FIRST HIGH-POWER ACS MODULE FOR J-PARC LINAC

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Abstract

An ACS (Annular Coupled Structure) cavity has been developed for an accelerating structure from 190 MeV to 400 MeV of the J-PARC Linac. One ACS module consists of two 17-cell accelerating tanks and one 9-cell bridge tank. In this accelerating section, 21 ACS accelerating modules will be installed. We fabricated a buncher module that consists of two 5-cell accelerating tanks and one 5-cell bridge tank as the first ACS cavity for the J-PARC. The operating frequency of the ACS is 972 MHz and designed E0 values for the buncher, the accelerating modules are 4.1 MV/m, 4.3 MV/m, respectively. In this high-power test, we achieved the stable operation of 50 Hz, 600 μs, 600 kW for 30 minutes or more. This power corresponds to the E0 value of 4.8 MV/m, which is enough for the requirements

INTRODUCTION

In the J-PARC linac, an ACS (Annular Coupled Structure) is used for the accelerating cavity in the high-energy part from 190 MeV to 400 MeV. The ACS was adopted because an axial symmetry of an electric field balances with shunt impedance.

It is scheduled that the linac starts with 181 MeV at first for the limitation of the budget, and the energy will be recovered up to 400 MeV afterwards, though the linac is planned to be 400 MeV in the phase-I. Therefore, the linac is composed of 50keV ionization source, 3 MeV RFQ, 50 MeV DTL, and 181 MeV SDTL. Furthermore, the various equipment of the beam transportation system are installed in this high-energy section (about 120 m): magnets and vacuum ducts for example. These magnets and magnet power supplies, etc. are already designed for 400 MeV operations.

The development of the ACS cavity for a buncher began in April 2002, which is the first module of the J-PARC ACS. The initial design was fixed by the electromagnetic field analysis and the model measurement[1, 2]. And then, through the RF tuning at the several steps and the assembling by brazing, etc., finally, the buncher module was transported to Tokai, on May 8, 2006. After installation to the test aria and the low-level RF measurement, the high-power test began on May 30. This paper describes some details and the result of these tests.

J-PARC ACS CAVITY

The ACS module consists of the one bridge tank and two accelerating tanks. The center of the bridge tank has a joint with a waveguide. Movable tuners for the frequency adjustment are attached in the excitation cell of the bridge tank. There is a manifold for the vacuum exhaust in both ends of the accelerating tank, and one module is exhausted with two ion pumps under operation.

The ACS has the 17-cell accelerating tank and the 9-cell bridge tank, and 21 ACS modules accelerates a H- beam from 190 MeV to 400 MeV. Moreover, two ACS modules are installed in matching section (MEBT2) between the SDTL and the ACS. They used as a buncher that has the 5-cell accelerating tank and the 5-cell bridge tank. The number of cells is decreased in the buncher though basic dimensions are as same as the module for acceleration. One module for the buncher was fabricated as the first module for the J-PARC ACS, and it was tested under the high-power operation. The main parameters and schematic drawings are shown in Table 1 and Fig.1 respectively.

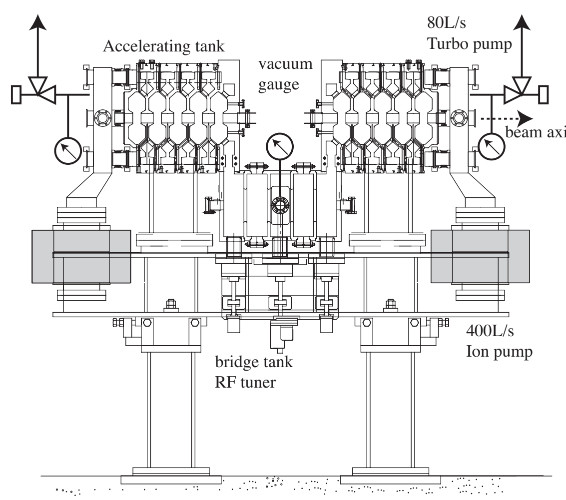

Figure 1: Schematic drawings of ACS buncher.

Table 1: The ACS buncher module main parameter

Frequency	972 MHz
β	0.556
Shunt impedance	33 MΩ/m
Accelerating Voltage E0	4.1 MV/m
No load Q0	17600
VSWR (including an RF window)	1.5
Accelerating tank length	0.857 m
Repetition	50 Hz
Pulse length	600 μs

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BEAD-PULL MEASUREMENT

One vector network analyzer (VNA) of the PC base (Agilent E8357A) measured the RF phase shift and accumulated the data simultaneously. Figure 2 shows the concept of the measurement.

