ANNULAR-RING COUPLED STRUCTURE FOR THE ENERGY UPGRADE OF THE J-PARC LINAC

H. Ao*, H. Asano, J. Tamura, N. Ouchi, J-PARC, JAEA, Ibaraki, Japan
F. Naito, K. Takata, J-PARC, KEK, Ibaraki, Japan

Abstract

The J-PARC linac is preparing to boost the beam energy from 181 to 400 MeV by using annular-ring coupled structures (ACS) for the 1-MW operation from the 3-GeV rapid cycle synchrotron. The mass-production of the ACS cavities started from March 2009 is proceeding on schedule and most of all the cavities have been fabricated until March 2012. The other cavities will be finished until March 2013. The first mass-produced ACS module was successfully conditioned up to 1.6 MW without any issues. For the installation schedule in 2013, the user operation has to be restarted after six months shutdown due to the strong requests from users. As yet, further work is necessary to arrange the schedule and the required manpower for the installation.

INTRODUCTION

The linac of Japan proton accelerator research complex (J-PARC), which is the injector of the 3-GeV rapid cycle synchrotron (RCS), is preparing to boost the beam energy from 181 to 400 MeV in order to raise the possible output power of the 3-GeV RCS from 0.6 to 1 MW. The output energy of the linac is upgraded by using annular-ring coupled structures (ACS). This energy upgrade will increase the limit on the number of particles due to a space charge effect $\Delta\nu \propto \beta^{-2}\gamma^{-3}$. Here, β and γ are Lorentz factors.

Figure 1 shows the schematic configuration of the linac. The downstream area where the ACS cavities will be installed in the future is used as the beam transport line for 181 MeV at present. The energy upgrade requires 25 ACS modules in total, which include 21 ACS accelerating modules, two ACS bunchers and two ACS debunchers. The two bunchers and three accelerating modules already have been fabricated as a prototype of the common ACS module. All the other cavities have to be mass-produced within a three-year period from March 2009. The cell dimensions of these modules are varied from module to module, which means that the frequencies of many types of cells have to be tuned within a short time. Thus, the iteration of a frequency tuning was reduced to only one step by using the results of the test cell measurement [1]. In the last of 2010, the first mass-produce d ACS module was completed and its high-power test was successfully finished to confirm the stable operation at the required input power.

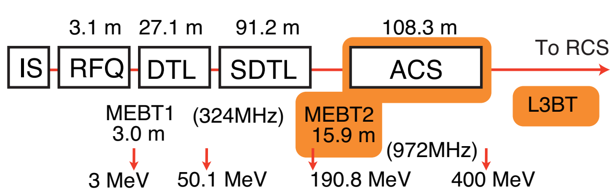

Figure 1: Schematic configuration of the linac.

In the middle of the mass-production, the Great East Japan Earthquake occurred in March 2011 and it severely damaged the linac facility. Fortunately, the factory which were making the ACS cavities is about 1000 km from the epicenter and did not affected.

This paper describes the present status of the ACS cavity fabrication, the measurement result of the first mass-produced ACS module and the installation scenario of the energy upgrade in 2013.

CAVITY FABRICATION STATUS AND INSTALLATION SCHEDULE

Figure 2 shows the progress of the cavity fabrication. At first, all the cavities were schedule to be fabricated until March 2012 and installed in summer of that year. However, the installation was postponed to 2013 due to the earthquake. Most cavities were fabricated until March 2012 according to the first schedule. Of the required 20 ACS modules, 17 modules are completed at present. Of the other three modules, two modules were already brazed and will be finished after assembling an RF window and cooling pipes. The last one module will be done until March 2013[1].

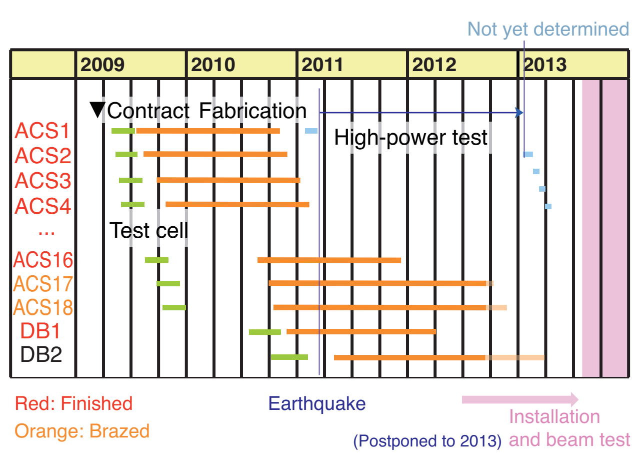

Figure 2: Current progress status of the ACS cavity fabrication.

[1] The schedule of the last three modules is not delayed due to technical issues since it was rearranged after the earthquake.

* hiroyuki.ao@j-parc.jp

The damaged overhead cranes are still not available in the linac building. Thus, the modules shipped before the earthquake are stored in the linac building, the ones completed after the earthquake are kept in the factory.

