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PROGRESS OF THE SPOKE CAVITY PROTOTYPING FOR THE JAEA-ADS LINAC

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Abstract

The Japan Atomic Energy Agency (JAEA) has been proposing an accelerator-driven nuclear transmutation system (ADS) as a future nuclear system. Toward the practical design of the CW proton linac for the JAEA-ADS, we are currently prototyping a low-β (≈ 0.2) single-spoke cavity. The cavity fabrication began in 2020. Most of the cavity parts were shaped in fiscal year 2020 by press-forming and machining. In 2021, we started welding the shaped cavity parts together. Each cavity part was welded together by preliminarily examining the optimum welding conditions using mock-up test pieces. So far, we have fabricated the body section and the two lid sections, and have confirmed that there were no significant problems with the cavity fabrication according to the frequency measurement of the temporarily-assembled prototype cavity.

INTRODUCTION

JAEA has been proposing an ADS as a future nuclear system to efficiently reduce high-level radioactive waste generated in nuclear power plants. In the ADS, long-lived nuclides are transmuted to short-lived or stable ones. One of the challenging R&D subjects to realize the ADS is the reliability of the accelerator [1, 2]. In the JAEA-ADS, a high-power (30 MW) proton beam with a final energy of 1.5 GeV is required with high reliability. Because the accelerator needs to be operated in CW mode, 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 quadruple (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).

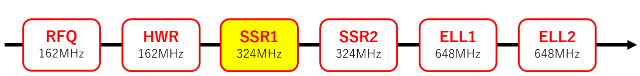

Figure 1: Proposed acceleration structure of the JAEA-ADS linac.

As a first step toward the practical design of the JAEA-ADS linac, we have decided to prototype the low-β single-spoke cavity and conduct a high-field performance test of the prototype spoke cavity at liquid helium temperature. The spoke cavity prototyping will provide us with various insights on the development of SC cavities with TEM $\lambda/2$-mode resonance. In addition, the high-field cavity testing will provide valuable information such as how much field gradient can be achieved with reasonable stability. Therefore, both prototyping and performance testing are essential to ensure the feasibility of the JAEA-ADS linac. In this paper, the progress of the spoke cavity prototyping for the JAEA-ADS linac is presented.

CAVITY DESIGN

The prototype spoke cavity with an operating frequency of 324 MHz was designed by electromagnetic simulation [5], and its dimensional parameters were optimized for higher cavity performance [6–8]. The cross-sectional views of the designed cavity are shown in Fig. 2. The cavity's design parameters are listed in Table 1. The multipactor analysis of the designed cavity without the coupler ports was presented in Ref. [7].

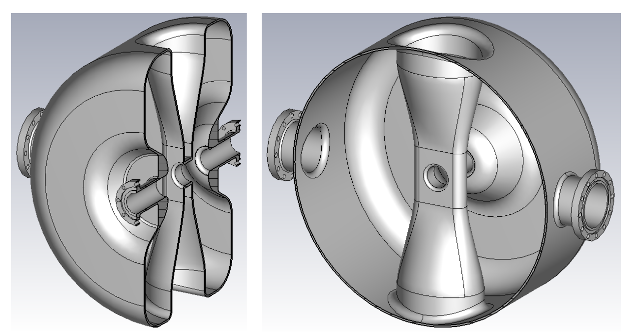

Figure 2: Cross-sectional views of the designed cavity.

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)

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CAVITY FABRICATION

The fabrication process for the prototype spoke cavity was investigated in fiscal year 2019, and the actual cavity fabrication began 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 the beam ports. These materials were provided by Tokyo Denkai Co., Ltd. Most of the cavity parts were shaped in fiscal year 2020 by press-forming and machining. The major parts were press-formed from 3.5 mm thick Nb sheets. The nose-shaped end drift-tubes (EDTs) 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. [8].

We have started welding the shaped cavity parts together by electron beam welding (EBW) in 2021. Before welding the actual cavity parts, each welding condition including EBW beam parameters was carefully investigated using mock-up test pieces made of Nb or Nb-Ti. Furthermore, prior to each EBW, all welding joints were acid cleaned (chemically polished) to remove impurities. The cavity's body section and beam port sections were fabricated in fiscal year 2021 and 2022, respectively [9, 10].

