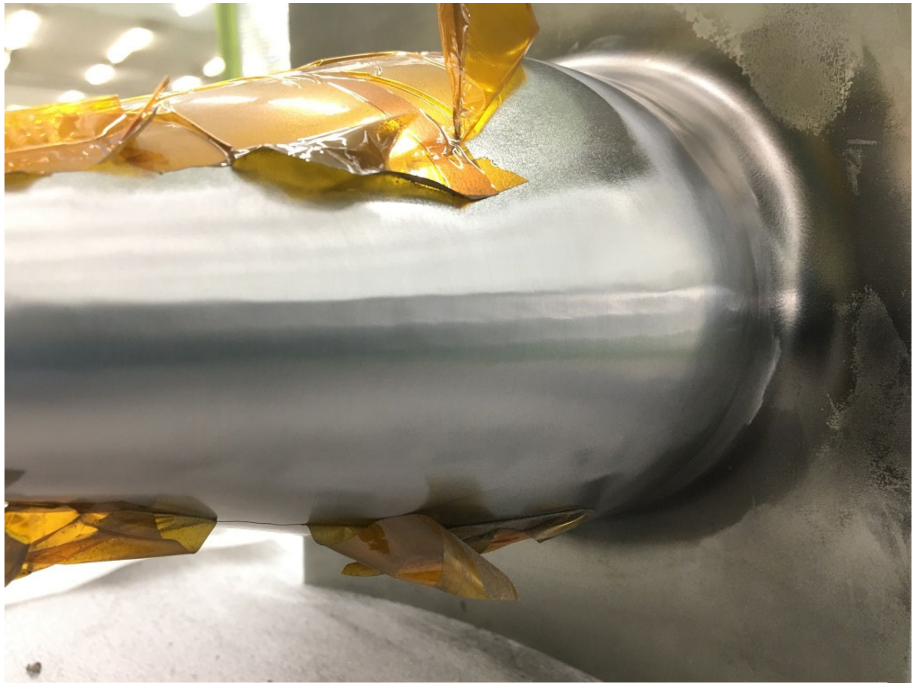
To ensure the smoothness of the cavity’s inner surface,
any notable edges, including the welding-bead undercut, were removed by machine polishing.



