Low Power RF Field Tuning of a Four-vane Type RFQ Stabilized with PISLs

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Abstract

A 432 MHz four-vane type radio-frequency quadrupole (RFQ) linac stabilized with π-mode stabilizing loops (PISLs) is under construction as a preinjector linac for the Japanese Hadron Project (JHP). It was designed to accelerate a 20-mA H^- beam from 50 keV to 3 MeV with a 3 % duty factor. We obtained the uniform distribution within ±1 % both longitudinally and azimuthally by adjusting the positions of dummy tuning plungers. The sizes of stab tuners and the standard positions of movable tuners were thus determined to reproduce the obtained field distribution.

I. INTRODUCTION

A 432 MHz radio-frequency quadrupole (RFQ) linac is under construction as a preinjector linac for the Japanese Hadron Project (JHP) [1,2,3]. This RFQ was designed to accelerate a 20-mA H^- beam from 50 keV to 3 MeV. Its rf duty of 3 % is quite higher than those of usual RFQs. These design values were determined from beam-optics considerations of the entire system. In order to achieve the requirements, keeping the maximum surface electric field less than 1.8-times of the Kilpatrick limit, the RFQ becomes about 2.7 m long (about four times of the rf wavelength).

In general, such a long four-vane type RFQ is difficult to fabricate without any field stabilizer against the dipole mode mixing for the following two reasons.

(1) Since the frequencies of several dipole modes (TE110-, TE111- and TE112-modes) are close to that of the accelerating mode (the lowest-order quadrupole mode :TE210-mode), those dipole modes are easily mixed with the accelerating mode via a small perturbation such as an imperfection in machining or an asymmetrical thermal deformation [4].

(2) The mixed dipole mode seriously affects the beam dynamics, since the dipole mode bends the beam and reduces the transverse acceptance.

Therefore, almost all four-vane type RFQs in operation are stabilized against the dipole mode mixing with vane coupling rings (VCRs) [5]. However, a VCR has complicated shape and is difficult to fabricate particularly in an RFQ operated with a high-duty factor, since large rf power is dissipated on the VCR. Although a continuous-wave (CW) four-vane type RFQ with VCRs successfully accelerated a proton beam at Chalk River Nuclear Laboratories (CRNL) [6], its length is short (about 1.3 times of the rf wavelength). In this RFQ, two pairs of VCRs with water-cooling channels are connected to the vanes near the two vane-ends by soldering. This method cannot be used to connect VCRs far from the vane-ends in a long RFQ which needs more pairs of VCRs like the present case.

There are the other structures [7], such as a four-rod type structure, which do not have any dipole mode. These structures were originally invented in order to reduce the size of a cavity, since the cavity diameter of a four-vane type structure with such a low resonant frequency becomes too large (more than 1 m). Therefore, the size of some elements of these structures, such as a rod of the four-rod type structure, becomes too small to fabricate at a high resonant frequency. Furthermore, the electric current is more densely concentrated on some parts in these structures than in a four-vane type structure at the same resonant frequency, for example, on the connection point of the rod to the support. The concentration of the electric current localizes the power dissipation, giving rise to the decrease in the Q-value.

In order to simultaneously meet the requirements of both high frequency and high duty factor for a long RFQ of the JHP, we proposed and studied a new field stabilizing concept : a π-mode stabilizing loop (PISL) [8, 9]. In this concept, each pair of the neighbouring quadrant cavities are coupled magnetically with closed loop couplers. The resonant frequencies of all the dipole modes are increased significantly higher than that of the accelerating mode by this coupling. According to the results of three-dimensional rf field analyses with MAFIA code package [10,11], the optimized PISL has the following advantages over the VCR :(1) easier fabrication, (2) higher Q-value, and (3) more uniform electric field distribution. These advantages and the stabilizing effect of the PISL were also confirmed empirically in a low power model cavity [12]. Therefore, we adopted the PISL for the RFQ of the JHP.

In this paper, we present the results of the low power rf field tuning of the prototype RFQ.

II. LOW POWER RF FIELD TUNING

In Figure 1, we present the cross-sectional view of the cavity in the plane of a pair of horizontal PISLs. A 5-mm diameter rod is inserted into the first and fourth quadrant cavities through a 15-mm diameter hole bored into the vane. A conductive closed loop is formed by the rod and the walls of these two quadrant cavities. This closed loop forms a PISL and couples these two quadrant cavities magnetically. A rod inserted into the second and third quadrant cavities also forms a PISL. The installation of the rod is significantly easier than that of the ring for the VCR, since the cooling water for the rod can be sealed outside the cavity, being separated from the rf field and the rf contact. As described in ref. 8, several pairs of vertical PISLs are required in order to increase the resonant frequencies of all the dipole modes. When we rotate Figure 1 by 90 °, the figure shows the cross-sectional view of the cavity in the plane of a pair of vertical PISLs. The positions of beads, which are used in order to measure the magnetic field distributions in the four quadrant cavities with bead perturbation method, are also shown in Figure 1.