In fiscal year 2023, the drift-tube (DT) electrode was welded to the spoke of the body section (Fig. 3), and also, the two lid sections were assembled with EBW. For welding the DT electrode, a ϕ60 mm hole was cut in the spoke by a wire electric discharge machine, and the DT electrode was machined from Nb cylindrical block. As shown in Figs. 4 and 5, respectively, the lid section "a" is composed of the end plate "a" and the EDT, while the lid section "b" is composed of the end plate "b", the gap-filling ring, and the EDT. Figures 6 and 7 show the fabricated body section with the DT welded to it and the fabricated lid sections, respectively. So far, any obvious welding defects, such as unpenetrated welds and welding holes, have not been found.

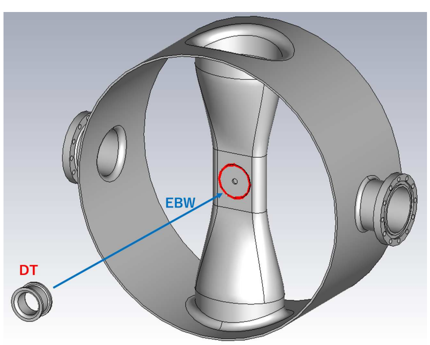

Figure 3: DT electrode and body section.

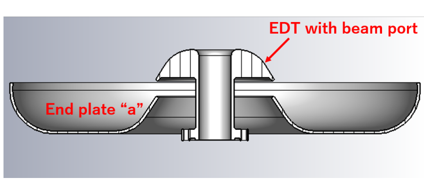

Figure 4: Lid section "a" before EBW assembly.

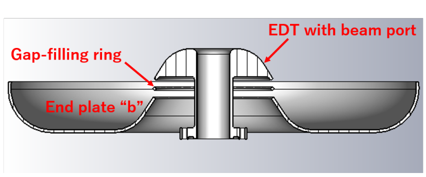

Figure 5: Lid section "b" before EBW assembly.

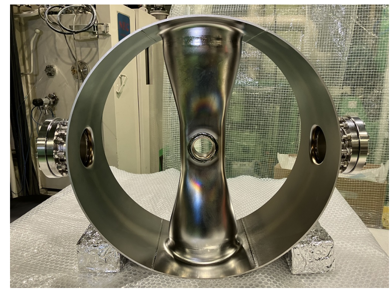
Figure 6: Fabricated body section with the DT welded to it.


Figure 7: Fabricated lid sections (left: "a", right: "b").

FREQUENCY MEASUREMENT

We have temporarily assembled the prototype spoke cavity and measured its resonant frequency to make sure there were no critical issues in the fabrication. As shown in Fig. 8, the cavity was assembled from the body section and the two lid sections with indium wires (ϕ1 mm) to ensure the electrical contact between the body and each lid section. A straight antenna was inserted into each of the two RF ports for the S_{21} measurement using a vector network analyzer. Before the temporary assembly for the frequency measurement, the


Figure 8: Setup for the frequency measurement.

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weld beads on the inner side of the cavity were ground and smoothed by machine polishing.

The measured frequency under atmospheric condition was 334.18 MHz, which was converted to 334.29 MHz in vacuum taking into account the humidity effect [11]. The body section was fabricated longitudinally (z-directionally) longer than the design dimension for frequency adjustment in the later fabrication process. Therefore, due to the longer gap length, the frequency of this temporarily assembled cavity with a longitudinal length of 355.5 mm is much higher than the final frequency of 324 MHz. Figure 9 shows the cavity-length dependence of the TEM $\lambda/2$-mode frequency obtained by simulation [5]. The simulated surface field distributions of the temporarily assembled cavity are shown in Fig. 10. The measured frequency (334.29 MHz) is not far from that obtained by simulation (333.49 MHz), and the difference (0.80 MHz) is well within the range of frequency adjustment by shortening the body section longitudinally.

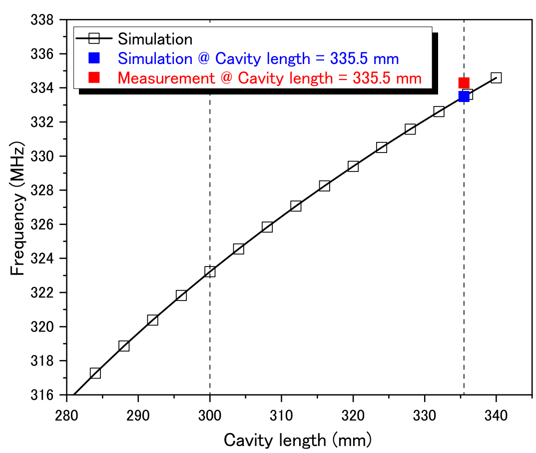

Figure 9: Simulated cavity-length dependence of the TEM $\lambda/2$-mode frequency of the prototype spoke cavity.