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

⇒ Mismatch :
Elliptical circumference

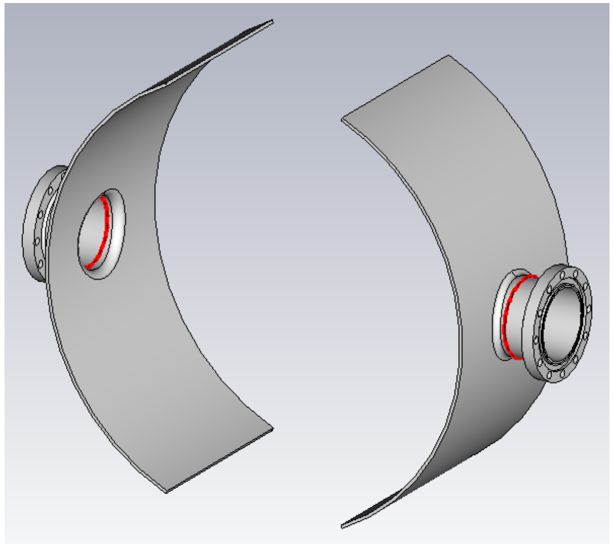


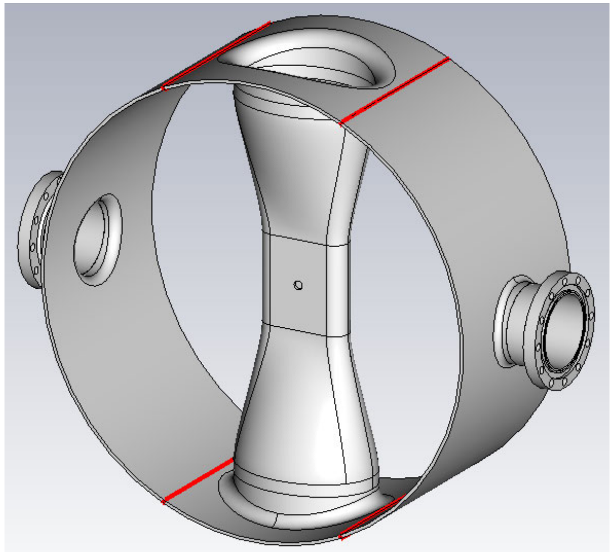


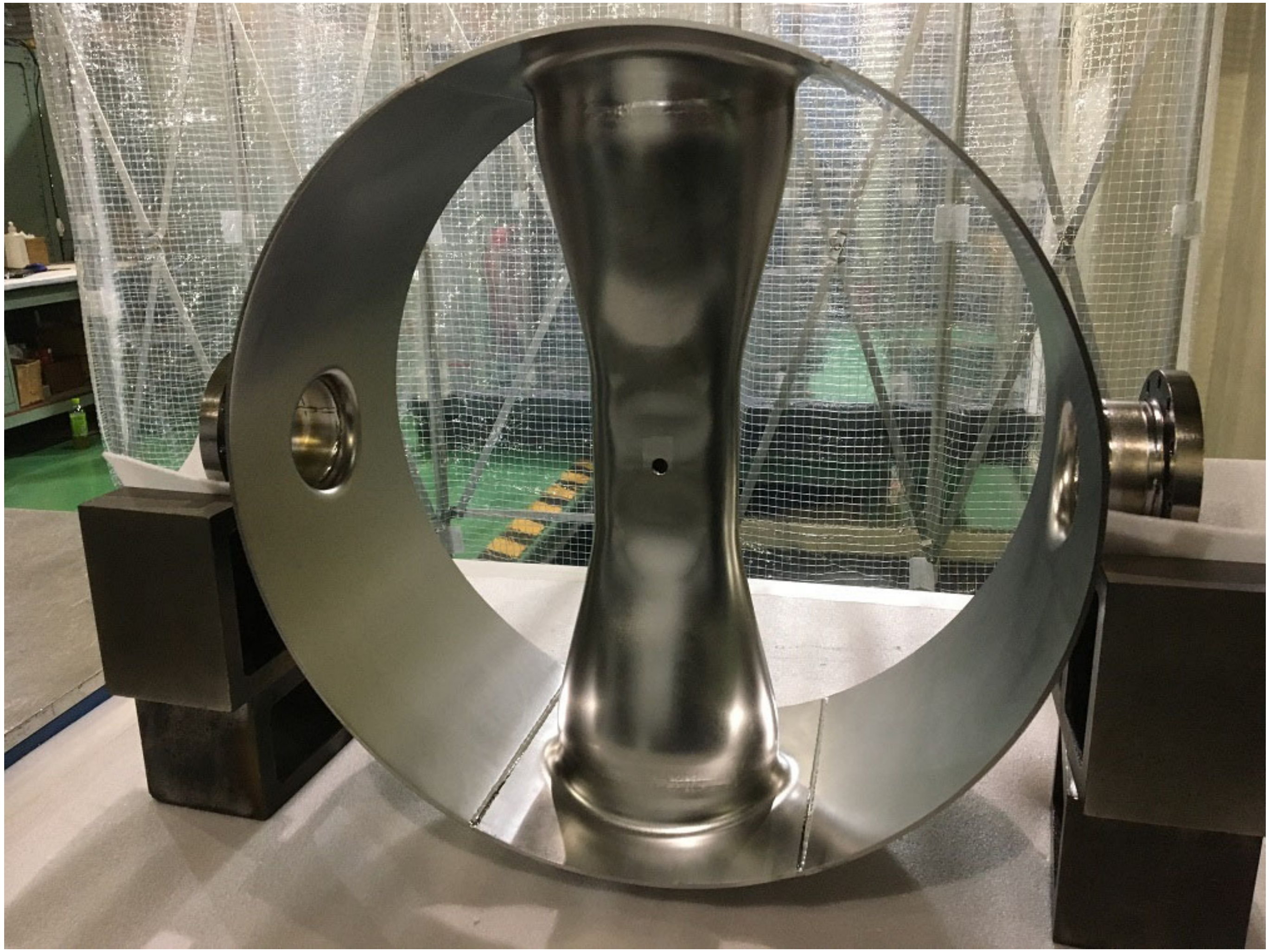
Long radial direction of the elliptical EBW line

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.

