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# THE FIRST REPLACEMENT OF THE RF WINDOW OF THE ACS CAVITY

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*Abstract*

In 2013, the Annular-ring Coupled Structure (ACS) cavities were installed to the Japan Proton Accelerator Research Complex (J-PARC) linac. Since then, the ACS cavities have been stably running. Although any serious problem induced by the RF window had not yet observed, we decided to replace the RF window of one ACS cavity by the newly manufactured one. The major motivations of the replacement are to check the surface condition of the RF window which have been under operation for nearly five years, to confirm that the new RF window fully meets specifications, and to learn how much time is required for high-power conditioning of the new RF window. By making use of the summer maintenance period of 2018, we carried out the replacement. This was the first experience for us to replace the RF window installed to the ACS cavity in the linac accelerator tunnel. As for the removed RF window, there was no any abnormal warning found with the visual examination. At the resuming of the cavity operation after the maintenance period, we conducted the high-power conditioning in a measured manner. It took around fifty hours so that the targeted peak power was stably input to the cavity through the new RF window. The ACS cavity with the new RF window is now stably operating.

## INTRODUCTION

In 2013, the Annular-ring Coupled Structure (ACS) [1, 2] cavities were installed to the Japan Proton Accelerator Research Complex (J-PARC) linac. The beam energy of the linac was upgraded from 180 MeV to 400 MeV by the twenty-five ACS cavities. Since then, the ACS cavities have been stably running. Figure 1 shows the ACS cavities installed in the beam line of the J-PARC linac.

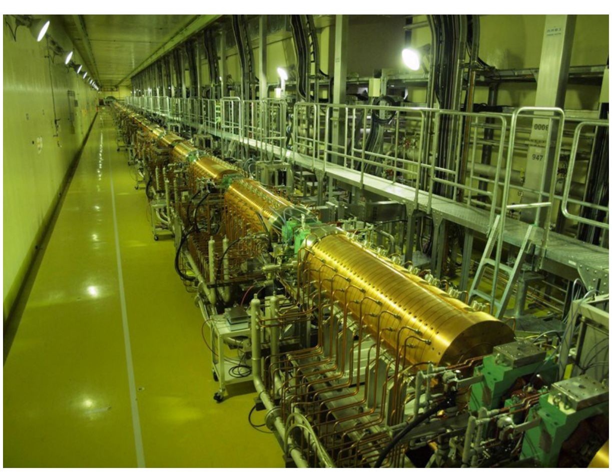

Figure 1: ACS cavities in the beam line of the J-PARC linac.

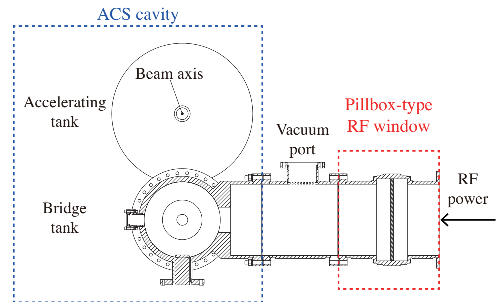


Figure 2: Configuration of the RF window and the ACS cavity in the J-PARC linac.

To maintain the operation availability, we have prepared spares of the RF windows for the ACS cavities [3–5], which could get broken with a long-term use under a high-power operation. Figure 2 shows a configuration of the RF window and the ACS cavity in the J-PARC linac. The ACS cavity consists of two accelerating tanks and one bridge tank. The rectangular waveguide is connected to the center cell of the bridge tank. The main parameters of the RF window are summarized in Table 1.

Table 1: Main Parameters of the RF Window 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 HA-95) |

Although any serious problem induced by the ACS RF window had not yet observed, we decided to replace the RF window of one ACS cavity by the newly manufactured one. The major motivations of the replacement are as follows:

- To check the surface condition of the RF window which have been under operation for nearly five years.
- To confirm that the new RF window fully meets specifications.
- To learn how much time is required for high-power conditioning of the new RF window.

## REPLACEMENT OF THE RF WINDOW

By making use of the summer maintenance period of 2018, we replaced the RF window of the ACS18 which is the eighteenth accelerating cavity in the order of beam

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energy. The manufacturing ID numbers of the replaced RF window and the new one are #19 and #30, respectively. The Voltage Standing Wave Ratio (VSWR) of the RF window #19 is 1.03. The RF window #30 was manufactured in fiscal year 2015, and its VSWR is 1.08 [5]. The measurement procedure of the VSWR is detailed in Appendix A of [4]. This was the first experience for us to replace the RF window installed to the ACS cavity in the linac beam line.

