ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB195

DEVELOPMENT OF A DISK-AND-WASHER CAVITY FOR THE J-PARC MUON g-2/EDM Experiment

Y. Takeuchi*, J. Tojo, Kyushu University, Fukuoka, Japan
Y. Nakazawa, Ibaraki University, Ibaraki, Japan
R. Kitamura, Y. Kondo, T. Morishita, JAEA, Ibaraki, Japan
E. Cicek, K. Futatsukawa, N. Kawamura, N. Saito, M.Otani,
T. Yamazaki, T. Mibe, M. Yoshida, KEK, Ibaraki, Japan
Y. Iwashita, Kyoto ICR, Kyoto, Japan
Y. Sue, K. Sumi, M. Yotsuzuka, Nagoya University, Nagoya, Japan
H. Yasuda, University of Tokyo, Tokyo, Japan

Abstract

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. A 1296 MHz disk and washer (DAW) coupled cavity linac (CCL) is being developed for use in the middle-beta section of the muon linac. The DAW CCL consists of 14 tanks with 11 cells each. All tanks are connected by bridge couplers and electromagnetic quadrupole doublets for focusing are installed in each bridge coupler. The basic design of the DAW cavity has already been completed, and now detailed cavity design studies and manufacturing process studies are underway. In this poster, we will report about these studies and the preparation status of manufacturing the DAW cavity.

INTRODUCTION

In the anomalous magnetic moment of muons (muon g−2), there was a discrepancy of more than 3σ between the Standard Model prediction and the experimental value measured with an accuracy of 0.54 ppm by Brookhaven National Laboratory (BNL) E821experiment [1], and it has long been argued that this might be a sign of new physics beyond the Standard Model. Recently, Fermilab's experimental group improved BNL's experimental equipment and conducted experiments in a similar method. The result is consistent with the previous experiment, and the discrepancy between the average of the two experiments and the Standard Model prediction [2] was updated to 4.2σ [3]. As a result, expectations for new physics discoveries are rising even more. However, since the two experiments employ the same method, it is extremely important to measure with different new methods and confirm the discrepancy. To validate the discrepancy, an experiment with a completely independent approach from the previous two experiments is planned at Japan Proton Accelerator Complex (J-PARC). The J-PARC experiment aims to measure the muon g−2 with a precision of 0.1 ppm and search for muon electric dipole moment with a sensitivity of 1.5×10^{-21} e· cm [4]. The experiment requires muon beam with low emittance from a muon linac to reduce uncertainties related to the muon beam which is dominant systematic uncertainties in previous experiments. The muons need to be accelerated in a sufficiently short time compared to the muon lifetime of 2.2 µs to suppress the decay loss. Therefore, for highly efficient acceleration, the muons are accelerated from thermal energy to relativistic energy using four RF structure depending on the beam velocity [5]. Figure 1 shows the configuration of the muon linac.

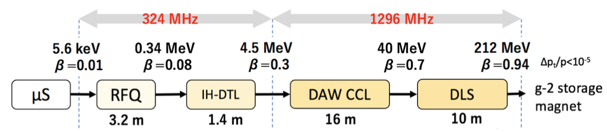

Figure 1: Configuration of the muon linac.

A 1296 MHz disk and washer (DAW) coupled cavity linac (CCL) is being developed for use in the middle-beta section of the muon linac. While DAW CCL has many advantages, such as high shunt impedance and high coupling between acceleration cells and coupling cells, the disadvantages is the difficulty of analyzing many adjacent modes. Therefore, there are few examples that are actually adopted. Figure 2 shows the configuration of the DAW CCL. The DAW CCL consists of 14 tanks with 11 cells each. All tanks are connected by bridge couplers and electromagnetic quadrupole doublets for focusing are installed in each bridge coupler. In this paper, status of development of the DAW cavity is described.

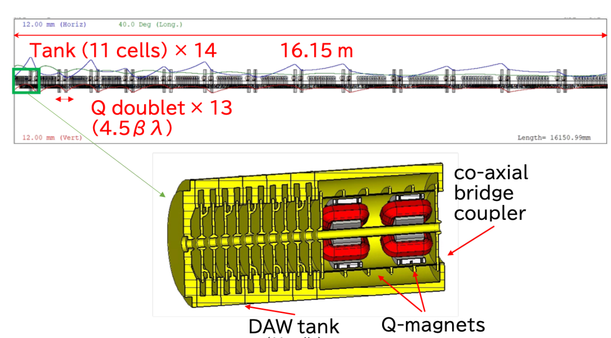

Figure 2: Top: Overall view of the DAW CCL. Bottom: Enlarged view of the first tank, the bridge coupler connected to it, and the quadrupole magnet installed inside it.