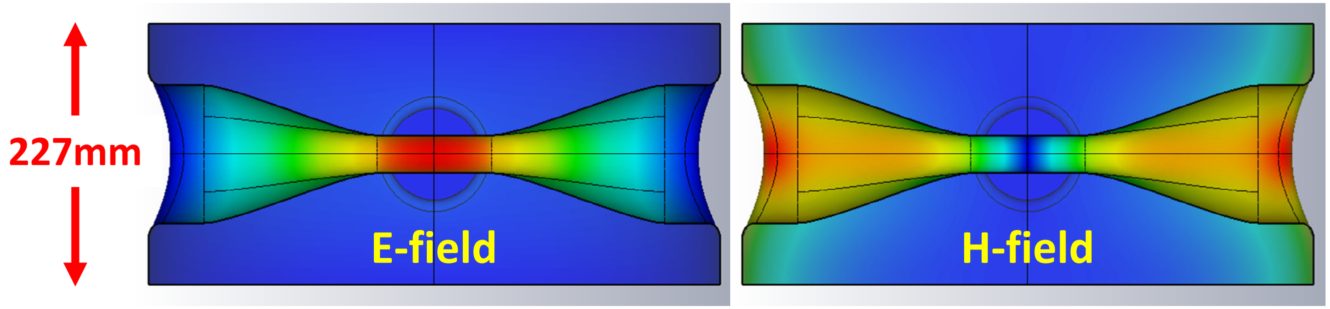




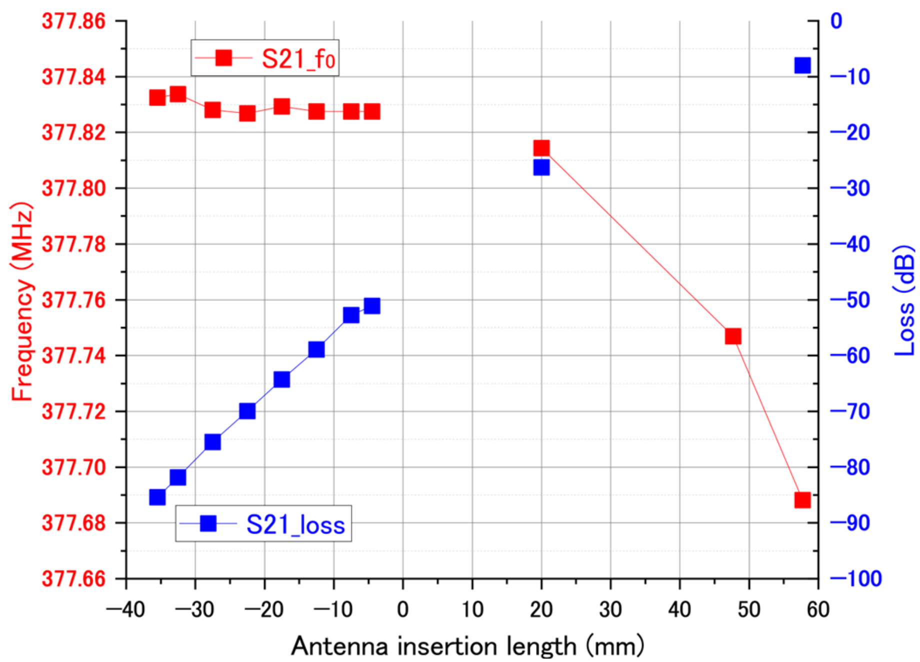


Frequency measurement (1/2)

- 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.

