STATUS OF MASS PRODUCTION OF THE ACS CAVITY FOR THE J-PARC LINAC ENERGY UPGRADE

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Abstract

The mass production of the ACS (Annular-ring Coupled Structure) cavity started in March 2009 for the J-PARC Linac energy upgrade from 181 MeV to 400 MeV. This upgrade project requires 18 ACS accelerating modules and two debunchers within three years. The schedule is so tight that we have to optimize the fabrication process. Thus the test cells were fabricated for the every geometrical beta before the mass production to confirm the initial design and the frequency tuning procedure. This paper describes our approach for the mass production and the current status.

INTRODUCTION

The 400-MeV energy upgrade of the Linac started in March 2009. This upgrade project requires 18 ACS accelerating modules and two debunchers within three years. Figure 1 shows the project schedule. It takes about 1.5 years to finish fabricating one ACS module, so that four or five module processes will be taking place in parallel. Accordingly, the systematization of the fabrication procedure is now on issue to proceed with the process sequentially. We therefore discussed about the key issues on the mass production with a manufacturer. The following sections describe these results in detail with the background of these issues.

MASS PRODUCTION STRATEGY

The ACS cavity has been developed for the J-PARC Linac from 190 MeV to 400 MeV[1]. Figure 2 shows the exploded view of the ACS cavity. The one ACS module consists of the two accelerating tanks and one bridge tank. The accelerating tank has 17 accelerating cells and 16 coupling cells.

We have discussed the mass production plan with the manufacturer to complete the fabrication within a limited period of time. As a result, the requirements are following: i) the number of the frequency tuning is reduced to one, and ii) accelerating tank and bridge tank are fabricated independently.

The first requirement is needed to reduce the time. Each cell frequency is tuned by a turning machine in the ACS structure. This frequency tuning required the two or three times for the prototype modules. We have to know the more accurate frequency tuning coefficients df/dr and realize the initial frequency as close to the target frequency

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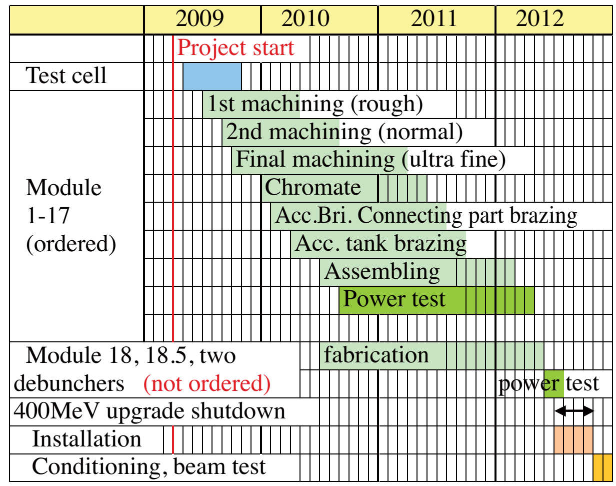

Figure 1: Schedule of the Linac 400 MeV energy upgrade. The 17 ACS modules are already ordered; each fabrication step of 17 modules (first, second, final machining etc.) proceeds in parallel. The first module will be finished in the summer of 2010.

to achieve it. We therefore decided to make the test cell for the all ACS modules to confirm the initial frequency because the cell of each module has different length that is proportional to the average beam velocity beta. In one module, which is composed of two tanks, the length of all accelerating cell is constant to reduce the variations. This decision, of course, includes the study of the beam dynamics design. Furthermore we changed the order of the frequency tuning for the accelerating cell. The accelerating cell of the prototype module had each geometrical beta for the accelerating tank, so that the frequency was tuned for each accelerating tank. In the mass production, the accelerating cell of the two accelerating tanks, that have the same geometrical beta, can be mixed and regrouped into two. For example, the all cells are numbered along the beam axis. Then the even-numbered cells are tuned at first and then the odd-numbered cells are tuned by using the measured frequency of the even-numbered cell. This procedure prevents the concentration of the frequency error at one accelerating tank in the whole module and reduces the difference of the average frequency from the desired frequency of the module.

The second requirement comes from the time limitation of the brazing furnace schedule. The bridge tank was fabricated after the accelerating tank for the prototype mod-

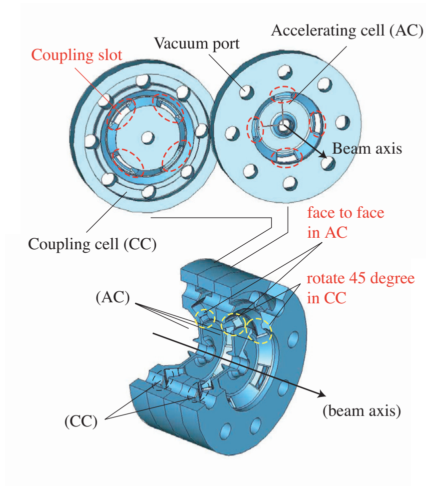

Figure 2: Exploded view of the Annular Coupled Structure (ACS) used at the J-PARC. The four coupling slots connect the Accelerating Cell (AC) and the annular ring type Coupling Cell (CC).

ules. This is because that the whole module frequency can be corrected by the bridge tank frequency. We therefore tuned and brazed the bridge tank after the final frequency measurement of the accelerating tank. Although this requirement removes the tuning knob by the bridge tank, it is believed that the expected error of the accelerating tank frequency is ± 0.15 MHz that could be corrected by the movable tuner margin of ± 0.28 MHz.

