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CURRENT STATUS OF THE SPOKE CAVITY PROTOTYPING FOR THE JAEA-ADS LINAC

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Abstract

The Japan Atomic Energy Agency (JAEA) has proposed an accelerator-driven system (ADS) to efficiently reduce high-level radioactive waste generated at nuclear power plants. 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. In 2021, we have started welding the cavity parts together. By preliminarily investigating the optimum welding conditions, each cavity part was joined with a smooth welding bead. Consequently, we have succeeded to fabricate the body section of the prototype spoke cavity.

INTRODUCTION

JAEA has proposed an ADS as a future project to efficiently reduce high-level radioactive waste generated at nuclear power plants. In the ADS, long-lived nuclides are transmuted to short-lived or stable ones. One of the challenging R&D aspects of the ADS is the reliability of the accelerator [1,2]. In the JAEA-ADS, a high-power (30 MW) proton beam with a final beam energy of 1.5 GeV is required with high reliability. Because the accelerator needs to be operated in CW mode to be compatible with the reactor operation, a super-conducting (SC) linac would be a suitable solution. The latest design of the JAEA-ADS linac is reported in Refs. [3,4]. As shown in Fig. 1, the proposed linac consists of a normal-conducting radio-frequency quadrupole (RFQ), half-wave resonator (HWR), low-β and high-β single-spoke resonators (SSR1 and SSR2, respectively), and low-β and high-β elliptical cavities (ELL1 and ELL2, respectively).

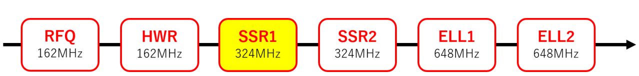

Figure 1: Accelerating structure proposed for the JAEA-ADS linac.

In preparation for the full-scale design of the JAEA-ADS linac, we have decided to prototype a low-β single-spoke cavity and conduct a high-field performance test of the prototyped cavity at liquid helium temperature. This prototyping will provide us with various insights on the development of SC cavities with $\lambda/2$-mode resonance. Furthermore, through the high-field cavity testing, we will acquire valuable information such as how much accelerating gradient would be achievable with reasonable stability. Therefore, both prototyping and performance testing are essential to ensure the feasibility of the JAEA-ADS linac. In this paper, the current status of the spoke cavity prototyping is presented.

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DESIGNED CAVITY

The prototype spoke cavity with an operating frequency of 324 MHz was designed by electromagnetic simulation [5–7]. Figure 2 shows the cross-sectional views of the designed cavity. The cavity's design parameters are listed in Table 1. The multipactor analysis for the designed cavity without the coupler ports is presented in Ref. [6].

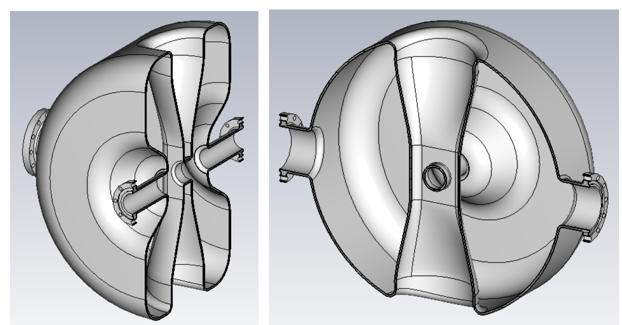

Figure 2: Cross-sectional views of the designed cavity.

Table 1: Design parameters of the prototype spoke cavity.

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)

CAVITY FABRICATION

The fabrication process for the prototype spoke cavity was reviewed in fiscal year 2019, and the actual cavity fabrication started in 2020. The prototype spoke cavity is made of pure niobium (Nb) except for the niobium-titanium alloy (Nb-Ti) flanges for the RF ports and beam ports. These materials were provided by Tokyo Denkai Co., Ltd. Most of the cavity

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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) and the port flanges were machined from Nb and Nb-Ti cylindrical blocks, respectively. The shaped cavity parts are shown in Figs. 9-11 of Ref. [7].

