IMPROVEMENT IN THE ACS CAVITY DESIGN FOR THE J-PARC LINAC ENERGY UPGRADE

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Abstract

The ACS is the accelerating structure for the J-PARC Linac from 190-MeV to 400-MeV. The mass production of the ACS with a tight time schedule is now an issue. This paper mentions two main issues. The first one is that the coupling slot machining especially needed much long time on the fabrication process. We simplify the finishing of the coupling slot, comparing the surface roughness and the machining time. From the low-level measurements with the test cells, the simplified slot machining is judged to be acceptable for the practical cavity. The second one is that the coupling mode frequency has about 0.5 MHz error after the final brazing, because that the frequency shifts by the brazing are not stable. Thus, we consider the coupling mode frequency tuning by the fixed tuner after the final brazing. The equivalent circuit analysis shows that the -0.5 MHz accelerating mode error and +1 MHz coupling mode error brings the 3.7 % electric field error under the correction with the 12 coupling cells.

INTRODUCTION

The ACS (Annular-ring Coupled Structure) cavities were under development for the J- PARC Linac [1, 2] from 190-MeV to 400-MeV. We have fixed the cavity specification, taking into account the results of the high-power conditioning [3] and the fabrication experience.

The mass production of the ACS with a tight time schedule is now an issue, since the user community strongly requests the beam power upgrade as early as possible. Therefore, the design and the fabrication process of the ACS cavity have been reexamined on the basis of the experience, stored during the course of the fabrication and the tuning of the prototype ACS tanks.

Here, we also discussed about the key issues on the mass production with a manufacturer. The cavity shape, that required complicated machining, was simplified to some extent, while the frequency tuning strategy was reconsidered to reduce the production period.

The present paper mentions two main issues about the recent progress of the ACS developments. The first one is the simplification of the coupling slot machining, and the other is the coupling mode frequency tuning after the final brazing. The following sections describe these results in detail with the background of these issues.

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SIMPLIFY COUPLING SLOTS

Background

The ACS cavity consists of many half-cell parts (cell), and vacuum brazing connects these cells. The 1300 cells are required for mass production (18.5 modules×2 tanks×17 cells×2 parts/cell=1258), so that it is very important to reduce the machining time of the cell.

On the cell machining process through the several R&D modules, the coupling slot machining especially needed much long time. Although the modules brought good results through the high-power conditioning, one slot machining required 3 hours 20 minutes with a 5-axis processing machine, thus one cell (4 slots) needed more than 13 hours only for the slot machining.

We, therefore, simplify the finishing of the coupling slot, comparing the surface roughness and the machining time for each machining step.

The four test cells are machined with the reexamined process. And then, the RF properties are measured to compare frequencies and Q-values before and after the simplification.

Machining Process

The new slot machining (See Fig.1) takes only 46 minutes that is much shorter than the original of 3 hours 20 minutes. The total machining time with a 5-axis processing machine will be reduced from 1.5 day/cell to 1 day/cell. It means that, at a rough estimate, the 1300 cells require two years and two months. It seems that it is the acceptable period for the mass production.

In this new machining process, we also restrict the movement of the tool within XYZ-axes and a rotation around the beam-axis. This restriction for the 5-axis "simultaneous" processing allows the machining process without the input programs that have been developed more than one month. It also makes very easy for an operator to input and change parameters, even though we use a 5-axis processing machine.

It is another great advantage to skip the programming process other than the machining time. The main reason for the long time development is not only the complicated structure of the ACS, but also the inefficient machining as, for example, it takes much more time for the surface finishing in a very small area.

Continuously, we are interested in simplifying the machining process for the other parts to optimize the balance between the machining time and the cavity properties.

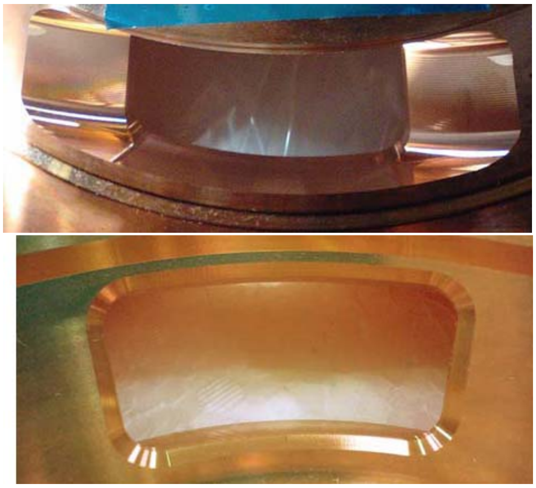

Figure 1: Simplified machining slots. The top is the coupling cell side view, the bottom is the accelerating cell side view.

