FABRICATION OF THE NEW RFQ FOR THE J-PARC LINAC

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Abstract

The J-PARC RFQ (length 3.1m, 4-vane type, 324 MHz) accelerates a negative hydrogen beam from 0.05MeV to 3MeV toward the following DTL. Since the current RFQ is not so stable, the fabrication of a new RFQ as a backup machine has been started. The beam dynamics design of the new RFQ is the same as that of the current RFQ for the quick resumption of operation, however, the engineering and RF designs are completely changed to increase reliability. The processes of the vane machining and the surface treatments have been carefully considered to reduce the discharge risk. Furthermore, the vacuum brazing technique is adopted as an integration method of vanes.

RFQ IN THE J-PARC LINAC

The J-PARC linear accelerator consists of an ion source, an RFQ, DTLs, separated DTLs (SDTL), and the beam transport line to the RCS synchrotron [1]. The J-PARC RFQ is a four-vane type cavity to accelerate negative hydrogen beam from 50 keV to 3 MeV with peak current of 30mA. The RF duty factor is 3% (600 μs with 50 Hz).

The operating RFQ became unstable for a few months at the end of 2008 [2], then, we started a preparation of a new RFQ as a backup machine. In this paper, the design of the new RFQ and the fabrication progress are described.

RFQ DESIGN

Table 1 shows the RFQ parameters. The beam dynamics design is the same as that of the present RFQ. However the DSR is chosen as a dipole suppressor in spite of the PISL used in the current RFQ because of the simplification of the mechanical structure.

Table 1: Main RFQ parameters

Frequency [MHz]	324
Inter-vane voltage[kV]	82.9
Max. surface field [MV/m]	31.6(1.77 Kilpatrick)
Ave. bore radius [mm]	3.7
Vane-tip curvature [mm]	0.89r0 (3.293mm)
Vane length [mm]	3172.1
Number of cells	294 + (transition cell, FFS)
Dipole tuner	DSRs

RF Tuners

In the new RFQ, the frequency is tuned by the temperature of the cooling water during the operation [3]. The cavity is equipped with totally 36 ports for 35 fixed tuners with vacuum slits and for one input coupler. Figure 1 is the cross sectional view. The diameter of the fixed tuner is 87 mm. The tuning range and field disturbance by fixed tuners are estimated using CST Micro Wave Studio 3D simulator. The frequency tuning range by all fixed tuners is 8 MHz (roughly 14 kHz/mm/tuner). The field tilt due to the vane modulation will be compensated by fixed tuners. As a result of the simulation, the field tilt due to the modulation is about +/- 17 %. The half of the tuner stroke (about +/- 4 mm) will be used to compensate this tilt.

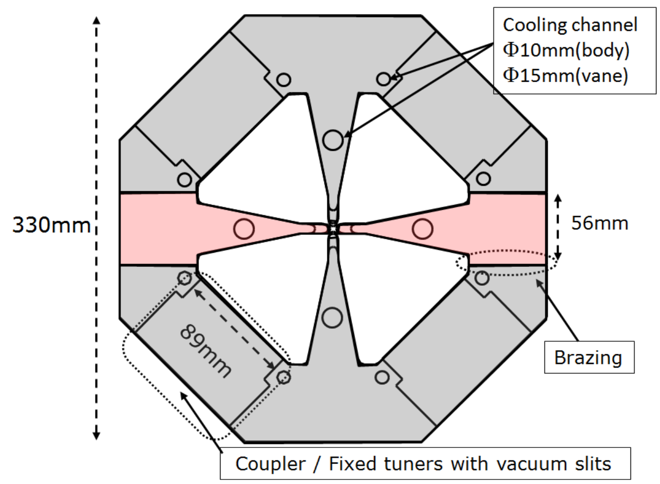

Figure 1: Cross sectional view of the cavity.

End-cut shapes and stubs

End-cut shapes were determined by the simulation also. The ambiguity of the simulation will be compensated by tuning the insertion length of the stabs from the end plate during the RF-tuning process. In the evaluation of the

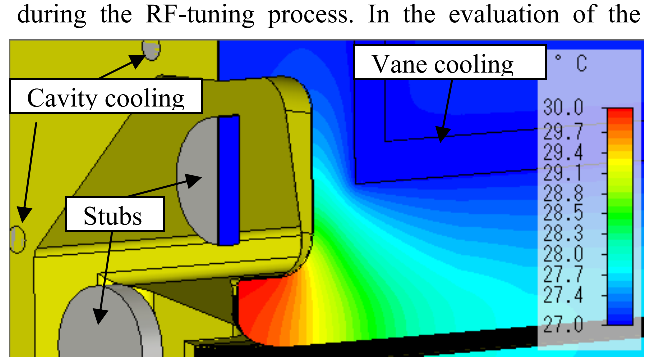

Figure 2: Temperature distribution near the end of the cavity.

