ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOMS046

FABRICATION AND LOW-POWER TEST OF DISK-AND-WASHER CAVITY FOR MUON ACCELERATION

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Abstract

The muon g-2/EDM experiment is under preparation at Japan Proton Accelerator Research Complex (J-PARC), and the muon linear accelerator for the experiment is being developed. A Disk-and-Washer (DAW) cavity will be used for the medium-velocity part of the accelerator, and muons will be accelerated from $v/c = \beta = 0.3$ to 0.7 with the operating frequency of 1.296 GHz. Machining, brazing, and low-power measurements of a prototype cell reflecting the design of the first tank of DAW were performed to identify fabrication problems. Several problems were identified, such as displacement of washers during brazing, and some measures will be taken in the actual tank fabrication. In this paper, the results of the prototype cell fabrication will be reported.

INTRODUCTION

At Japan Proton Accelerator Research Complex (J-PARC), an experiment using muons accelerated by a linac is planned to measure the anomalous magnetic moment of muons and to search for the electric dipole moment [1]. A 1296 MHz disk and washer (DAW) cavity is being developed for use in the medium-velocity section of the muon linac [2]. DAW cavity is a type of coupled cavity linac (CCL) consisting of disks, washers, and supporting stems. DAW CCL has many advantages, such as high shunt impedance and high coupling between the accelerating and coupling cells, but has the disadvantage that many adjacent modes are difficult to analyze. For this reason, there are only a few cases where it is actually employed [3]. However, recent improvements in computational capabilities have made it possible to design cavities including stems that fully account for 3D electromagnetic fields. The muon DAW consists of three modules with four or five tanks per module, and each tank has 11 acceleration gaps. The tanks are connected to each other by bridge couplers (bc), and each bc is equipped with an electromagnetic quadrupole doublet for focusing. Each module is driven by a 2.5 MW L-band klystron. The configuration of the muon DAW is shown in Fig. 1.

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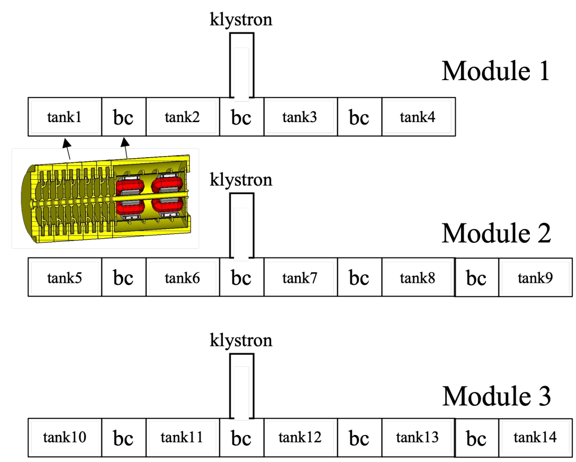

Figure 1: The configuration of the muon DAW. Schematic of the entire accelerator and 3D model of the 1st tank with bc is shown.

PROTOTYPE CELL FABRICATION

The cavity shape has been carefully studied using the CST MW studio [4], and fabrication of the cavity was begun in 2021. Prior to the first tank, a prototype cell was fabricated, and several tests were conducted to identify problems in the fabrication process and to study countermeasures. Configuration of the prototype cell is shown in Fig. 2.

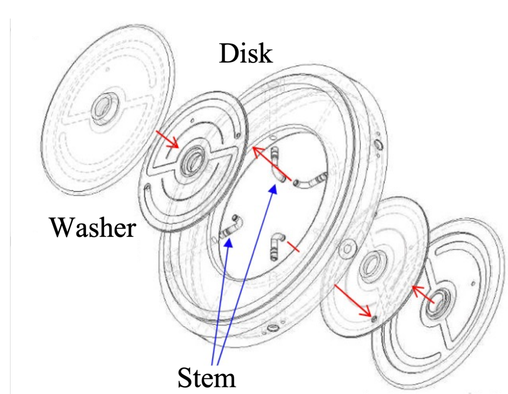

Figure 2: Configuration of prototype cell.

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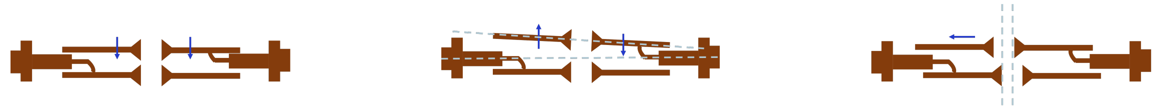

Figure 4: A schematic diagram of problems found in the dimensional measurements after brazing. Left : Position of the upper side washer sinks against disk. Center : Poor parallelism between washers and disk. Right : Defect in concentricity between washers and disk. In reality, the upper and lower washers have their stems out of phase by 90°, and each washer has two stems, but for the sake of clarity, the figures show them as if they had one stem in phase with each other.

