

VSWR ADJUSTMENT FOR ACS CAVITY IN J-PARC LINAC

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Abstract

In the Japan Proton Accelerator Research Complex (J-PARC) linac, negative hydrogen beams are accelerated from 190 MeV to 400 MeV by Annular-ring Coupled Structure (ACS) cavities. The RF input coupler of the ACS21 cavity, which is the twenty-first (the last) accelerating cavity in the order of beam acceleration, had a comparatively larger Voltage Standing Wave Ratio (VSWR) value than the other ACS cavities. Therefore, we designed and manufactured a rectangular waveguide which have a capacitive iris to adjust the coupling factor of the ACS21 cavity. By making use of the summer maintenance period in 2018, we installed the newly manufactured waveguide to the cavity. Consequently, the VSWR of the ACS21 was successfully decreased to the target value which leads to the critical coupling under the nominal accelerating condition with 50-mA peak beam current.

INTRODUCTION

In the Japan Proton Accelerator Research Complex (J-PARC) linac, negative hydrogen beams are accelerated from 190 MeV to 400 MeV by Annular-ring Coupled Structure (ACS) cavities [1, 2]. The J-PARC ACS consists of two buncher cavities, twenty-one accelerating cavities, and two debuncher cavities. All the ACS cavities are operated with 972 MHz of accelerating mode ($\pi/2$ -mode) frequency.

One ACS cavity is divided into two accelerating tanks and one bridge tank. With respect to the accelerating cavity, there are seventeen accelerating cells and sixteen coupling cells in each accelerating tank, while there are five accelerating cells and four coupling cells in the bridge tank. Figure 1 shows the accelerating cavity of the J-PARC ACS. The electromagnetic field is excited in the accelerating cells, whereas the field is not excited in the coupling cells. The accelerating mode ($\pi/2$ -mode) frequency is tuned to the op-

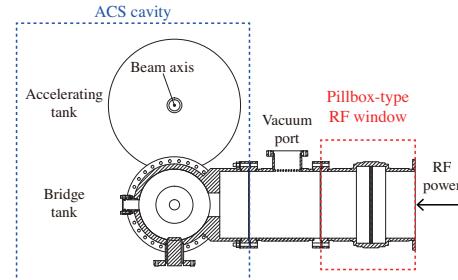


Figure 2: Bridge coupler of the J-PARC ACS.

erating frequency of 972 MHz by adjusting the position of the five plungers in the accelerating cells of the bridge tank. The rectangular waveguide is connected to the center cell part of the bridge tank. As shown in Fig. 2, an RF power passing through the pillbox-type RF window [3] is fed into the cavity through the iris in the center accelerating cell.

The RF input coupler of the ACS21 cavity, which is the twenty-first (the last) accelerating cavity in the order of beam acceleration, had a comparatively larger Voltage Standing Wave Ratio (VSWR) value than the other ACS cavities. Therefore, we designed and manufactured a rectangular waveguide which has a capacitive iris to adjust the coupling factor of the ACS21 cavity. This was the first experience to change the matching condition of the ACS cavity which had been operated for beam acceleration. In this paper, the VSWR adjustment for the ACS21 cavity performed in the summer maintenance period of 2018 is presented.

DESIGN OF THE CAPACITIVE IRIS

The matching of the ACS cavity and the waveguide is determined by the configuration of the coupling iris. Therefore, it is more difficult to change the VSWR of the ACS than the case of coaxial-type couplers where the coupling factor can be tuned by changing the direction of the loop antenna or by taking the straight antenna in and out the cavity. To adjust the coupling factor of the ACS21 cavity¹, we decided to provide the rectangular waveguide, which is located between the cavity and the RF window as shown in Fig. 2, with a capacitive iris by using the same scheme as [4] where the VSWR of the ACS11 cavity was corrected from 1.85 to 1.45 by the 20-mm width iris.

To get the critical coupling under the nominal accelerating condition with 50-mA peak beam current, we set the target value of the VSWR of the ACS21 cavity to 1.46.

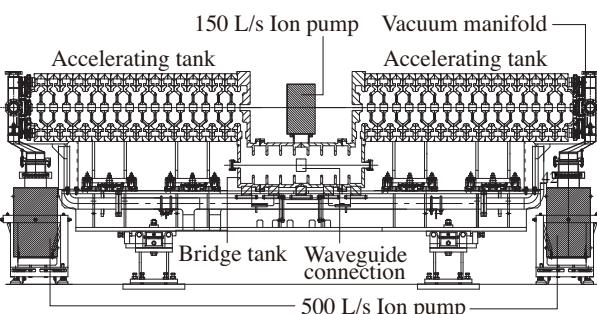


Figure 1: Accelerating cavity of the J-PARC ACS.