We have started welding the cavity parts together in 2021. All the shaped cavity parts are joined together by electron beam welding (EBW). Before welding the actual cavity parts, the EBW beam parameters for each welding condition were investigated using mock-up Nb test pieces. All welding grooves were acid cleaned (chemically polished) to remove impurities prior to each EBW. By preliminarily examining the optimal EBW conditions, each cavity part was welded together with a smooth welding bead. The EBW lines for fabricating the spoke part and the cavity-side parts are shown in Figs. 3 and 4, respectively. Figure 5 shows the EBW lines for joining the spoke part and the cavity-side parts together. So far, no obvious welding defects such as unpenetrated welds and welding holes have been found. In order to ensure the smoothness of the cavity's inner surface, any notable edges, including the welding-bead undercut, were removed by machine polishing. Figure 6 shows the fabricated cavity's body section[1].

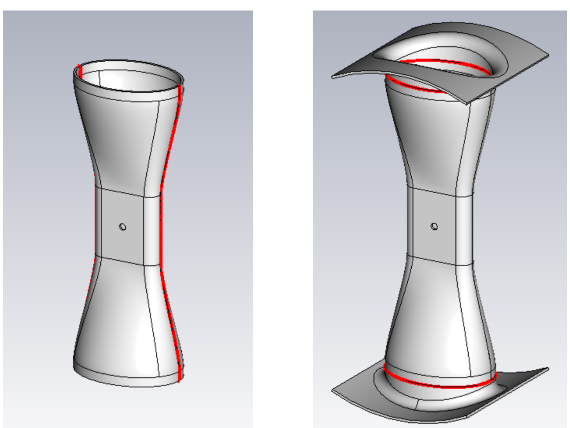

Figure 3: Sloped EBW lines for joining the two half spokes together (left). Elliptical EBW lines for joining the spoke and the spoke-roots together (right).

FREQUENCY MEASUREMENT

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 itself is not a cavity structure because it has not yet been lidded by the end-plate parts (Fig. 9 of Ref. [7]). Therefore, we temporarily placed the body section between two aluminum (Al) plates for the frequency measurement as shown in Fig. 7. To ensure the electrical contact between the body section and the Al plates, we attached shield fingers [8] to the Al plates in a circular

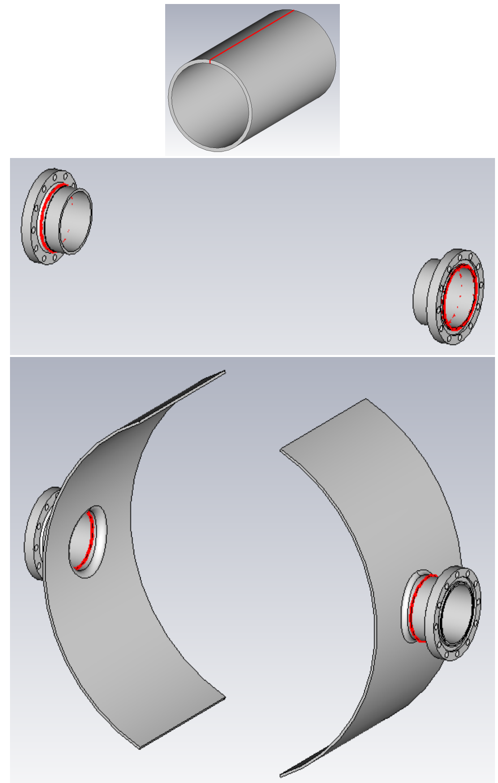

Figure 4: EBW lines for piping the RF port (top), for joining the RF-port pipe (Nb) and the RF-port flange (Nb-Ti) together (middle), and for joining the RF port and the cavity-side part together (bottom).

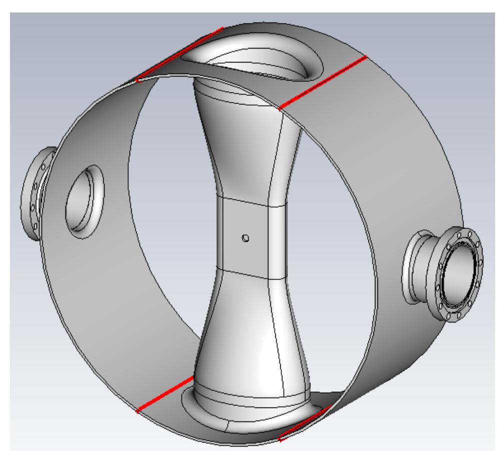

Figure 5: EBW lines for joining the spoke part and the cavity-side parts together.

