FABRICATION AND LOW-POWER MEASUREMENTS OF THE J-PARC 50-mA RFQ PROTOTYPE

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Abstract

An RFQ, whose peak current is 50mA, has been developed for the J-PARC linac. We adopt a laser beam welding(LBW) method to fabricate the RFQ cavity. A prototype cavity was successfully fabricated and low-power measurements have been performed. We obtained the nominal frequency and field uniformity within 1%.

INTRODUCTION

In the first stage of the commissioning, the J-PARC linac will start with a beam energy of 181 MeV and a peak current of 30mA[1]. However, it is strongly required to accomplish 400 MeV and 50mA as soon as possible. For this purpose, JAEA has developed an Radio-Frequency-Quadrupole(RFQ) linac for 50mA peak current. In order to withstand the high-duty operation in the future, we adopt metallurgically jointed copper blocks for the cavity structure, and we tried a novel method, Laser Beam Welding (LBW), in assembling the cavity. In general, similar RFQ's are fabricated with brazing method [2][3]. In contrast to the brazing, the heat load of the LBW is very local, hence, there is a possibility to achieve higher accuracy than that of the brazing. One more important merit of the LBW is that the copper is not annealed at all. In this paper, we describe the fabrication and low-power measurements of the J-PARC 50mA RFQ prototype.

DESIGN OF THE J-PARC 50 mA RFQ

The J-PARC 50mA RFQ accelerates the H^- particles from 50 keV to 3 MeV as a first acceleration structure. The RF-pulse length is 600 μsec, the repetition is 50 Hz and the resonant frequency of the cavity is 324 MHz.

The cell parameters have been designed with KEKRFQ [4], and the particle simulation has been performed by using PARMTEQM[5]. In Table 1, the design parameters of the J-PARC 50mA RFQ are listed.

Table 1: Design parameters of the J-PARC 50mA RFQ

Cavity structure	4-vane
Vane length	3874 mm
Number of the cells	362
Inter vane voltage	80.7 kV
Maximum surface field	31.5 MV/m (1.77 Kilpatrick)
Average bore radius	3.6 mm
Vane-tip shape	$0.89 r_0$ (3.204 mm)
Transmission *	94.5 %
Transverse emittance* (normalized, rms.)	0.160 π mm · mrad.
Longitudinal emittance* (normalized, rms.)	0.0923 π MeV · deg.

*PARMTEQM calculation (1.0 π mm·mrad. (100%, normalized, waterbag), 60mA injection)

The vane length of the J-PARC 50mA RFQ is 3874 mm and the cavity consists of longitudinally divided three modules. The first, second and third modules are 1304.1 mm, 1266.5 mm and 1303.4 mm in length, respectively. The length is adjusted to divide the vane at the peak (or bottom) of the modulations. Each module consists of four peaces (quadrants), and it is assembled by means of the LBW method. The weld has roles of both the RF-contact and the vacuum seal. The material of the cavity is pure oxygen free copper. The three modules and the end-plates are bolted together and Helicoflex type metal O-rings are used as RF-contacts and ordinary metal O-rings seal the vacuum. The J-PARC 50mA RFQ is equipped with 24 RF-field pick-up monitors, 30 fixed stab-tuners with vacuum ports, and 2 RF-couplers located at the longitudinally different positions. The resonant frequency during the operation is tuned by controlling the temperature of the cooling water of the vanes. For the RFQ, 20 pairs of π-mode stabilizing loops (PISL's) [6] are employed in order to stabilize the accelerating mode against a dipole mode mixing. The interval between the horizontal and vertical PISL's is 210 mm.

The inside dimensions of the cavity have been determined based on the SUPERFISH[7] and MAFIA[8] calculations. The result of the calculations are summarized in Table 2. The absolute value of the design frequency was derived from the SUPERFISH result by taking the effect of the PISL's into account. The frequency shift between with and without the PISL's was estimated with two different MAFIA calculations (with and without PISL's)

FABRICATION OF THE PROTOTYPE CAVITY

In Figure 1, a drawing of the prototype cavity is shown. This cavity corresponds to the first module of the J-PARC 50mA RFQ (entrance side 1/3 part), and was fabricated as a part of the complete RFQ, that is, it has the vane modulations, RF-contacts and vacuum seals in order to be usable for high-power and beam operation. A sub module is connected to form a complete cavity, because the first module

