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LOW-REFLECTION RF WINDOW FOR ACS CAVITY IN J-PARC LINAC

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Abstract

In the Japan Proton Accelerator Research Complex (J-PARC) linac, the Annular-ring Coupled Structure (ACS) cavities have been stably operating. To maintain this operation availability, we manufactured three backups of the pillbox-type RF windows for the ACS cavities in fiscal year 2015 and 2017. It is desirable to minimize the RF reflection of the RF window to prevent standing waves from exciting between the cavity and the RF window, and not to significantly change the optimized coupling factor between the cavity and the waveguide.

To realize the minimization, the relative permittivities of the ceramic disks of the RF windows were evaluated by measuring the resonant frequencies of the pillbox cavity containing the ceramic disk. On the basis of the evaluated relative permittivities, the pillbox-part lengths of the RF windows were determined. The measured Voltage Standing Wave Ratios (VSWRs) of the manufactured RF windows are just about 1.08 and these are applicable for the practical use.

INTRODUCTION

The beam energy of the Japan Proton Accelerator Research Complex (J-PARC) linac was upgraded from 190 to 400 MeV by twenty-five Annular-ring Coupled Structure (ACS) [1, 2] cavities in 2014, and these ACS cavities have been stably operating. To maintain this operation availability, we started to prepare spares of the RF windows for the ACS cavities, which could get broken with a long term use under a high-power operation. Figure 1 shows a configuration of the RF window and the ACS cavity in the J-PARC linac, and the main parameters of the RF window are summarized in Table 1.

The electromagnetic wave reflection of the RF window should be minimized to prevent standing waves from exciting between the cavity and the RF window, and not to significantly change the optimized coupling factor between the cavity and the waveguide. However, the dielectric constant of the ceramic material, which affects the reflection coefficient of the RF window, may vary depending on the manufacturing lot of the ceramic disk. Therefore, to realize the impedance matching condition which minimizes the RF reflection of the RF window, it is necessary to know the dielectric constant of the ceramic disk.

In the J-PARC linac, the dielectric constants of the ceramic disks for the ACS RF windows were evaluated by measuring the resonant frequencies of the pillbox cavity containing the ceramic disk in the manufacturing process of the RF window, and the dimensions of the RF windows were determined in accordance with the evaluated dielectric constants. By this means, the impedance matching condition was accomplished [3, 4].

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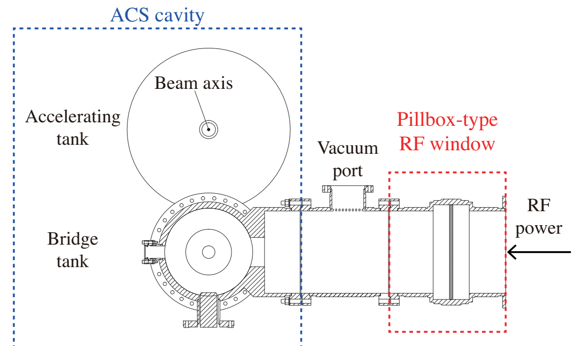

Figure 1: Configuration of the RF window and the ACS cavity in the J-PARC linac.

Table 1: RF Window Parameters for the J-PARC ACS Cavity

Frequency	972 MHz
Peak power	2.0 MW
Pulse length	600 µs
Pulse repetition	50 Hz
Ceramic material	Al_2O_3 95% (NGK-NTK HA95)

By using the same scheme as above, we newly manufactured three pillbox-type RF windows for the J-PARC ACS cavities, one (ID number "#30") in fiscal year 2015 and two (ID number "#32" and "#33") in fiscal year 2017, as the backups. In this paper, the procedure to determine the dielectric constants of the ceramic disks and the measured Voltage Standing Wave Ratios (VSWRs) of the three RF windows are presented.

VSWR OF PILLBOX-TYPE RF WINDOW

The VSWR of a pillbox-type RF window can be adjusted by the pillbox-part length. The pillbox-type RF window for the J-PARC ACS is shown in Fig. 2. The ceramic disk with a thickness of 10 mm is located in the longitudinal center of the pillbox part, and the diameter of the pillbox and the ceramic disk is 285 mm. Figure 3 and 4 show the dependencies of the VSWR of the RF window at 972 MHz on the relative permittivity ε_r of the ceramic disk with the fixed pillbox-part length: $L = 116$ mm and on the length L with $\varepsilon_r = 8.2$, respectively. These dependency trends were obtained by ANSYS HFSS. It is found from these figures that although the VSWR is affected by the dielectric constant, it can be

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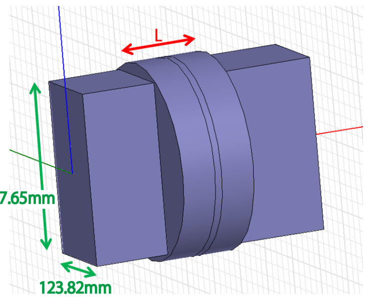

Figure 2: Pillbox-type RF window for the J-PARC ACS.