pattern with the same diameter as the cavity. Accordingly, the open faces of the body section were short-circuited with conducting surfaces at a cavity length of 227 mm, which is the distance between the inner faces of the two Al plates. As shown in the upper picture of Fig. 7, the small holes ($\approx \phi 10$ mm) drilled in the spoke center, which were used for holding the spoke during extra-length cutting, were sealed

[1] The drift tube electrode is to be machined from Nb block and welded to the spoke center in a future fabrication phase.

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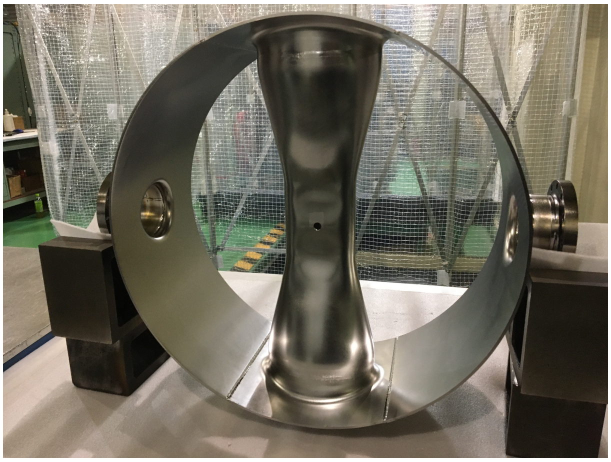

Figure 6: Fabricated cavity's body section.

Figure 7: Setup for the frequency measurement.

with Al tapes. A straight antenna was inserted into each of the two RF ports (RF input and RF pickup, respectively) for the frequency measurement using a vector network analyzer.

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 [9]. On the other hand, the frequency obtained by simulation (CST Studio Suite [10]) was 379.15 MHz with the same cavity length of 227 mm (Fig. 8). The simulated $\lambda/2$-mode field distribution for the cavity's body section is shown in Fig. 9. The measured frequency is not too far from that obtained by simulation. Although the cause of the difference between the measurement and the simulation has not yet been identified, this difference is well within the range of frequency

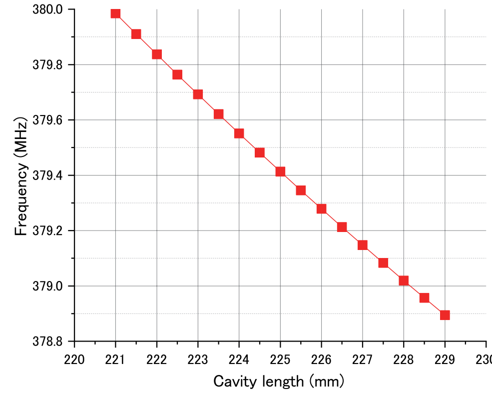

Figure 8: Simulated cavity-length dependence of the $\lambda/2$-resonance mode frequency.

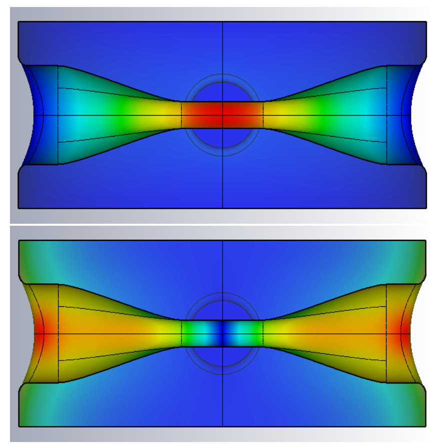

Figure 9: Simulated surface electric (upper) and magnetic (lower) field distribution.

adjustment in the final fabrication phase by shortening the length of the cavity's body section.

SUMMARY

We have started welding the cavity parts together in 2021. Before welding the actual cavity parts, we investigated the optimum EBW beam parameters for each welding condition by using mock-up Nb test pieces. As a result, each cavity part was joined with a smooth welding bead. We have successfully fabricated the body section of the prototype spoke cavity.

ACKNOWLEDGMENTS

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

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