FREQUENCY TUNING OF TEST CELL

Test cell design

The basic cell design had been improved for the mass production[2]. Since one ACS module consists of two accelerating tanks, we call them T01 and T02 for the ACS module 01, for instance. The accelerating tanks from T03 to T41 (except T21 and T22) were designed based on the experience of the prototype ACS. The geometrical beta dependence of the accelerating cell frequency was evaluated by the electro-magnetic simulation of the Microwave Studio and the measurement results of the three prototype cells (T01, T21, and T42). The initial design frequency was set to 973 MHz that was 1 MHz higher than the operating frequency of 972 MHz. The tuning process will decrease the frequency and the frequency tuning range of 2 MHz is reserved for the machining volume. The number of the test cell is decided to be one pair par one tank (two pair for the one geometrical beta), considering for the machining and the RF measurement redundancy.

Required accuracy of the coefficient α

This section describes the error evaluation of the frequency tuning. The accelerating cell and the bridge cell have the tuning volume around the cell equator region. Because magnetic field concentrates in this part, expanding the radius of the cell r decreases the frequency f; the coefficient α is defined by df/dr.

The frequency shift Δf must be evaluated finally in the frequency tuning process. It is given by the product of coefficient α and amount of the machining Δr:

$$\Delta f = \alpha \times \Delta r.$$

Thus, if we denote by $\sigma^2_{\Delta f}, \sigma^2_{\alpha}, \sigma^2_{\Delta r}$ each population variance, and by $m_{\Delta r}, m_{\alpha}$ each mean value, then we get

$$\sigma^2_{\Delta f} = m^2_{\Delta r}\sigma^2_{\alpha} + m^2_{\alpha}\sigma^2_{\Delta r}$$

by propagation of error. Here the typical values of them for the accelerating cell are following: $\sigma_{\Delta r} = 0.01$ mm, $m_{\alpha} = 1$ MHz/mm, and $m_{\Delta r} = 0.3$ mm. Substituting these values into the above equation, we obtain

$$\sigma^2_{\Delta f} = (0.3)^2\sigma^2_{\alpha} + 1 \times (0.01)^2.$$

Here, the error of the frequency shift should be lower than the measurement error: $\sigma_{\Delta f} < 0.03$, so that we get

$$\sigma_{\alpha} < 0.094 \quad \text{MHz/mm}. \tag{1}$$

The coefficient α is given by

$$\alpha = \frac{\Delta f}{\Delta r}.$$

Thus if we denote by $\sigma^2_{\alpha}, \sigma^2_{\Delta f}, \sigma^2_{\Delta r}$ each population variance and by $m_{\Delta r}, m_{\Delta f}$ each mean value, then, we get

$$\sigma^2_{\alpha} = \frac{1}{m^2_{\Delta r}}(\sigma^2_{\Delta f} + \frac{m^2_{\Delta f}}{m^2_{\Delta r}}\sigma^2_{\Delta r})$$

by propagation of error Here the typical values for the accelerating cell are following: $\sigma_{\Delta f} = 0.03$ MHz, $\sigma_{\Delta r} = 0.01$ mm, and $\frac{m_{\Delta f}}{m_{\Delta r}} \simeq 1$ MHz/mm. Substituting these values into the error equation, we obtain the following:

$$\sigma^2_{\alpha} = \frac{1}{m^2_{\Delta r}}(0.03^2 + 0.01^2).$$

Here, the error of the coefficient α have to be lower than 0.094, so that we get

$$m_{\Delta r} > 0.34 \quad \text{mm}.$$

As discussed above, the coefficient α should be lower than 0.094 (see Eq. 1), so that we have to measure the frequency shift with a minimum of 0.34 mm machining. The same equation can be applied to the coupling cell. It gives $\sigma_{\alpha} <$ 0.2 MHz/mm and $m_{\Delta r} > 0.32$ mm for the coupling cell.

Measurement result

Figure 3 shows the frequency tuning coefficient for the accelerating cell and the coupling cell.