Disk and Washers are made of oxygen-free copper, and stems are made of stainless steel with copper plating. Dimensional measurements of each part of the prototype cell after machining showed that each dimension was within ±30 µm of the design value.

Effects of Brazing

Brazing was performed with the configuration shown in Fig. 3 to evaluate the effect of brazing. Visual inspection after brazing did not reveal any flaws or discoloration that could affect functionality, and vacuum testing showed no problems with the helium leakage of less than 1.3×10^{-10} Pa m^3/s. On the other hand, dimensional measurements of prototype cell after brazing identified several problems. The displacement of the washer was observed only on the upper side, and deterioration of parallelism and concentricity was observed on both the upper and lower sides, but was more pronounced on the washer on the upper side. A schematic diagram of these problems is shown in Fig. 4. Table 1 summarizes the deviations between the measured and designed values in the dimensional measurements after brazing. During brazing, the upper washer is supported only by the joint with the stems, so it is deformed by the weight and lowered in position (Fig. 5). In contrast, the lower washer is fixed by the base, so there is no problem. In addition, a gap occurs between the positioning jig and the washer during brazing due to the difference in thermal expansion coefficient. As a result, the upper washer is supported only by the stem, which moves and its effect appears on the lower side, which is thought to deteriorate the parallelism and concentricity of the upper and lower washers (Fig. 6).

Table 1: The summary of the deviations between the measured and designed values in the dimensional measurements after brazing.

Washer position (upper side)	
Difference from design value	−0.678 mm
Parallelism	
Taget value	0.1
Measured value	0.595 (upper side)
	0.132 (lower side)
Concentricity	
Target value	0.1
Measured value	0.362 (upper side)
	0.245 (lower side)

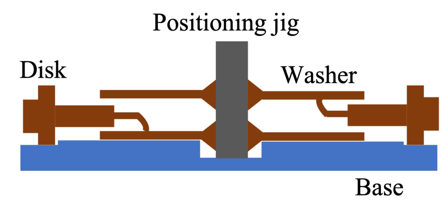

Figure 3: The configuration for brazing.

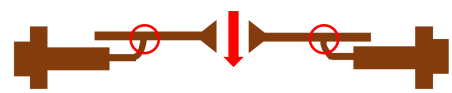

Figure 5: Schematic diagram of cause of displacement of upper side washer. The upper side washer is supported at only two points at the joint with the stems, and it is thought that the load was concentrated at these two points, causing deformation during brazing.

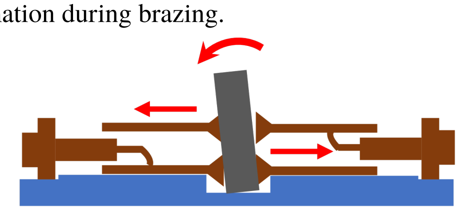

Figure 6: Schematic diagram of causes of parallelism and concentricity deterioration. The gap between the positioning jig and washer causes the jig to tilt, which in turn causes the upper washer to shift significantly and the lower washer to shift as a result.

To solve these problems, two-step brazing is being considered for brazing in the actual cavity. First, a washer is brazed only on the lower side, which is fixed with the base and not deformed, and then turned over and another washer is brazed on the lower side. At this time, additional jigs are used to prevent the position of the first brazed washer from being lowered. A schematic diagram of two-step brazing is shown in Fig. 7. In addition, the jig material is changed so that the coefficient of thermal expansion of the jig and washers are the same to prevent gaps during brazing.

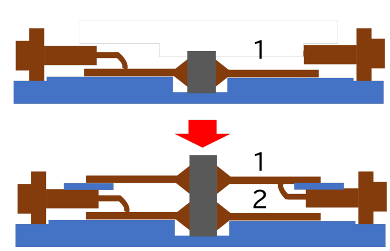

Figure 7: A schematic diagram of two-step brazing.

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Pressure Test

A pressure test of the cooling channel was also performed. The displacement from the reference plane was measured at the cooling channel position and in the radial direction by applying pressure to the cooling channel. The outer circumference of the washer was used as the position reference plane (no deformation). No deformation was observed at the test pressure of 0.3 MPa, but a deformation occurred at the test pressure of 0.9 MPa. The deformation occurred in the yellow-colored area in Fig. 8, and the maximum deformation encountered was about 500 µm (Fig. 9). The deformation is thought to be caused by pressure added to surfaces other than the cooling channel due to insufficient brazing. It is expected to be possible to deal with this problem by adding brazing foil material and increasing the brazing strength when fabricating the actual cavity.