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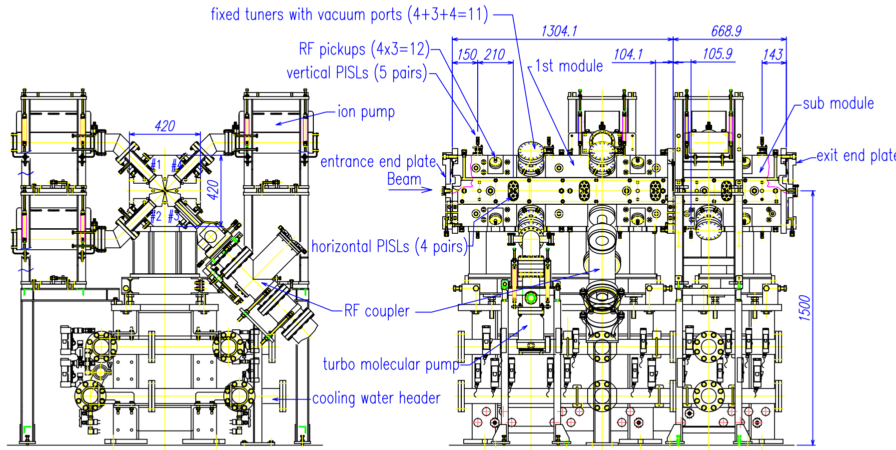

Figure 1: Schematic drawing of the 50mA RFQ prototype.

Table 2: SUPERFISH and MAFIA calculation results

SUPERFISH	Frequency:f_{SF}	334.444 MHz
	Q-value:Q_{SF}	11403
	Power dissipation:P_{SF}	317 kW
MAFIA (w/o PISL's)	Frequency:f_{MFWOP}	332.867 MHz
	Q-value:Q_{MFWOP}	11067
MAFIA (w PISL's)	Frequency:f_{MFWP}	322.412 MHz
	Q-value:Q_{MFWP}	11577
f_{MFWOP}-f_{MFWP}:Δf_{MF}		10.455MHz
Design frequency:f_{SF}-f_{MF}		323.989MHz

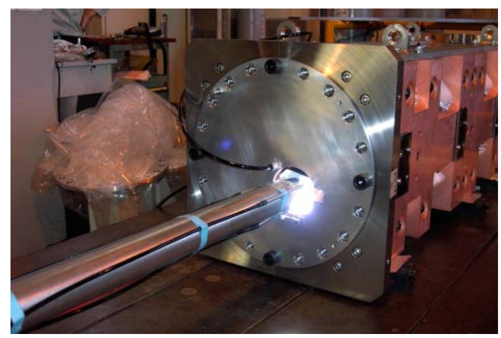

Figure 3: LBW processing the cavity inside.

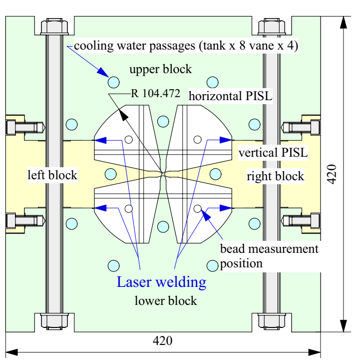

Figure 2: Sectioned drawing of the J-PARC 50mA RFQ.

has no end-cut of the vanes; this sub module enable us to perform low-power and high-power measurements.

Figure 2 is a sectioned drawing of the cavity. The quadrants which compose a module were cut out from the oxygen free copper blocks. The vane tips and inside the cavity were cut with formed cutters. Machining accuracy of the vane tips were within 15μm.

Before the LBW process, the cavity was once assembled and low-power tuners, low-power end-plates and RF pick-ups were attached to perform frequency and field measurements. The objective of this measurements is to check whether the machining was done correctly according to the design. At this stage, the PISL's were not assembled to the cavity.

Afterward, the cavity and peripheral parts were dissembled, then, the quadrants were jointed with the LBW method. Mechanically, the quadrants were connected with bolts, and the LBW sealed the inside of the modules. In order to prevent the motion of the vane tips, the outside of the modules was also welded. The laser used was CO_2 laser and power of the laser was 5 kW at the welding point. During the welding of the module inside, the modules were filled with argon gas. In Figure 3, a photo of the inside welding process is shown. The variations of the relative position of the vane tips before and after the welding were less than 13μm.

After the LBW process, the PISL's are assembled and the tuning of the resonant frequency and field distributions was performed with the low-power tuners, low-power end-plates and low-power couplers. (Details of the measurements are described in the next section.)

The high-power parts were machined based on the dimensions decided from the data of this measurements, and final assemble was done.

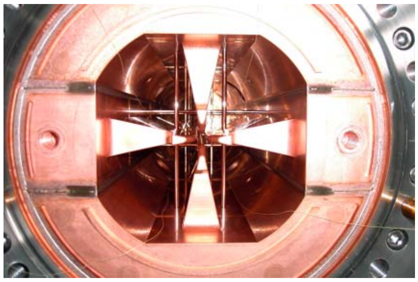

Figure 4: Inside the cavity of the J-PARC 50mA RFQ.