This VNA can be called a PC with the RF measurement function, and the operating system of the VNA is one application on Windows. Thus, using Excel and VBA on this VNA, Excel can handle the data between the applications. Excel also plot the data, so that we can confirm the electric field distribution in real time on the VNA. This system not only simplifies the RF measurement but also records high-speed (10 points/second or more) because of no external communication. Moreover, various applications are possible.

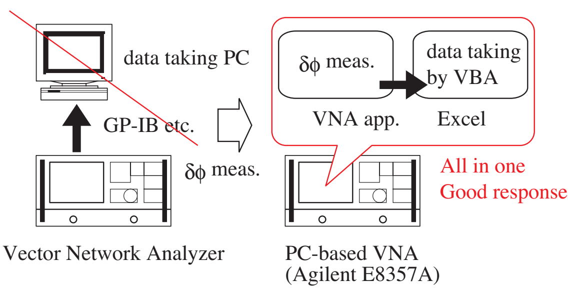

Figure 2: Vector network analyzer (VNA) measured the RF and accumulated the data simultaneously.

The frequency shift with the bead-pull method was derived from the change in phase arg(S21) at the resonance frequency. The relation between the frequency and the phase was confirmed by the measurement. The bead was moved keeping a constant speed by the pulse motor, and the VNA measured the phase shift continuously.

Figure 3 shows the electric field distribution when we adjust the cavity to 972 MHz of the operating frequency with the tuner. In this measurement, the wire is 0.165mm, and the bead diameter is 3 mm, and the beam bore is 40 mm in the diameter. The frequency shift was 5.3 kHz in the peak, and the short time fluctuation (30 seconds) of the base line was $\pm$ 0.04 kHz when the bead stayed outside of the acceleration gap.

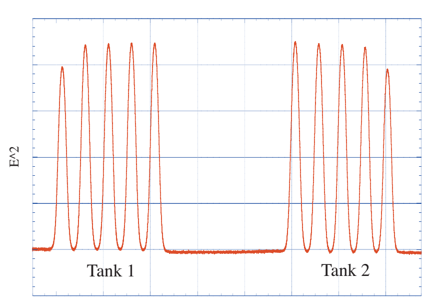

Figure 3: Electric field distribution of the ACS buncher.

HIGH-POWER TEST

Vacuum and RF Interlock

The two ion pumps of 400L/s were installed in both ends of the accelerating tank. The B-A gauge was set up in the view-port for the RF window at the center cell of the bridge tank. Using this B-A gauge, the RF interlock cuts the RF power larger than the pressure of 1×10^{-4} Pa. The reflected power was monitored from the directional coupler installed in the waveguide. When the reflected power exceeded the limit value, this monitoring system cuts the RF power in a few micro seconds.

Aging History

Figure 4 shows the aging history. At first the peak power had been increased with the fixed pulse width of 20 μs. The repetition of 50Hz was fixed through this whole test. It took 15 hours until reaching the target power (600 kW). For the next step, the pulse length had been increased from 20 μs to 600 μs with fixed peak power of 600 kW. It took 35 hours from the start of the test until reaching 600 μs pulse width with a 600 kW peak and 50Hz repetition.

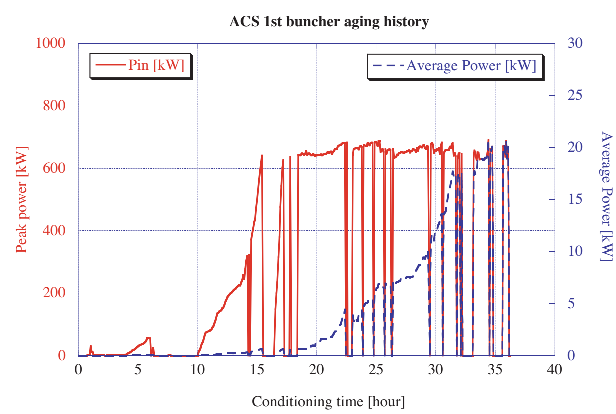

Figure 4: Aging history (Peak power:red, Average:blue).

Figure 5 shows the history of the vacuum pressure under the high-power operation. We operated the peak power and the pulse length so that the pressure did not exceed more than 5×10^{-5} Pa. As a result, the main trigger of the interlock was the reflection power even if the pulse length was increased, and the trigger by the pressure was few case. Moreover, the heat generation and the spark in the RF window were not confirmed. We think that the low average power did not become a major source of these phenomena because of a short module for the buncher.

In Figure 5, the notation of VAC means the pressure of the bridge cavity center, and IP1 and IP2 mean the pressure from the current of the ion pump. When a RF power was not inputted, the average pressures were 1×10^{-5} Pa at the bridge and $6 \sim 7 \times 10^{-6}$ Pa at the ion pumps, although we worried about a high pressure at the bridge (the vicinity of the RF window is the furthest from the ion pump) because the vacuum pumps were only installed at both ends of the accelerating tanks.