With respect to the removed RF window (#19), there was no any abnormal warning found with the visual examination. The surface condition of the removed RF window remained good as indistinguishable from a new one. Figure 3 shows the removed RF window, and the vacuum side of the ceramic disk is shown in the right side picture. The vacuum side surface of the ceramic disk is coated with titanium nitride of 10-nm thickness to suppress the electron emission. On the other hand, the RF windows removed from the drift tube cavities of the J-PARC linac after a few years of beam operation were obviously discolored. This is possibly caused by the fact that the RF window of the drift tube cavity is located in the same space with the beam whereas that of the ACS cavity is installed toward the iris of the bridge tank which is off the beam axis. On the basis of this visual confirmation, we concluded that a periodical replacement of the ACS RF window is not be indispensable over the next few years unless any problem related to the RF window arise.

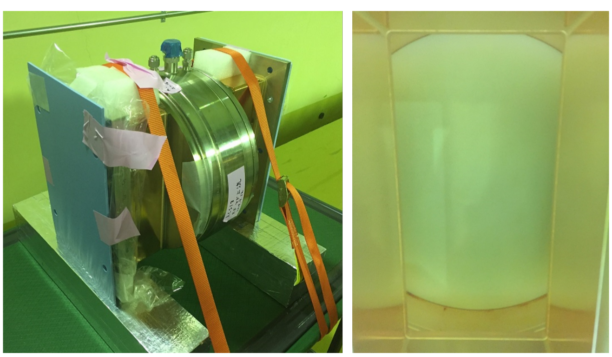

Figure 3: Removed RF window (#19).

We measured the VSWR of the ACS18 cavity before and after replacing the RF window. As summarized in Table 2, the measured VSWR of the ACS18 cavity with the RF window #19 was 1.63, and that with #30 was 1.56. In this measurement, the position of the frequency tuner was set

Table 2: Measured VSWR of the ACS18 Cavity

| Cavity | RF window (VSWR) | Pressure [Pa] | VSWR |
|---|---|---|---|
| ACS18 | #19 (1.03) | $1.2 \times 10^{-7}$ | 1.632 |
| ACS18 | #19 (1.03) | $\approx 1.0 \times 10^{5}$ | 1.626 |
| ACS18 | without RF window | $\approx 1.0 \times 10^{5}$ | 1.740 |
| ACS18 | #30 (1.08) | $\approx 1.0 \times 10^{5}$ | 1.555 |
| ACS18 | #30 (1.08) | $6.4 \times 10^{-7}$ | 1.559 |

Table 3: Cavity Parameters of the ACS18

| | | | |
|---|---|---|---|
| Total accelerating length | $L$ | 3.63 | [m] |
| Shunt impedance per length | $Z_{sh}$ | 53.9 | [MΩ/m] |
| Averaged accelerating field | $E_0$ | 4.12 | [MV/m] |
| Wall loss | $P_0$ | 1.14 | [MW] |
| Beam loading (50mA) | $P_{beam}$ | 0.54 | [MW] |

to 17.20 mm to minimize the RF reflection at the operating frequency of 972 MHz under the high-vacuum condition. Table 3 lists the cavity parameters of the ACS18, where $E_0$ (averaged accelerating field) and $Z_{sh}$ (shunt impedance per length) are defined by using the accelerating voltage: $V_0 = \int E_z(r=0)dz$ as $E_0 = V_0/L$ and $Z_{sh} = (V_0^2/P_0)/L$, respectively. The coupling factor with a nominal peak current of 50 mA is estimated as

$$\begin{aligned}\beta_{beam} &= \frac{P_0}{P_0 + P_{beam}} \times \beta \\ &= \frac{1.14\ [\mathrm{MW}]}{1.14\ [\mathrm{MW}] + 0.54\ [\mathrm{MW}]} \times 1.56 = 1.06\end{aligned}$$

Therefore, almost matched condition is obtained.