Here the test cell frequency was tuned two times. The average of the accelerating cell frequency was 973.05 ± 0.1

MHz after the initial machining. The target frequency is 972 MHz; it had 1 MHz tuning margin. Thus this margin was roughly divided into two tunings in ratio of 7:3. This is because that the first step aimed to get more accurate coefficients and the second step kept the minimum radius of 0.34 mm to get the meaningful data for both times.

Although the first results (#1) from T23 to T42 were smaller than the SUPERFISH in the accelerating cell results, the second results (#2) were close to the SF. These results are not well understood at this time. Overall, the coefficients were slightly higher than the 0.95 times of SF.

The coupling cell result shows that the fluctuation from T03 to T08 was lager than the other tanks. This is because that the tank No.3 has the smallest geometrical beta and the cell thickness is also small. The cell flatness were, therefore, not good for the RF measurement. It caused these fluctuations.

Based on the these results, the initial dimensions were revised for the mass production.

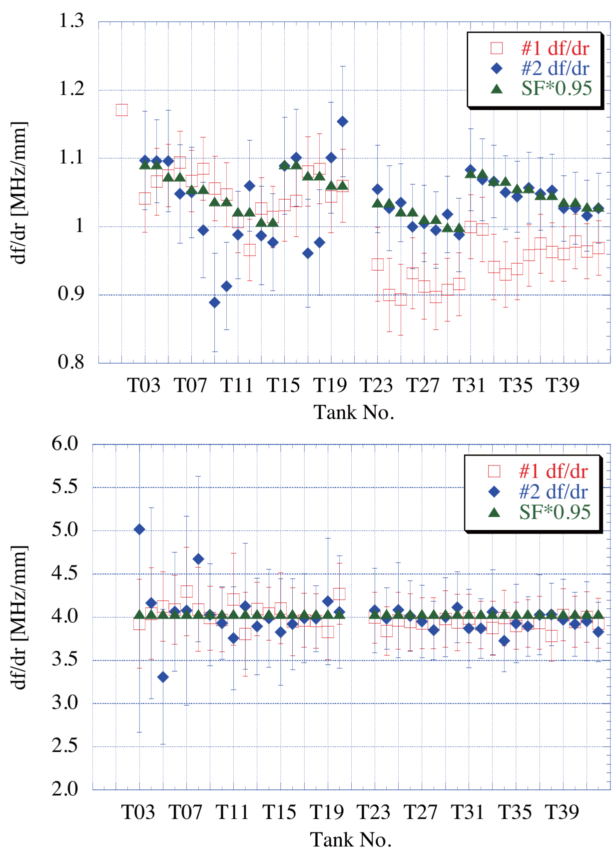

Figure 3: Coefficient α of the accelerating cell (above) and the coupling cell (bottom). The red squares are coefficients of the first tuning, the blue diamonds are of the second tuning, and the green triangles show the 0.95 times of the SUPERFISH calculation.

FABRICAION STATUS

Tuning result of the accelerating tank

Table 1 summarizes preliminary result of the accelerating tank frequency tuning that was achieved in one time machining. The accelerating cell target is 971.93 MHz for the all tanks. The coupling cell target is following: T03-04, T05-06 and T07-08 are 976.54, 976.07 and 975.76 MHz, respectively. These results are within the measurement error of ± 0.03 MHz for accelerating cell and ± 0.05 MHz for the coupling cell.

Table 1: Accelerating tank frequency (MHz)

	Acc. cell	**Coup. cell**
T03	971.935 ± 0.008	976.559 ± 0.019
T04	971.932 ± 0.023	976.545 ± 0.017
T05	971.939 ± 0.019	976.085 ± 0.019
T06	971.938 ± 0.026	976.070 ± 0.030
T07	971.942 ± 0.016	975.711 ± 0.013
T08	971.938 ± 0.011	975.761 ± 0.060
⋮	⋮	⋮

Bridge tank and other component

The low-level RF properties were measured for the seven bridge tanks and the six RF windows. The bridge cell measurement is running four months behind schedule, because the measurement tools were reexamined for the mass production. There is no significant effect for the whole schedule.

The mechanical design of the movable tuner was revised to enlarge the tolerance of an assembly. The mass production started in late 2009 after the operation test with the prototype ACS module. The four tuner units have been completed.

SUMMARY

Although we had only three months for the preparation of the mass production from the funding to the start of fabrication, the sequence is almost on schedule: test cell design, measurement, initial design for mass production, measurement and frequency tuning. We have to continue the following process, brazing, measurement and tuning, working together the manufacturer within the limited schedule.

REFERENCES

[1] H. Ao et al. "First High-Power ACS Module for J-PARC Linac", Proc. of the 2006 Linac Conf., August 2006, p.725-727

[2] H. Ao et al. "Improvement in the ACS Cavity Design for the J-PARC Linac Energy Upgrade", Proc. of the 2008 Linac Conf., September 2008, p.915-917