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¹ Although the reflection from the total load (the cavity and the RF window) is determined by the combination of the VSWRs of the cavity and the RF window, we aimed to realize the best matching only with the cavity assuming that the RF window itself has no reflection.

Table 1: Cavity Parameters of the ACS21

Total accelerating length	L	3.72	[m]
Shunt impedance per length	Z_{sh}	53.6	[MΩ/m]
Averaged accelerating field	E_0	4.12	[MV/m]
Wall loss	P_0	1.18	[MW]
Beam loading (50mA)	P_{beam}	0.54	[MW]

Table 1 lists the cavity parameters of the ACS21, 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. If the coupling factor without beam (β) is set to 1.46, the coupling factor with beam (β_{beam}) is derived as

$$\begin{aligned}\beta_{beam} &= \frac{P_0}{P_0 + P_{beam}} \times \beta \\ &= \frac{1.18 \text{ [MW]}}{1.18 \text{ [MW]} + 0.54 \text{ [MW]}} \times 1.46 = 1.00\end{aligned}$$

We had to design the capacitive iris which reduces the VSWR of the ACS21 cavity from 2.0 to 1.46. The iris thickness was set to 10 mm. And then, the iris position was narrowed down to three candidates (short, middle, and long) as shown in Fig. 3. The position and the width of the iris were determined by using the three-dimensional electromagnetic field analysis software ANSYS HFSS. Figure 4 shows the adopted analysis model where a quarter of the geometry was analyzed using symmetric property. In this model, the configuration of the ACS21 cavity was represented by the center accelerating cell of the bridge tank (a half cell), the adjacent coupling cell (one cell), and the adjacent accelerating cell (a half cell).

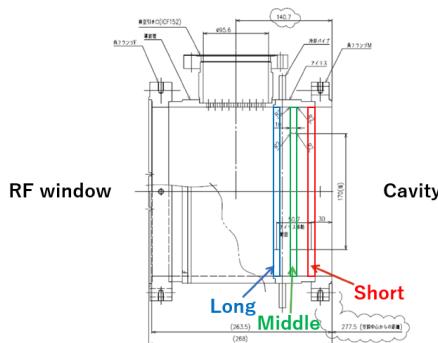


Figure 3: Candidates of the iris position.

In the simulation, the electrical conductivity of the end cell surface, shown by the bluish-violet color in Fig. 4, was modified so that the end half cell covers the total wall loss of two accelerating cells in the bridge tank and seventeen accelerating cells in the accelerating tank. We assumed that the stored energy of one accelerating cell in the bridge tank is a quarter of that in the accelerating tank, since the cell-to-cell coupling factor for the bridge tank was designed to be twice as large as that for the accelerating tank. Therefore,

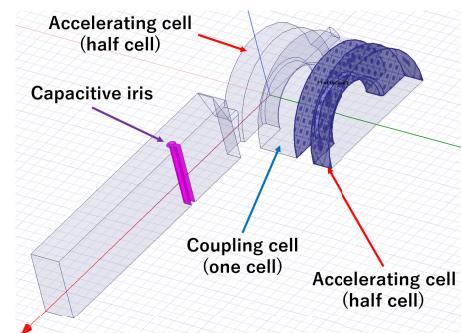


Figure 4: Analysis model of the bridge coupler.

$2 \times (2 + 17 \times 4) = 140$ times of wall loss dissipated in the end half cell was taken into the simulation. As the surface resistance (R_s) is expressed as

$$R_s = \sqrt{\frac{\omega\mu}{2\sigma}}$$

where ω , μ , and σ are the angular frequency, permeability, and conductivity, the conductivity ($\sigma = 5.8 \times 10^7 \text{ S/m}$) was divided by the square of 140. And moreover, the radius of the end accelerating cell was adjusted so that the excited $\pi/2$ -mode field have the minimum reflection at the operating frequency of 972 MHz.