The original plan was to condition all the ACS modules at a high-power test area in the linac building, and then to be installed to the beam line. However, the conditioning has been suspended since the concrete floor of the test area was cracked and broken by the earthquake. Since the repair schedule is not yet determined even now, there is no prospect for restarting the conditioning. Most of the ACS modules, therefore, have to be conditioned after the installation just before the beam test.

Figure 3 shows the preliminary installation schedule in 2013. Due to the strong requests from users, the user operation have to be restarted after six months, which are a usual summer shutdown (3 months) and an extra shutdown (3 months) for the energy upgrade.

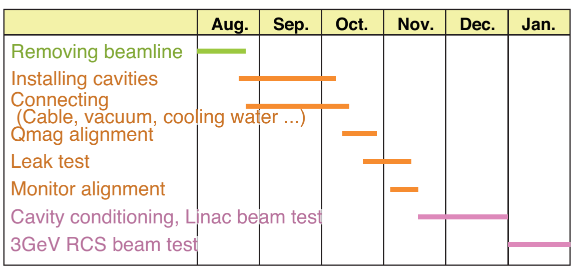

Figure 3: Installation schedule of the energy upgrade in 2013 (preliminary).

In the linac, a 50 mA ion source and an RFQ have to be installed in the same period. Also, existing beam line components require annual maintenance. Thus, further work is necessary to arrange the schedule and the required manpower in order to complete the upgrade installation within 3.5 months.

MASS-PRODUCED ACS MODULES

Low level measurement

Figure 4 shows the configuration of the ACS accelerating module. One ACS module consists of two accelerating tanks and one bridge tank. As an example of the measurements of the mass-produced modules, this section describes the results of the first mass-produced module, which is named as M04 (it includes accelerating tanks T07 and T08[2]).

Table 1 lists the accelerating mode and the coupling mode frequencies after brazing. These frequencies are tuned within the target frequency of 972.04 ± 0.1 MHz. For the accelerating mode, the frequency was tuned only before the brazing. For the coupling mode, the frequency was adjusted by using coupling cell tuners after brazing.

Figure 5 shows the result of the electric field measurement using the bead-pull method (The bead material is

[2]21 ACS modules accelerate H^- beams up to 400 MeV. The accelerating modules are numbered from M01 to M21, and the accelerating tanks are also numbered from T01 to T42, in order of increasing beam energy.

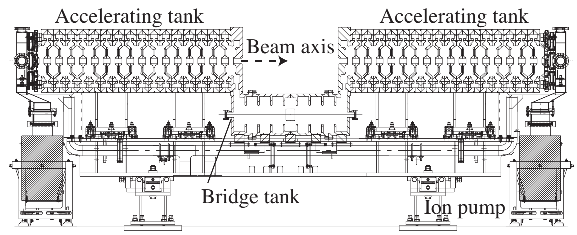

Figure 4: ACS accelerating module. One ACS module consists of two accelerating tanks and one bridge tank.

Table 1: Accelerating mode and coupling mode frequencies after brazing (MHz)

Tank	Accelerating mode	Coupling mode
T07	972.02	972.05
T08	971.98	972.02

SUJ-2[3]. The diameter is 3 mm. The beam bore of the ACS is 40 mm.) This data was measured in normal atmosphere and calibrated so that the frequency shifts at $E_z = 0$ points in the drift space are expressed as zero. The electric field distribution is sufficiently acceptable for beam acceleration.

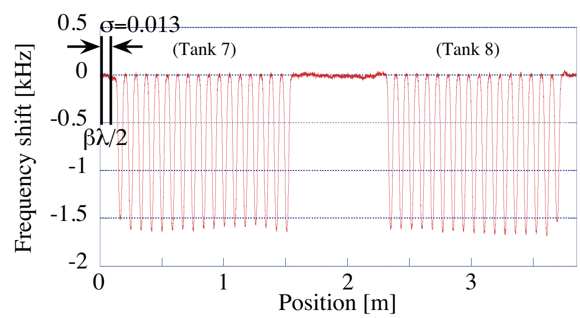

Figure 5: Electric field measurement by the bead-pull method. The frequency shifts were calculated from the measured phase shifts.

Table 2 lists a shunt impedance $Z, Z/Q$. Here, the designed Q-value is calculated by Microwave Studio. This model is only an accelerating tank. Including the bridge tank, the calculated $Z, Z/Q$ values should be smaller according to the ratio of the stored energy of $34/\{34 + 5 \times (24/100)\} = 0.966$. Here, the stored energy ratio between an excited cell in a bridge tank and a accelerating cell was evaluated as 24.0% using the measured coupling factor between an accelerating tank and a bridge tank (Here, the number of the excited cell is five.). The calculated values by Microwave Studio are $Z = 46.9$ MΩ/m and $Z/Q = 2.50 \times 10^3$ Ω/m. Thus, the designed Z and

[3]Provided by Japanese Industrial Standards. It is equivalent to AISI 52100 or DIN 100Cr6.