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end-cut depth, the default height of the stubs were taken as 10 mm. Figure 2 shows the temperature distribution with 3% RF duty. The highest temperature rise is 3 degrees C.

FABRICATION

Mechanical design topics are listed in Table 2. We have adopted a vacuum brazing for the vane unification.

Table 2: Mechanical design topics

Material	High-purity oxygen-free copper with HIP(Hot Isostatic Pressing)
Drilled hole plugging	Electron beam welding (EBW)
Annealing	600 degree C in vacuum furnace
Vane machining	Numerical-controlled machining with ball-end mill
Surface treatment	Chemical polishing (3-5µm)
Integration method	Vanes and ports are jointed in one step brazing
Unit cavities connection	Welding for vacuum seal, bolting for mechanical alignment

Figure 3 shows the overview of the RFQ cavity. The cavity is longitudinally divided by three unit cavities. At the connection of unit cavities, the vacuum will be sealed by the welding at stainless-steel flange. A bellows will be sandwiched between flanges for the smooth alignment between the unit cavities. As color-coded shown in Fig. 1, the unit cavity consists of two major vanes and two minor vanes. The major vanes have the ports for tuners/coupler and pickup monitors. We chose the numerical-controlled machining using ball-end mills for the modulation machining. The vanes, ports, and flanges are jointed by one-step brazing using the brazing alloy of Ag72-Cu28. The fabrication process of the unit cavity is summarized as follows:

- Deep hole processing for cooling channels.
- Rough machining (residual skin: 1 mm).
- Plugging through holes by EBW.
- Annealing.
- Semi-final machining (residual skin: 0.2 mm).
- Final machining.
- Assembling for RF checking and machining for flange fit.
- Surface treatment (Chemical polishing).
- Assembling and brazing.

At the moment, the vacuum brazing of the first unit cavity has been performed. The second and third units are in the EBW and annealing process.

Drilling and Rough Machining

The first process is a deep hole drilling for the cooling-water channel. The material length of the unit cavity is 1.2 m. The boring has done by a gun-drill machine from both sides to the centre of the material. The deviation of the hole position at the meeting point was less than 1 mm. Then, the cavity shapes such as end-cut, hole for ports, cross-sectional shape, were roughly formed.

Plugging Drilled Hole and Annealing

Before the heat treatment, the drilled holes has plugged by EBW. As a result of the EBW test, more than 5 mm depth of fusion without fatal defect was obtained in which the width of the weld bead is less than 4 mm. The weld bead was removed at the final machining process.

The stress by the machining should be removed before the final machining. To evaluate the thermal deformation, the test piece (TP) with the half length of the unit cavity was heated. The observed deformation was less than 0.1 mm in the straightness measurement. Then, we determined the residual skin depth for the final cutting about 1 mm as a margin for the deformation due to the release of internal stress. The annealing condition was taken as 600 degrees C for three hours in the vacuum oven.

Vane Machining

The shape of the RFQ vane modulation is a complex curved surface so that the two-dimensional machining

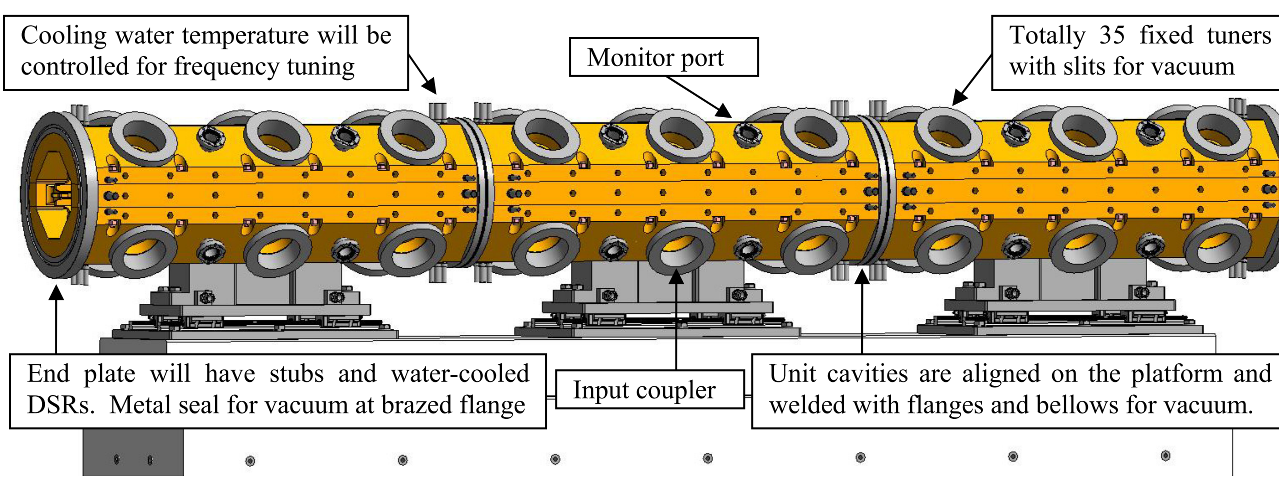


Figure 3: Over view of the RFQ cavity.