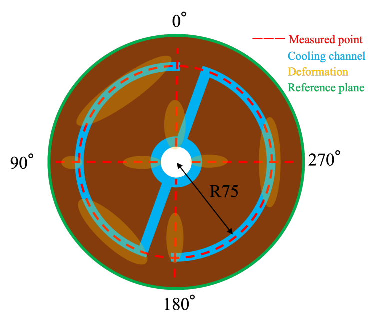

Figure 8: A schematic diagram of the pressure test.

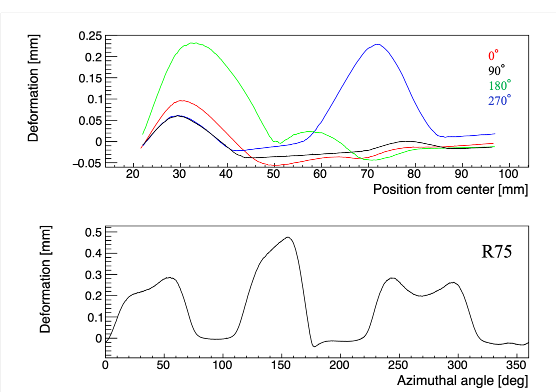

Figure 9: The deformation measured by the pressure test.

Low-Power Measurement

The prototype cell was fitted w ith e nd p lates a nd low power measurements were made.Test results are shown in Fig. 10. There was a difference of about 5 MHz between the measured accelerating mode frequency and the simulated design value. The other modes also deviated from the sim-ulation within 0.7%. Similar results were obtained for the coupling mode. Although the cause of the deviation is not fully understood, it is considered to be due to deformation caused by brazing and displacement of the washers. It is expected that measures taken during brazing will improve this frequency deviation from the design value.

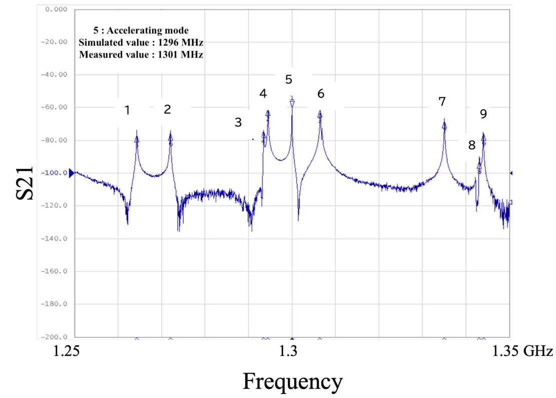

Figure 10: A example of frequency measurement result with the prototype cell.

CURRENT STATUS AND FUTURE PLANS

Each part of the first tank has already been machined. Photographs of the disk, washer, and stem for the first tank actually fabricated are shown in Fig. 11. The brazing and performance evaluation of the first tank will be completed during 2022, and the cavities for the remaining tanks will be fabricated sequentially.

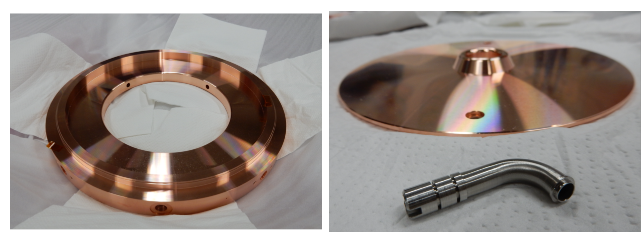

Figure 11: Photo of disk (left), washer, and stem (right) for the first tank.

CONCLUSION

The muon g-2/EDM experiment is under preparation at J-PARC, and the muon linear accelerator for the experiment is being developed. A DAW cavity will be used for the medium-velocity part of the accelerator. Prior to the fabrication of the first tank of the DAW, a prototype cell was used to identify fabrication problems and establish a fabrication method. Problems such as washers shifting during brazing were found, and countermeasures were discussed. Based on these findings, brazing of the first tank will be completed, and low-power tests are scheduled to be conducted during this fiscal year.

ACKNOWLEDGEMENTS

This work is supported by JSPS KAKENHI Grant Numbers 25800164, 15H03666, 15H05742, 16H03987, 16J07784, 18H03707, 18J22129, 19J21763, 20J21440, 20H05625, 21K18630, 21H05088, 22H00141, JST FOREST Program (Grant Number JPMJFR212O), and the natural science grant of the Mitsubishi Foundation. This paper is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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