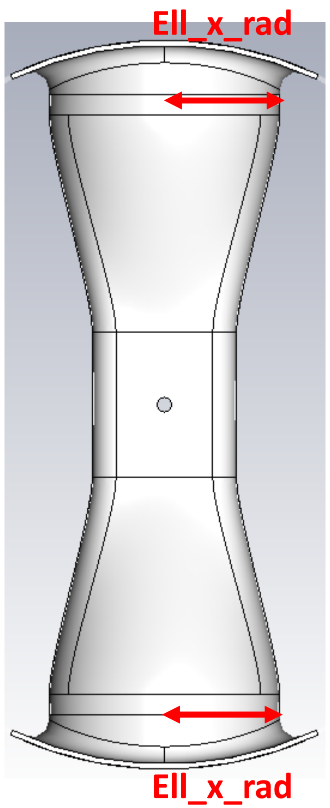


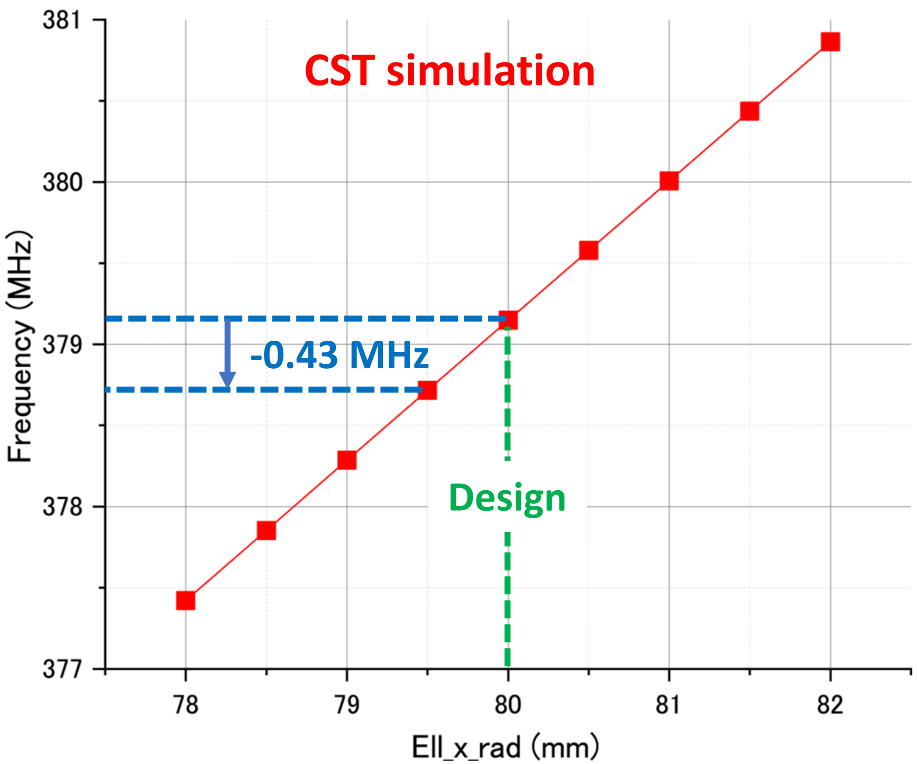
S21 frequency measurement

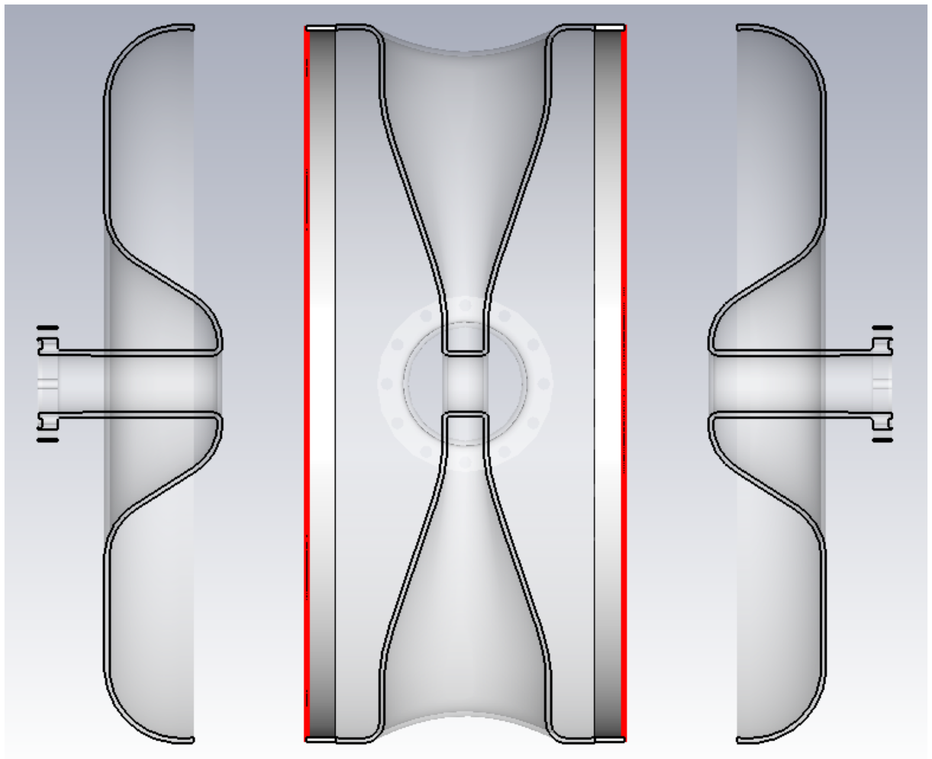


Frequency measurement (2/2)

- 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.







df/dz = 0.68 MHz/mm

Summary

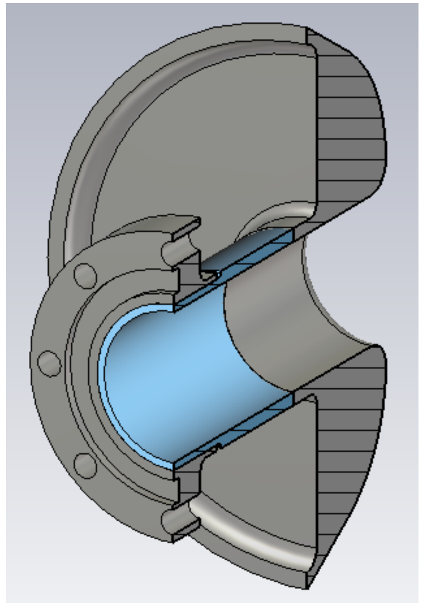
- As a first step toward the full-scale design of the CW proton linac for the JAEA-ADS, we are now prototyping a low-β (around 0.2) single spoke cavity.

- 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.

[1] J. Tamura et al., "RF Design of the Prototype Spoke Cavity for the JAEA-ADS Linac", JPS Conf. Proc. **33**, 011049 (2021).

[2] J. Tamura et al., "Present Status of the Spoke Cavity Prototyping for the JAEA-ADS Linac", SRF'21, WEPCAV011 (2021).

[3] J. Tamura et al., "Current Status of the Spoke Cavity Prototyping for the JAEA-ADS Linac", LINAC'22, MOPOGE14 (2022).