Test Cell Measurements

The four test cells (#B, #C, #D and #E) are fabricated and measured to compare the frequencies. Table 1 summarizes these results.

Table 1: Frequency and Q-value of the original machining and simplified test machining

	Average freq. of the original cells (Q)	
Acc.mode	973.52 ± 0.08 MHz (8300 ± 900)	
Coup. mode	978.56 ± 0.02 MHz (5000 ± 1800)	
Coupling	5.931 ± 0.006 %	
	Test E+B	Test C+D
Acc.mode	974.27 (8290)	974.29 (8170)
Coup. mode	983.54 (3620)	983.57 (4570)
Coupling	5.776 %	5.796 %

The test cell Q-values of the accelerating cell are as same as the original error range of 8300 ± 900. Although the test cell Q-values of the coupling cell are a little smaller than the original of 5000 ± 1800, they are acceptable change.

From these low-level measurements, the simplified slot machining is judged to be acceptable for the practical cavity, although the small corrections are required for the frequency tuning about the accelerating and coupling mode frequencies.

FREQUENCY TUNERS ON THE COUPLING CELL

Background

The accelerating and coupling cell frequencies of the ACS cavity are tuned with the additional machining before the brazing process. Although the frequency tuning includes the frequency shifts by the brazing, these shifts are not stable and they bring the error of 0.1 MHz for the accelerating mode frequency and 0.5 MHz for the coupling mode frequency after the final brazing.

In the present design, the accelerating mode frequency can be tuned to the operating frequency by the movable tuner, the coupling mode frequency, however, has no tuning method after the final brazing.

The coupling mode frequency error reduces the recovering effect from the tilt of the electric field distribution.

Thus, we consider the coupling mode frequency tuning by the fixed tuner after the final brazing. The number of tuners should be minimized for the cost reduction in the mass production.

In the following section, the equivalent circuit analysis [4] simulates the error correction for the coupling mode frequency. This simulation evaluates the fluctuation of the electric field amplitude under the assumed frequency errors, a tuner arrangement and the corrected coupling mode frequency.

Equivalent Circuit Analysis

Table 2 shows the parameters for these simulations. We assume that the accelerating mode and the coupling mode errors are -0.5 MHz and +1 MHz respectively. This accelerating mode error of -0.5 MHz is based on the experience of the R&D modules of ± 0.3 MHz. The coupling mode error of 1 MHz includes not only the brazing shift of 0.5 MHz, but also the more large tolerance for the frequency tuning in the future. This error is also assumed to be the reversed sign of the accelerating one, which intends to be more critical situation for the field tilt.

Table 2: Accelerating cell (AC) and coupling cell (CC) parameters for the simulation

Number of total cell	77	Acc. tank (17 ACs+17 CCs)×2 + Bri. tank (5 ACs+ 4 CCs)
ACs error	-0.5	MHz
CCs error	+1	MHz
Coupling	6	%

As the first step of the simulation to see the trend of the electric field, we evaluate the two type corrections: corrected by the every two coupling cells, and by the every four coupling cells. Figure 2 shows these results. The correction amount of the frequency is so adjusted that the electric field amplitudes at the both end-accelerating cells (#1 and #17) are equal in the one accelerating tank. The corrections are uniform for the all coupling cells in this simulation.

Here, this amplitude error is defined as (Max.-Min.)/Average, so that the two errors are 3.7 % for the every two cells correction (red) and 10 % for the every four cells (blue) as shown in Fig. 2. In this case, the correction amounts of the frequency are -0.8 MHz for the every two cells correction (red) and -2.3 MHz for every four cells correction (blue) respectively.