We decided to set the position and the width of the capacitive iris to "short" position and 23 mm, respectively. Figure 5 shows the dependences of the VSWRs with different iris positions on the iris width obtained by the simulation. To validate the VSWR values directly obtained by using this analysis model (shown by the empty symbols in Fig. 5), we experimentally measured the VSWR of the ACS21 cavity exclusive of the RF window. Although the simulation indicated the VSWR without the iris as 2.3, the measured VSWR value was 2.0. Therefore, the VSWR values obtained by the simulation were normalized by multiplying 2.0/2.3 to have a consistency with the measurement result. The normalized values are shown by the filled-in symbols in Fig. 5. According to the dependences of the normalized VSWR values, it was found that the capacitive iris which has

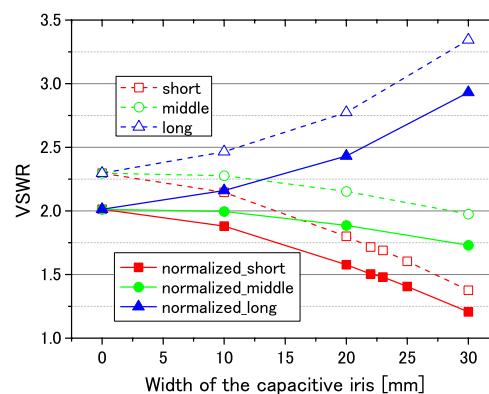


Figure 5: Dependences of the VSWRs with different iris positions on the iris width obtained by the simulation.

23-mm width at the "short" position decreases the VSWR of the ACS21 cavity to the targeted value.

The designed iris width was confirmed also by the alternative simulation method as follows. The conductivity of the end half cell was adjusted to $5.8 \times 10^7 / 163^2$ S/m so that the simulated VSWR value directly corresponds to the measured value (2.0) without the capacitive iris. This means that the cell-to-cell coupling factor for the accelerating tank is 2.16 times of that for the bridge tank. Using this conductivity, the VSWR with different iris widths at "short" position were simulated. As shown in Fig. 6, the targeted VSWR value of 1.46 is obtained by 23 mm of the iris width. Both of the simulation methods show that the capacitive iris with 23mm-width realizes the VSWR adjustment from 2.0 to 1.46 for the ACS21 cavity. In accordance with this design, the rectangular waveguide with the capacitive iris was manufactured.

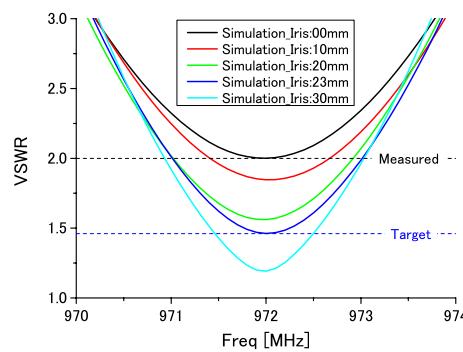


Figure 6: VSWR with different iris widths at "short" position obtained by the simulation ($\sigma = 5.8 \times 10^7 / 163^2$ S/m).

INSTALLATION TO THE CAVITY

By making use of the summer maintenance period in 2018, we installed the newly manufactured waveguide to

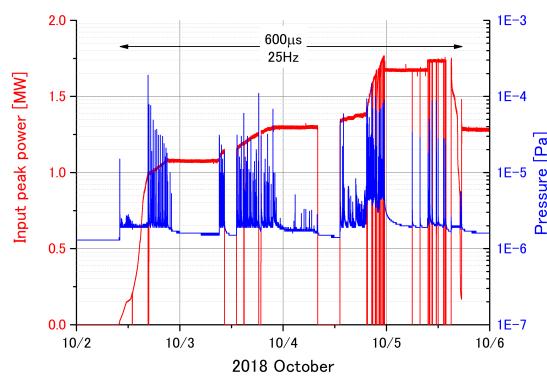


Figure 7: Conditioning history of ACS21 in 2018.

the ACS21 cavity. The measured VSWR² was 1.466, and it was in good agreement with our estimation.

After the maintenance period, the ACS21 cavity with the RF window #19 [5] was conditioned up to 1.75 MW without any serious problem. Figure 7 shows the conditioning history of the ACS21 cavity. About a half year have passed since the newly manufactured waveguide had been installed. At present, the ACS21 cavity is stably operating.

SUMMARY

We designed and manufactured the rectangular waveguide with capacitive iris for the ACS21 cavity which had relatively larger VSWR than the other ACS cavities. In the design stage, we confirmed the iris width by the alternative simulation method, and then, we got the good agreement in both the simulation methods. By utilizing the summer maintenance period of 2018, we installed the new manufactured waveguide. The measured VSWR was in good agreement with our estimation. We successfully adjusted the VSWR of the ACS21 cavity in the J-PARC linac.

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² In this measurement, the position of the frequency tuner was set to 22.75 mm to minimize the RF reflection at the operating frequency of 972 MHz under the high-vacuum condition.