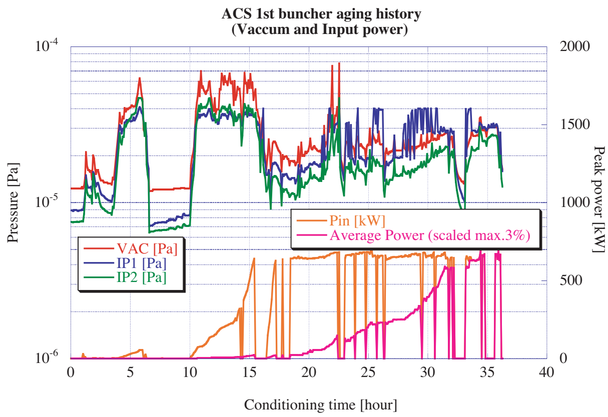

Figure 5: Input power and vacuum pressure.

Input Power of Cavity

About one week aging was continued after the aging process shown in Fig. 4 and 5 for a more stable operation. The power measurement system had been confirmed and improved in this process. We measured three types of the RF power: input (Pin), reflection (Pr), and cavity picking up (Pcav). Figure 6 shows the schematic view of the power measurement system.

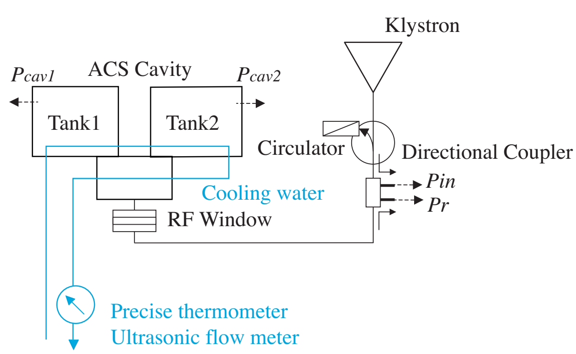

Figure 6: RF power measurement system.

We observed that the measured input power (Pin) and reflected power (Pr) fluctuated by a tuner position. The reflected power was changed by the tuner position, thus we consider that the reflected power makes a standing wave to decrease a power separation in the directional coupler. Therefore, Fig.4 and 5 were recorded as the peak power changed slightly in the process of keeping the peak power and increasing only the pulse length. This is because that the resonance frequency was shifted by a wall-loss according to an increase in the average power, and then the reflected power was going up.

To fix an achieved input power, we evaluated an input power not only with an RF power measurement but also the canonical evaluation using a precise thermometer and the ultrasonic flow meter . The temperature rise and the volume of the cooling water indicate the heat load in the cavity. Table 2 summarizes the measured and evaluated input powers: measured by the pickup port at the both ends of accelerating tank and canonical evaluation with cooling water.

Table 2: Summary of input power measurement

By pickup of tank 1:	619±10 kW
By pickup of tank 2:	618±10 kW
By evaluation from cooling water:	632±18 kW

The accuracy by the pickup measurements were estimated from the error of RF measurement system: ±0.07 dB(fluctuation: ±0.02 dB(absolute value accuracy ±0.05 dB of the power meter)). In addition, there may be an error of an RF connector. Furthermore, for the calibration of the coupling level of the each picking up port, we attached a N-waveguide converter at the input waveguide, and measured the transmitted power (S21) between a N-waveguide converter and the cavity pickup. In this case, the power in the cavity will be overestimated.

The accuracy by a cooling water measurement was evaluated that the measured flow had 3% error. It is also necessary to consider the error of the thermometer.

Consequently, we think that the peak power of 600 kW could be inputted even if there were the some measurement errors. This power corresponds to about 4.8 MV/m in accelerating voltage (E0) more than 4.1 MV/m of buncher design. It is also higher than E0=4.3 MV/m for the accelerating module. We confirmed the stable operation more than 30 minutes. There was no problem of the balance between two accelerating tanks under the high-power operation. This is because that the measured power with the pickup Cav1 and Cav2 did not show the large difference.

SUMMARY

We confirmed that the peak power of 600 kW at 50 Hz and 600 μs was successfully inputted to the buncher cavity, and the stable operation reached more then 30 minutes. This cavity is the first module of the J-PARC ACS. This power corresponds to E0=4.8 MV/m, which also satisfies E0=4.3 MV/m of the accelerating module design. Consequently, this high-power test result means that the basic design of the accelerating module is reliable for the next step

REFERENCES

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[2] V. V. Paromonov, "The Annular Coupled Structure Optimization for JAERI/KEK Joint Project for High Intensity Proton Accelerators", KEK Report 2001-14(2001)