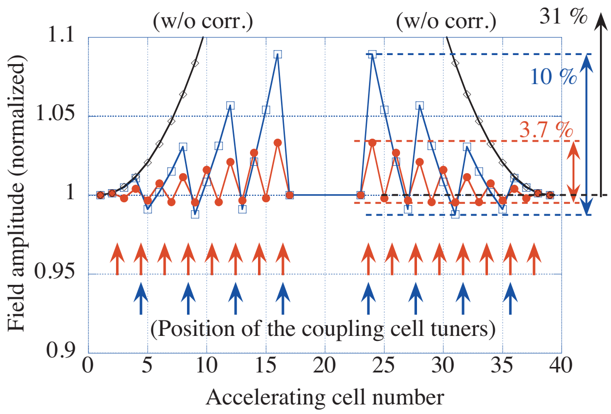

Figure 2: Simulated electric field distribution after the coupling mode frequency correction. The vertical axis is normalized at the first cell (#1). The arrows indicate the tuner position for the coupling cells. The red plot shows the case of the every two cells correction, the blue plot shows the every four cells correction, and the black plot shows the without correction.

This result indicates the small and distributed coupling cell tuners are suitable for the small fluctuation of the electric field more than the large and localized tuners.

The above result also shows that the electric field error is accumulated from the end cell to the center cell. Thus, the other solutions are expected for the small error of 3.7 % with less number of tuners.

For the next step, we rearrange the tuner and readjust the correction amounts of the frequency for the target of the 3.7 % error. Fig. 3 shows this results.

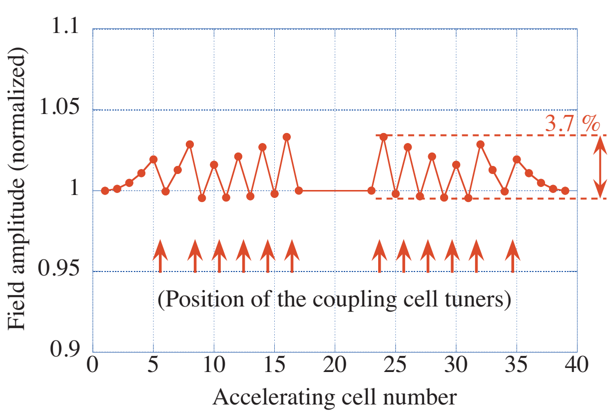

Figure 3: Simulated electric field distribution after the coupling mode frequency correction. The vertical axis is normalized at the first cell (#1). The arrows indicate the tuner position for the coupling cells. The total 12 coupling cells are corrected mainly around the center part of the module.

As shown in Fig. 3, this solution can suppress the electric field error under 3.7 % with reducing four tuners from the solution of Fig. 2. In this case, the amounts of the frequency tuning are -1.8 MHz for the two outside tuners (#5, #8, #31 and #34) and -0.8 MHz for the other tuners.

Tuner design

Based on the results in the previous section, this section describes the basic concept of the fixed coupling cell tuner. Figure 4 shows the draft design of the tuner.

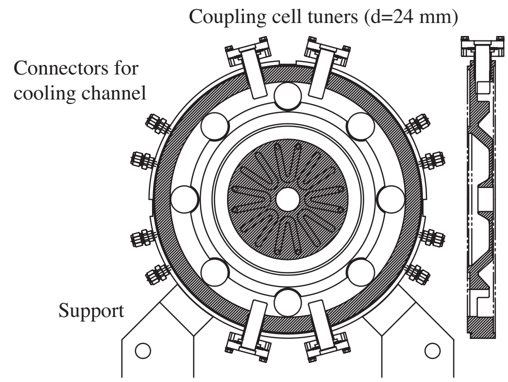

Figure 4: Draft design of the fixed coupling cell tuner. The four tuners are able to be attached for the maximum case.

The two tuners will be sufficient to correct the assumed frequency errors.(See Table 2) This reason is as follows. The tuner with 24 mm diameter in Fig. 4 can change the frequency up to 2 MHz evaluated from the MW-Studio (microwave studio). The required correction amount of the frequency is less than ± 1.8 MHz, so that the two tuners can cover this correcting range.

Consequently, we fix that the baseline design has total 24 tuners on 12 coupling cells, and that the one coupling cell has the two tuners.

SUMMARY

It was found that the simplified slot machining is acceptable for the practical cavity through the test cell measurement.

The equivalent circuit analysis shows that the coupling mode frequency error of +1 MHz brings the 3.7 % electric field error under the correction. For this correction, we consider that the baseline design has 24 tuners.

An R&D module including these improvements will be fabricated to confirm the properties under the high-power operation. The detail design and the further optimization for the mass production also will be developed with this module.

REFERENCES

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