using the specially formed milling cutters with wheel profile is a typical machining method for RFQ fabrication. We have chosen a three-dimensional machining using the commercially supplied ball-end mills for the vane modulation machining. The surface roughness of the small TPs made of an annealed oxygen-free copper was typically 0.8 μm (Ra), in which the curvature of the used ball-end mill was 5 mm. The accuracy of the modulation shape was confirmed by the test machining of the full size aluminium TPs. Although the measured cross-sectional shape had enough dimension accuracy, the height of the ridge line of the vane had the local deviation of 0.05 mm (banana shape) longitudinally. In order keep the machining error less than 0.02 mm, the final machining carried out in several-step process with the check of the dimension. Figure 4 shows the final machining of the modulation with the ball-end mill.

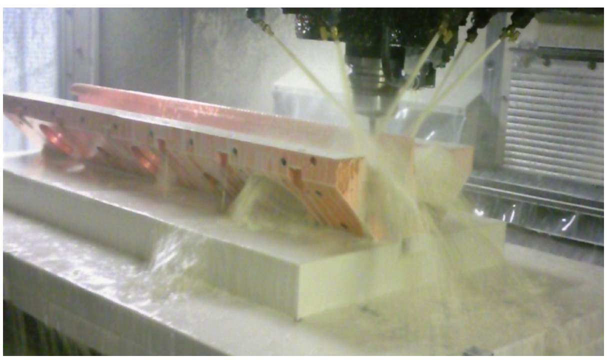


Figure 4: Modulation machining with the ball-end mill.

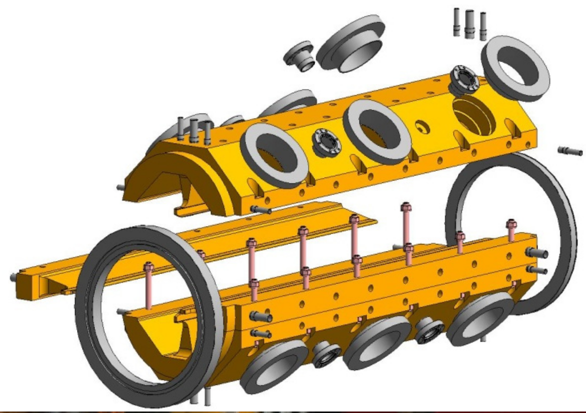
Surface Treatment

To reduce the discharge risk in the high electric field, the inner surface was chemically polished after the machining. After a lot of studies with changing the polishing solutions and conditions, the condition of 3-5 μm polishing with the solution of nitric acid series has been fixed for the finishing of the vane.

Vacuum Brazing

Figure 5 shows the schematic drawing of the unit cavity assembling for the brazing. Vanes are aligned each other along the outer lateral plane, then, fixed together using bolts made of SUS304. Ports are bolted on the cavity with springs and washers. The stainless-steel flanges at both ends of the unit 1 cavity are mounted by staking the copper body near the boundary. After the brazing, the resonant frequency of the operating mode was 0.26MHz higher than that before the brazing. The Q-factor increased from 6800 to 9400, which is 87 % of the Superfish calculation.

After the brazing, we found the vacuum leak at the stainless-steel flange of the cavity exit. The cause of this trouble is clear. Namely, during the heating in the vacuum furnace, nonuniform heating more than 40 degrees C was observed by the distributed thermocouple attached on the cavity. We consider that the leaked flange was pushed out by thermally-expanded vane unequally and brazed at the mismatched position. To repair it, we try the removal of the displaced flange with dry-cutting method and re-brazing the flange in this summer.



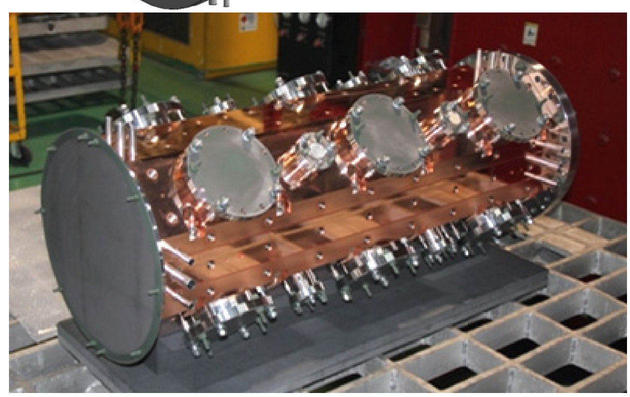


Figure 5: Upper is the schematic drawing of the unit cavity assembling. Lower is the RFQ just before the brazing.

SCHEDULE

Units 2 and 3 will be brazed at this summer. After the connection of the unit cavities and the RF tuning, the high-power test will be performed at the end of 2010.

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