ISBN 978-3-95450-122-9

Table 2: Q-value, shunt impedance Z, Z/Q

	Designed	Achieved	%
Q-value	1.78×10^4	1.85×10^4	
Z	45.3 MΩ/m	45.7 ± 2.4 MΩ/m	100.9
Z/Q	2.42×10^3 Ω/m	2.47×10^3 Ω/m	102.1

Z/Q become $Z = 46.9 \times 0.966 \simeq 45.3$ and $Z/Q = 2.50 \times 10^3 \times 0.966 \simeq 2.42 \times 10^3$.

In the table 2, the measurement error of Z was evaluated by shifting the line of $E_z = 0$ ($\Delta f = 0$) to $\sigma = \pm 0.013$ for the electric field integration $\int E_z dz$ (see Fig. 5).

The one of the reasons that the measured Z/Q is slightly higher than 100% is the error of the stored energy ratio. The connecting part between an accelerating tank and a bridge tank is not periodic structure. Thus, it is difficult to evaluate the stored energy ratio only by the coupling factor ratio. To compare the design and the measured value, it is desirable to measure Z and Z/Q for each accelerating tank only, since it does not need the correction for the bridge tank. In the recent modules, the measured Z/Q is in good agreement with the designed one using the measurement for an accelerating tank only.

High-power test

The dissipated power of the cavity inner surface is 1.2 MW, which is evaluated by using $Z = 45.7$ MΩ/m listed in Table 2, the cavity length of 3.083 m, and the accelerating field of 4.2 MV/m. In this power test, the cavity was conditioned up to 1.6 MW including a margin of 15% for the accelerating field. Although the designed pulse length is 600 μs, finally it was extended to 650 μs in order to keep a feedback pulse length. Figure 6 shows the conditioning history of the first mass-produced module (M04). The input power shows the average value of the four pickup antennas attached to both the ends of two accelerating tanks. The vacuum pressure was measured at the center of the bridge tank using Bayard-Alpert gauge.

The conditioning time to reach the target power of 1.6 MW was 60 hours, which is acceptable range for considering future conditioning of the mass-produced modules. Table 3 lists the required conditioning times comparing the short ACS (buncher) module [2]. These cavities were conditioned under the same RF duty (the pulse length of 600 μs, the repetition of 50 Hz). However, the number of accelerating cells of M04 is 3.4 times larger than that of a buncher (5 cells per an accelerating tank). The conditioning time of M04 takes twice longer than that of the buncher module.

The achieved vacuum pressure was 2.0×10^{-6} Pa under the 1.6 MW operation after the 240 hours conditioning. This value is lower than the target vacuum pressure of 4×10^{-6} Pa, which is requirement to reduce the beam loss from residual gas less than 0.1 W/m. However, the residual gas caused beam loss in the SDTL section (see Fig. 1), which is operated at less than this target pressure [3].

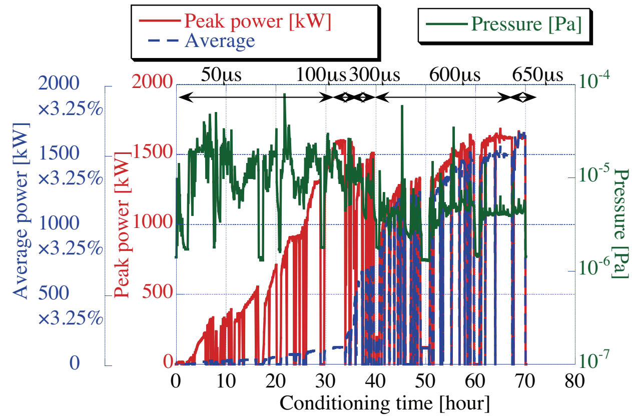

Figure 6: Conditioning history of the first mass-produced module (M04). Red: peak power, Blue: average power, Green: vacuum pressure in the cavity. The repetition is 50 Hz throughout this conditioning.

Table 3: Power level and conditioning time [E_0, E_{sp} (MV/m)]

Time (h)	Power (kW)	E_0	E_{sp}	Kilpatrick
ACS (buncher)				
33	600	5.3	29.6	1.0
ACS (M04)				
60	1600	4.9	26.9	1.0

Thus, the improvement of the vacuum pressure is one of the key issues for future high intensity beam operation. The vacuum pressure distribution on the beam axis in the ACS module and its improvements need to be further examined, for example, by using a completed ACS module until the installation.

SUMMARY

The mass-production of the ACS cavities started from March 2009 is proceeding on schedule and most of all the cavities have been fabricated until March 2012. The other cavities will be finished until March 2013. The first mass-produced ACS module (M04) was successfully conditioned up to 1.6 MW without any issues.

With respect to the cavities, vacuum components and quadrupole magnets will be prepared to be attached to an accelerating module. In addition, the improvement of the achieved vacuum pressure needs to be further examined before the energy upgrade installation. In order to complete the upgrade installation within 3.5 months, further work is necessary to arrange the schedule and the required manpower.

REFERENCES

[1] H. Ao *et al.*, in Proceedings of IPAC'10, 2010, p. 618.

[2] H. Ao *et al.*, Phys. Rev. ST Accel. Beams 15, 2012, 011001.

[3] A. Miura *et al.*, in Proceedings of LINAC10, 2010, p. 587.