* takeuchi@epp.phys.kyushu-u.jp

CAVITY DESIGN

Although several studies have been conducted by optimizing the cavity shape when using typical β values [6], this time we conducted a simulation using the β value of the first tank of the actual machine (0.296) in preparation for the actual machine production. In cavity design, first, a two-dimensional model without washer supports, as shown in Fig. 3, was optimized by calculating the acceleration and coupling mode using SUPERFISH [7]. Then, a three-dimensional model with washer supports was made in CST MICROWAVE STUDIO (MWS) [8] based on the optimized two-dimensional model, and the dispersion curve (see Fig. 4) was examined to see if there are any unfavorable modes near the operating frequency.

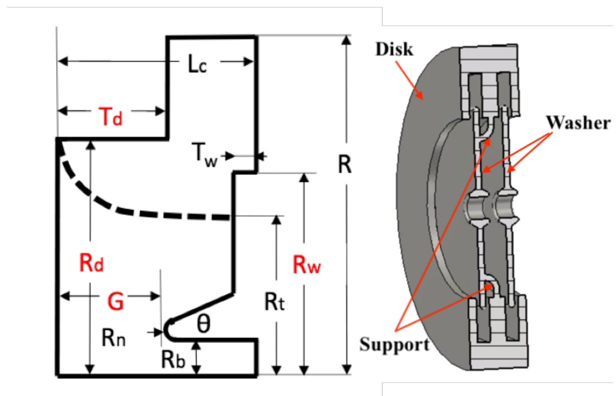

Figure 3: Left: Two-dimensional model of the DAW cavity. Red characters are variable parameters in the optimization process. Right: Three-dimensional model of 2-cell DAW cavity.

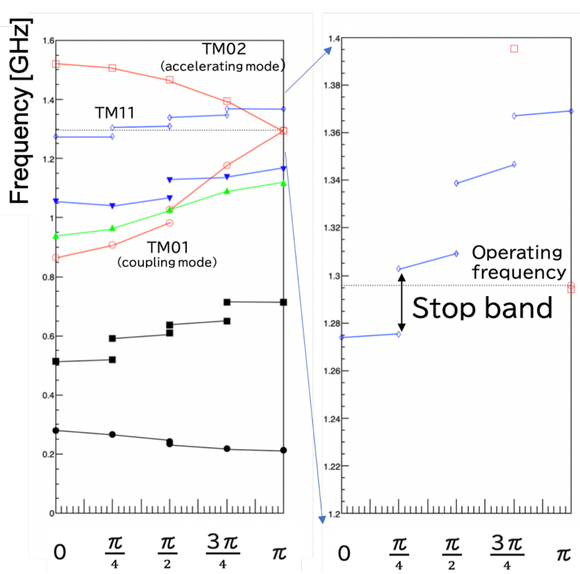

Figure 4: TM02 is accelerating mode, and TM01 is coupling mode. The operating frequency is 1296 MHz. TM11 is close to the operating frequency, but it seems that there is no problem because the operating frequency sit in the stopband.

COOLING-WATER SYSTEM

Cooling-water system for the DAW cavity have been also considered. In current design, the DAW cavity is equipped with 1 cavity wall cooling-water channel (outer) and 2 washer cooling-water channels (inner) for every two cells, as shown in Fig. 5.

The temperature distribution and deformation due to the heat loading of the DAW cavity during high-power operation were analyzed with CST MPHYSICS STUDIO (MPS). The heat transfer coefficient were 8200 W/m^2· K for outer, 9900 /W/m^2· K for inner, calculated from the diameter of water channel and the averaged flow speed, and 14 W/m^2· K for the outer wall of the cavity, assuming natural convection. Assumed RF peak power was 420 kW and the duty factor of the RF power was 0.1 %. In this case, the maximum temperature rise in the DAW cavity is about 7 degrees, and the maximum von Mises stress due to deformation was about 4 MPa. The temperature profile and the thermal stress contour resulting from RF heating are shown in Fig. 6. A frequency shift due to deformation of about -170 kHz has been calculated.