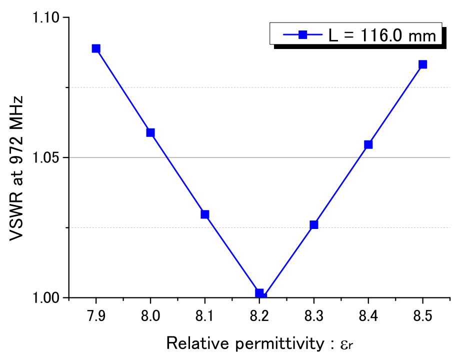

Figure 3: Dependency of the VSWR on the relative permittivity ε_r with the pillbox-part length: L = 116 mm.

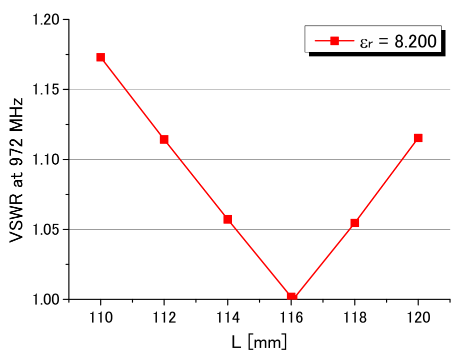

Figure 4: Dependency of the VSWR on the pillbox-part length L with the relative permittivity: ε_r = 8.2.

minimized by adjusting the pillbox-part length according to the dielectric constant. Therefore, we need to know the value of the relative permittivity of the ceramic disk for the impedance matching condition.

EVALUATION OF RELATIVE PERMITTIVITY OF DIELECTRIC DISK

The relative permittivities of the ceramic disks were evaluated by measuring the resonant frequencies of the pillbox cavities. The pillbox cavity is composed of a combination of a copper outer sleeve containing the ceramic disk in its longitudinal center and two aluminum plates terminating the upper and bottom sides of the circular cylinder. We focused on the TM_{011}-mode and TE_{011}-mode frequencies of the pillbox cavity for the relative permittivity evaluation,

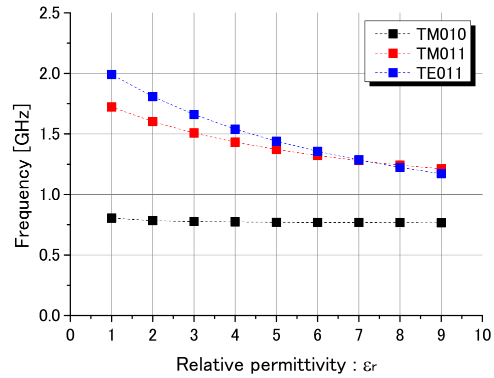

Figure 5: Dependencies of TM_{010}, TM_{011}, and TE_{011} frequencies on the relative permittivity of the ceramic disk.

because the electric fields of these resonant modes are localized in the ceramic disk and the dependencies of these resonant-mode frequencies on the relative permittivity of the disk are comparatively large as shown in Fig. 5 obtained by CST Microwave Studio (MWS). The resonant frequencies of TM_{011} mode and TE_{011} mode were measured with two straight antennas (Fig. 6) and with two loop antennas (Fig. 7), respectively. Figure 8 and 9 show the measured frequencies and Q values under the different suppressing forces to the aluminum short-circuiting plates.

The suppressing force does not affect the Q value of TE_{011} mode, whereas the Q value of TM_{011} mode drastically increases with the suppressing force. This is because the surface current on the inner contact between the aluminum short-circuiting plate and the copper outer sleeve is negligibly small in the TE_{011} mode. The relative permittivities of the ceramic disks were evaluated by applying the measured frequencies to the relation between the frequency and the relative permittivity obtained by the simulations (SUPERFISH for TM_{011} mode, MWS for TM_{011} mode and TE_{011} mode) as shown in Fig. 10. Table 2 summarizes the mea-

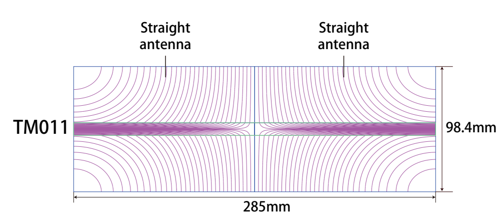

Figure 6: Electric field of the TM_{011} mode and the straight antennas for the resonant frequency measurement.