LOW-POWER MEASUREMENTS

The low-power measurements have been performed before the LBW, after the LBW and after the high-power parts were assembled. The frequency was measured with a network analyzer, and the field distributions were measured with a bead perturbation method. The positions of the beads were drawn in Figure 2.

After the LBW, the PISL's were attached to the cavity and the tuning of the cavity was carried out. First of all, the longitudinal and azimuthal field distributions were adjusted to obtain the uniformity of within 1% with the low-power tuners. At the same time, the resonant frequency was tuned to be 324 MHz; the measured frequency was converted to the one when the cavity inside is vacuum and the temperature of the cavity is 27 °C. In addition, the insertion, length and angle of the RF-coupling loop were tuned to make the coupling β=1.5. The maximum difference of the tuner positions from the initial ones was 7.7 mm. The response of one tuner is 6.7 kHz/mm around the initial position, and the frequency shift from the change of intervals of the vanes (in case that both the horizontal and vertical are changed) is calculated to be 240 kHz/10 μm.

After the high-power parts were assembled, the final low-power measurements were performed. Figure 5 shows the cavity under the measurement.

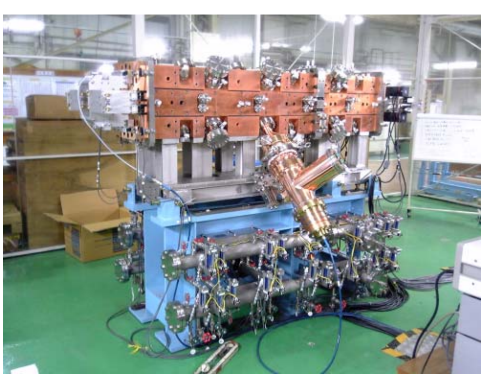

Figure 5: Field measurement of the prototype cavity.

The final value of the frequency was 324.071 MHz (vacuum, 16 °C). This frequency is converted to 324.010 MHz if the cavity is 27 °C (operating temperature of the cooling water). The unloaded Q-value was 9885. This correspond to 87 % of the SUPERFISH calculation. The separation between the acceleration mode and the nearest dipole mode was 22.66 MHz. In figure 6, the measured field distributions are shown. The vertical axis represents the perturbation of the frequency due to the insertion of the bead; the frequency shift is proportional to the magnitude of the field. The uniformity of the field was less than 1 %.

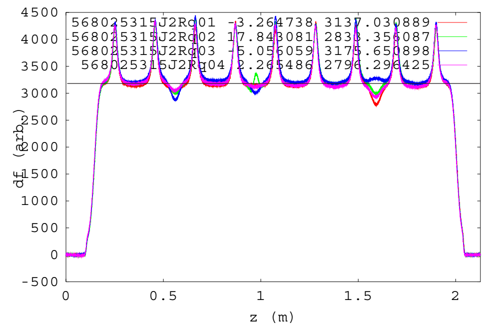

Figure 6: Field distributions of the 50mA RFQ prototype.

CONCLUSION

We fabricated a prototype cavity of the J-PARC 50mA RFQ with a laser beam welding (LBW) method. This cavity demonstrate the feasibility to fabricate an RFQ with the LBW method. In the next step, a high-power test will be carried out.

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REFERENCES

[1] Y. Yamazaki(eds.), "Accelerator technical design report for J-PARC", KEK-Report 2002-13; JAERI-Tech 2003-44, 2003.

[2] D. Schrage et al., "CW RFQ fabrication and engineering", *Proc. of 1998 Linac Conf.*, 679–683, 1998.

[3] A. Ratti et al., "The design of a high current high duty factor RFQ for the SNS", *Proc. of EPAC 2000*, 495–497, 2000.

[4] A. Ueno and Y. Yamazaki, "New beam-dynamics design procedure for RFQs", *Proc. of 1990 Linac Conf.*, 329–331, 1990.

[5] K. R. Crandall et al., "RFQ design codes", LA-UR-96-1836, 1996.

[6] A. Ueno et al., "Beam test of the pre-injector and the 3-MeV H^- RFQ with a new field stabilizer PISL", *Proc. of 1996 Linac Conf.*, 293–297, 1996.

[7] J. H. Billen and L. M. Young, "POISSON SUPERFISH", LA-UR-96-1834, 1996.

[8] T. Weiland, "On the unique numerical solution of Maxwellian eigenvalue problems in three dimensions", *Part. Accel*, 17:227–242, 1985.