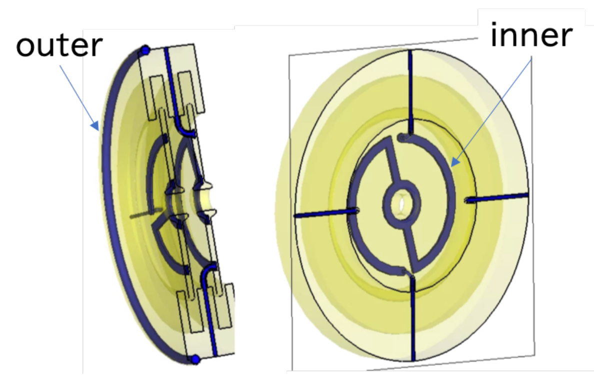

Figure 5: Current water-channel design of the DAW cavity. Diameter of "outer" is 8 mm, diameter of "inner" is 4 mm. The averaged flow speed of water is 2.0 m/s.

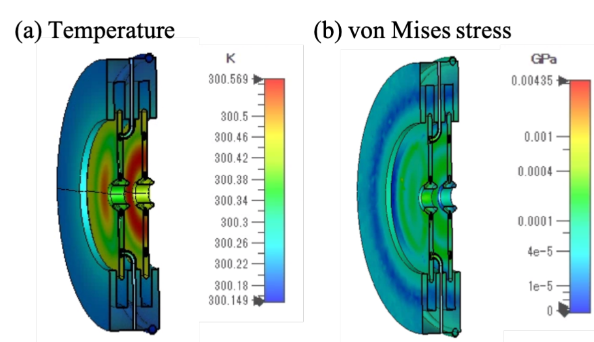

Figure 6: (a) The temperature distribution obtained by CST MPS with current water-channel design. The ambient temperature and the initial temperature of the water are 27 degrees. (b) The calculated result of the von Mises stress. The maximum von Mises stress occurs at the joint between the washer and washer support.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB195

BRIDGE COUPLER

The DAW tanks are connected by coaxial bridge couplers. The coaxial bridge coupler has a structure similar to a DAW cavity and a high coupling coefficient. Since it is placed on the beam axis, it is limited to the installation of focusing devices or monitors. The geometry of the bridge coupler was determined using SUPERFISH (see Fig. 7). After the axial length was determined by the distance between the DAW tanks ($4.5-\beta\lambda$), the other dimensions were determined so that the resonance frequency was 1296 MHz. Based on the determined geometry, a three-dimensional model was created and the electric-field distribution when the tanks were connected by a bridge coupler was confirmed by CST MWS simulation (see Fig. 8).

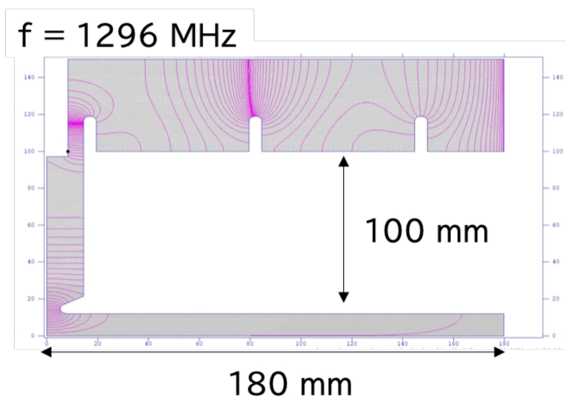

Figure 7: Optimized geometry and simulated electric-field distribution of coaxial bridge coupler.

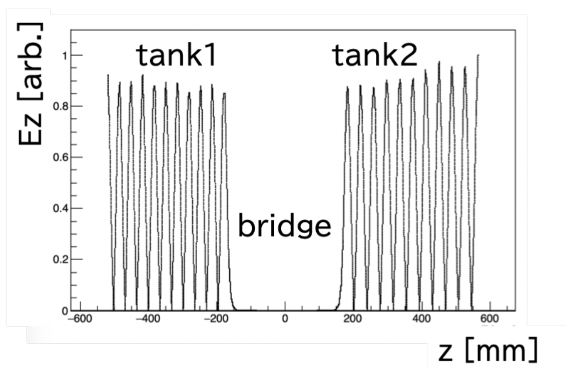

Figure 8: Simulated electric-field distribution of two DAW tanks (without end cells) connected by coaxial bridge coupler.