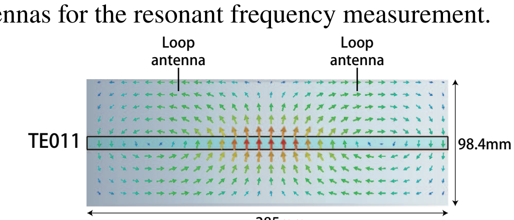

Figure 7: Magnetic field of the TE_{011} mode and the loop antennas for the resonant frequency measurement.

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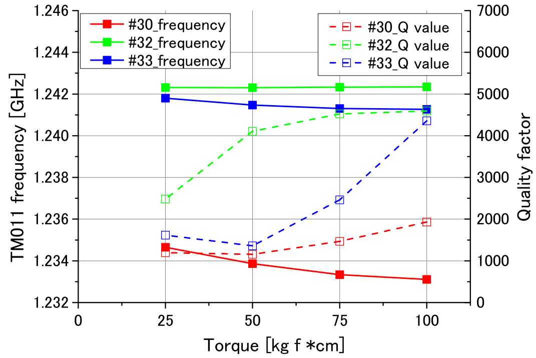

Figure 8: Measured TM_{011}-mode frequency and Q value.

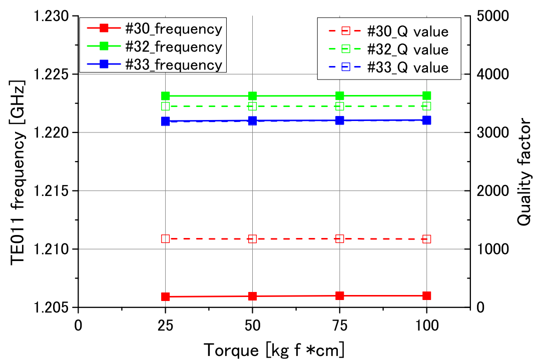

Figure 9: Measured TE_{011}-mode frequency and Q value.

sured frequencies and the evaluated relative permittivities. As for the TE_{011} modes, the relative permittivities which can be analytically obtained by using a cavity resonator method (detailed in Appendix. C of [4]) are also listed in this table, and these values are well matched with that obtained by the simulation. The differences of the relative permittivities evaluated by TM_{011} and TE_{011} modes are 0.063, 0.015, and 0.013 for ID #30, #32, and #33, respectively. It is shown in Fig. 3 that the difference of the relative permittivity of 0.063 induces the difference of VSWR as about 0.02, and this difference would not be really matter.

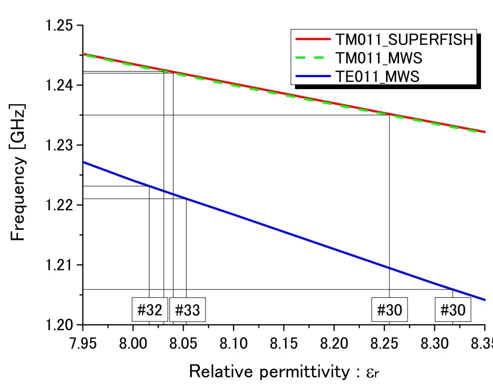

Figure 10: Correlation between the TM_{011} and TE_{011} frequencies and the relative permittivity of the ceramic disk.

Table 2: Frequencies and Evaluated Relative Permittivities

ID	mode	frequency [GHz]	ε_r (simulation)	ε_r (analysis)
#30	TM_{011}	1.2350	8.255	—
#30	TE_{011}	1.2059	8.318	8.313
#32	TM_{011}	1.2423	8.031	—
#32	TE_{011}	1.2231	8.016	8.005
#33	TM_{011}	1.2420	8.040	—
#33	TE_{011}	1.2210	8.053	8.042

The pillbox-part lengths were determined according to the evaluated relative permittivities. These lengths are 112.4 mm, 115.7 mm, and 115.3 mm for ID #30, #32, and #33, respectively. After completion of the fabrication, we measured the VSWRs of these RF windows, and these are just about 1.08. These manufactured RF windows are applicable for the practical use, although the measured VSWRs are higher than we expected.

SUMMARY

We manufactured three spares of the pillbox-type RF windows for the ACS cavities in fiscal year 2015 and 2017. The relative permittivities of the ceramic disks were evaluated by measuring the resonant frequencies of the pillbox cavity containing the ceramic disk. On the basis of the evaluated relative permittivities, the pillbox-part length were determined to minimize the RF reflection of the RF window. The measured VSWRs of the manufactured RF windows are 1.08 and these are applicable for the practical use.

ACKNOWLEDGMENTS

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