## HIGH-POWER CONDITIONING

At the resuming of the cavity operation after the maintenance period of 2018, we conducted the high-power conditioning in a measured manner. Figure 4 shows the conditioning history of ACS18. The blue line shows the vacuum pressure measured with the B-A gauge installed to the center cell of the bridge tank. The cavity was evacuated with two 500-L/s ion pumps and one 150-L/s ion pump. The red line shows the input peak power. The input peak power is gradually increased with the fixed pulsed length of 600 µs and with the fixed repetition cycle of 25 Hz. The target value of the input peak power was set to 1.8 MW including some margin to the sum of the estimated wall loss of 1.14 MW and the beam loading of 0.54 MW. During the night, the input peak power was kept at a bit lower level than the achieved value. While the high-power conditioning, sharp

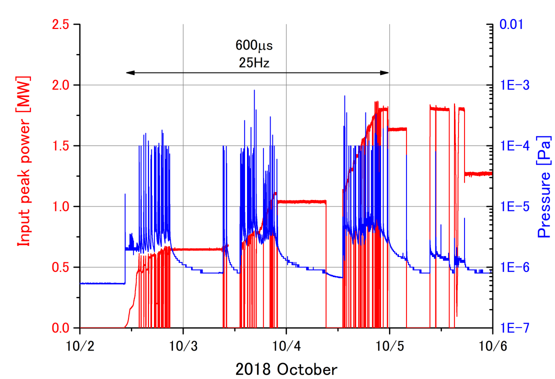


Figure 4: Conditioning history of ACS18 in 2018.

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increases of the vacuum pressure happened frequently as shown by the blue spikes in Fig. 4. Also, discharges in the vicinity of the RF window were often detected by the arc sensor installed toward the vacuum side of the RF window. These phenomena became obstacles for increasing the input power. At an input peak power from 600 to 800 kW, the outgassing rate increased. However, no additional outgassing was observed after the cavity had been conditioned up to this level. The discharge rate also decreased as the conditioning progressed.

It took around fifty hours so that the targeted peak power was stably input to the cavity through the new RF window. In this situation, it is considered that only the newly installed RF window (#30) was conditioned, as the ACS18 cavity itself had been fully conditioned. Although the time required for the conditioning was less than that for the first conditioning of both the cavity and the RF window, it was longer than we expected. The first conditioning history of ACS18 in 2013 is shown in Fig. 5. It took about 110 hours to input 2 MW of peak power. It should be noted that the input peak power was increased to 2 MW with a short pulse length of 50 µs, and then, the peak power was increased to 2 MW with a nominal pulse length of 600 µs. It was found that we have to secure a period of at least fifty hours only for the conditioning of the new RF window.

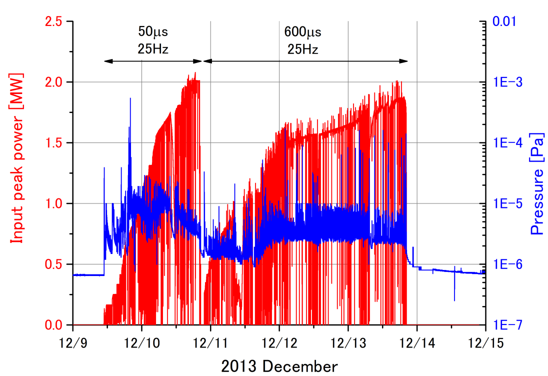


Figure 5: Conditioning history of ACS18 in 2013.

About a half year have passed since the replacement of the RF window has been carried out. The ACS18 cavity with the new RF window (#30) is now stably operating. The removed RF window (#19) was installed to the ACS21 cavity in the same summer shutdown period of 2018 [6]. The ACS21 cavity with the RF window #19 is also stably operating.

## SUMMARY

In the summer maintenance period of 2018, we replaced the RF window of the ACS18 cavity by newly manufactured one. We visually confirmed that the surface of the removed RF window, which had been operated for nearly five years, remained good condition. Therefore, we concluded that a periodical replacement of the ACS RF window is not indispensable over the next few years. As the result of the high-power conditioning conducted after the maintenance period, we found that a period of at least fifty hours should be secured for conditioning the new RF window. And furthermore, according to the fact that the ACS18 cavity with the new RF window is now stably operating, we confirmed that the newly manufactured RF window meets the specifications.

## ACKNOWLEDGMENTS

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