QUADRUPOLE MAGNET

Quadrupole magnet installed inside the bridge coupler has been also designed by using POISSON [7] and CST EM STUDIO (EMS). It has been designed to simultaneously satisfy both the spatial constraint that it can be installed inside the bridge coupler and several requirements for the magnetic field obtained from the beam dynamics simulation. Table 1 shows the design parameters of the quadrupole magnet. The simulation results show that a gradient of 9.6 T/m and a sufficient effective length can be achieved (see Figs. 9, 10).

Table 1: Quadrupole Parameters

Outer radius	95 mm
Bore radius	16 mm
Gradient	9.6 T/m
Effective length	80 mm
Current	10 A
Yoke material	SS400
Conductor	2 mm × 3 mm 103 turn

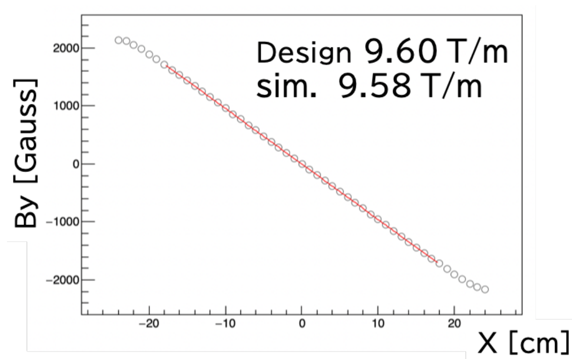

Figure 9: Simulated vertical magnetic field strength along horizontal axis.

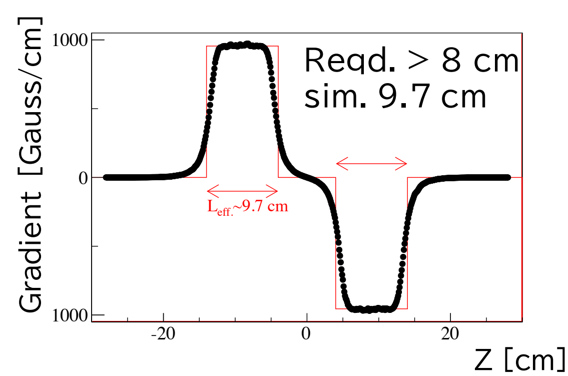

Figure 10: Simulated magnetic field gradient along beam axis.

SUMMARY AND PROSPECT

A 1296 MHz DAW CCL is being developed for use in the middle-beta section of the muon linac. The basic design of the DAW cavity has already been completed, and now detailed cavity design studies and manufacturing process studies are underway. In this fiscal year, we will complete detailed design of the DAW cavity, and plan to fabricate the first tank of the actual machine.

ACKNOWLEDGEMENTS

This work is supported by JSPS KAKENHI Grant Numbers, JP18H03707, JP18H05226, and JP20H05625.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB195

REFERENCES

[1] G. W. Bennett *et al.*, "Final report of the E821 muon anomalous magnetic moment measurement at BNL", *Phy. Rev.D*, vol. 73, no. 7, p. 072003, Apr. 2006. doi:10.1103/PhysRevD.73.072003

[2] T. Aoyama *et al.*, "The anomalous magnetic moment of the muon in the Standard Model", *Physics Reports*, vol. 887, pp. 1–166, 2020. doi:10.1016/j.physrep.2020.07.006

[3] B. Abi *et al.*, "Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm", *Phy. Rev. Lett.*, vol. 126, no. 14, p. 141801, Apr. 2021. doi:10.1103/PhysRevLett.126.141801

[4] M. Abe *et al.*, "A New Approach for Measuring the Muon Anomalous Magnetic Moment and Electric Dipole Moment", *Prog. Theor. Exp. Phys.*, vol. 2019, no. 5, May. 2019. doi:10.1093/ptep/ptz030

[5] Y. Kondo *et al.*, "Re-Acceleration of Ultra Cold Muon in JPARC Muon Facility", in *Proc. IPAC'18*, Vancouver, BC, Canada, Apr.–May 2018, pp. 5041–5046. doi:10.18429/JACoW-IPAC2018-FRXGBF1

[6] M.Otani *et al.*,"Disk and washer coupled cavity linac design and cold-model for muon linac" in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 1924–1927. doi:10.18429/JACoW-IPAC2019-TUPRB117

[7] J. H. Billen and L. M. Young, "Poisson Superfish", Los Alamos, NM, USA, Rep. LA-UR-96-1834, 1996.

[8] CST Studio Suite, Computer Simulation Technology (CST). https://www.cst.com/products/CSTMWS