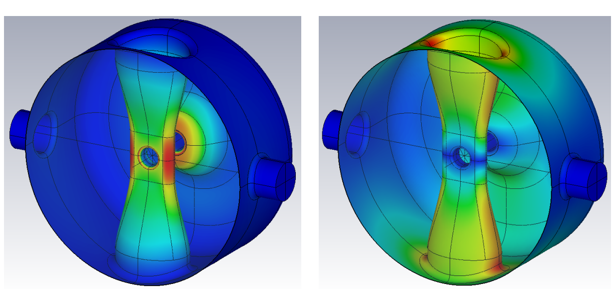

Figure 10: Simulated surface electric (left) and magnetic (right) field distributions.

SUMMARY

We have started welding the shaped cavity parts together in 2021. Before welding the actual cavity parts, we examined the optimum EBW beam parameters for each welding condition by using mock-up test pieces. Consequently, we have successfully fabricated the body section and the two lid sections. By measuring the resonant frequency of the temporarily assembled cavity, we confirmed that there were no significant problems with the cavity fabrication. We are now proceeding to the final EBW assembly of the prototype spoke cavity.

ACKNOWLEDGMENTS

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REFERENCES

[1] B. Yee-Rendon, "Overview of ADS Projects in the World", in *Proc. LINAC'22*, Liverpool, UK, Aug. 2022, pp. 310–313. doi:10.18429/JACoW-LINAC2022-TU2AA01

[2] J. Belmans *et al.*, "MINERVA 100-MeV Accelerator Technical Design Report", SCK CEN, Mol, Belgium, Rep. SCK CEN/37038477, Jan. 2021.

[3] B. Yee-Rendon, Y. Kondo, F. Maekawa, S. Meigo, and J. Tamura, "Design and Beam Dynamic Studies of a 30-MW Superconducting Linac for an Accelerator-Driven Subcritical System", *Phys. Rev. Accel. Beams*, vol. 24, p. 120101, 2021. doi:10.1103/PhysRevAccelBeams.24.120101

[4] B. Yee-Rendon, Y. Kondo, J. Tamura, K. Nakano, F. Maekawa, and S. Meigo, "Beam Dynamics Studies for Fast Beam Trip Recovery of the Japan Atomic Energy Agency Accelerator-Driven Subcritical System", *Phys. Rev. Accel. Beams*, vol. 25, p. 080101, 2022. doi:10.1103/PhysRevAccelBeams.25.080101

[5] https://www.3ds.com/products/simulia/cst-studio-suite

[6] J. Tamura *et al.*, "Electromagnetic Design of the Prototype Spoke Cavity for the JAEA-ADS Linac", in *Proc. SRF'19*, Dresden, Germany, Jun. 2019, pp. 399–402. doi:10.18429/JACoW-SRF2019-TUP007

[7] J. Tamura *et al.*, "RF Design of the Prototype Spoke Cavity for the JAEA-ADS Linac", in *Proc. 3rd J-PARC Symposium (J-PARC2019)*, vol. 33, p. 011049, 2021. doi:10.7566/JPSCP.33.011049

[8] J. Tamura *et al.*, "Present Status of the Spoke Cavity Prototyping for the JAEA-ADS Linac", in *Proc. SRF'21*, East Lansing, MI, USA, Jun. 2021, pp. 612. doi:10.18429/JACoW-SRF2021-WEPCAV011

[9] J. Tamura *et al.*, "Current Status of the Spoke Cavity Prototyping for the JAEA-ADS Linac", in *Proc. LINAC'22*, Liverpool, UK, Aug. 2022, pp. 180–183. doi:10.18429/JACoW-LINAC2022-MOPOGE14

[10] J. Tamura *et al.*, "Fabrication Progress of the Prototype Spoke Cavity for the JAEA-ADS Linac", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 1588–1590. doi:10.18429/JACoW-IPAC2023-TUPA120

[11] C. Montgomery, *Technique of Microwave Measurements*, McGraw-Hill Book Company, Inc, New York, USA, 1947.