Figure 2 shows the longitudinal outside view of the cavity before installing tuners, couplers and monitors. Eight pairs of horizontal PISLs and eight pairs of vertical PISLs are installed as shown in this figure. There are twenty vacuum ports (V), eight movable tuner ports (Tm), ten stab tuner ports (T), two coupler ports

(C) and twenty loop monitor ports (M) on the cavity. We carried out the measurements described in this paper, installing eighteen dummy movable tuning plungers with micro-meters into both the movable- and stab-tuner ports (Tm and T), and two dummy couplers into the coupler ports (C). Twenty loop monitors were also installed into the loop monitor ports (M). The dummy tuners were used in order to determine the sizes of the stab tuners and the standard positions of the movable tuners. The loop shapes of the couplers were also determined by using the dummy couplers.

At first, we measured the dispersion curves of the quadrupole modes (TE21n) and the two degenerated dipole modes (TE11n-A and TE11n-B). The results are shown in Figure 3. As can be seen from this figure, the PISLs generated the frequency separations of larger than 27 MHz between the accelerating mode (TE210-mode) and the dipole modes. During the measurement, we located all the dummy tuners at the positions where their effects vanished.

The measured resonant frequency of the accelerating mode was by 1.14 MHz lower than designed. The designed value was obtained with an aid of MAFIA analyses on the basis of the empirical data measured with a low power model. The decrease of the 0.8 MHz was due to the deformation arising from the welding of the cooling water pipes to the cavity. We attribute the remaining small discrepancy of 0.34 MHz to the errors in machining and/or the MAFIA analyses.

Next, we measured the magnetic field distributions in the four quadrant cavities with bead perturbation method. The results before adjusting the dummy tuners are shown in Figure 4a. The results after adjusting the dummy tuners are shown in Figures 4b and 4c. The frequency of the accelerating mode was tuned to the operating frequency of 432 MHz. The field distributions are presented in the forms of the squares of the magnetic field strengths, since the frequency shift measured by the bead perturbation method is proportional to the square of the field strength. The frequency shift was caused by a 4.5 mm diameter aluminum bead moving along each of the four quadrant cavities.

Sixteen steep peaks can be seen in each of the four quadrant cavities. These are the modified magnetic field patterns observed at the positions very close to the bars for the PISLs. The shortest distance between the bead and the bar is about 7 mm as shown in Figure 1. The magnetic field patterns can also be modified near the vacuum ports, near the dummy couplers and near the dummy tuners. We must avoid these local disturbances in order to estimate the amounts of the field tilt (the mixed higher-order quadrupole mode) and the mixed dipole mode. Therefore, we compare the field strengths among the four quadrant cavities at the positions of the loop monitors.

As can be seen from Figure 4a, the distributions were already fairly uniform, even without any adjustment of the dummy tuners. The distributions are tilted longitudinally from +6 to -10 %. (The fields are tilted from +3 to -5 %.) The field tilt seems to be mainly caused by the non-uniform inter-vane capacitance along the length, since the inter-vane capacitance is slightly changed according to the shape of the vane modulation. On the other hand, the difference among the field distributions in the four quadrants is around ±2 %. (The difference in the field strength is ±1 %.) This value is 1.3 times as large as the measured value in the low power model. The present RFQ was fabricated in the same way as the low power model except for the above-mentioned welding of the water cooling pipes. The welding seems to mix the dipole mode to the accelerating mode slightly more than the low power model.

As shown in Figures 4b and 4c, the uniformity of the distributions becomes less than ±2 %. (The field uniformity is less than ±1 %.) In Figure 4c, each distribution is shown separately, where the vertical axis is expanded in order to show details. The peak height of the distributions observed at the position of each dummy tuner is proportional to the inserted length of the tuner. It is noted that the difference among the field distributions in the four quadrants is less than ±1 %, which is of the same order of the measurement error. (The difference of the field strength is ±0.5 %.) This implies that the mixed dipole mode is less than 0.5 % of the accelerating mode.

The measured Q-value of the accelerating mode of 6950 is slightly higher than the value of 6800 measured in the low power model.

III. CONCLUSIONS

We carried out the low power rf field tuning of the prototype RFQ for the JHP by using the dummy tuners. It was possible to tune the frequency of the accelerating mode to the operating frequency of 432 MHz with a good field uniformity within ±1 %. It is noted that the admixture of the dipole mode is less than 0.5 %.

In near future, we will test the RFQ for the beam after installing the stab tuners and the movable tuners, each of which is machined to the size of the corresponding dummy tuner.

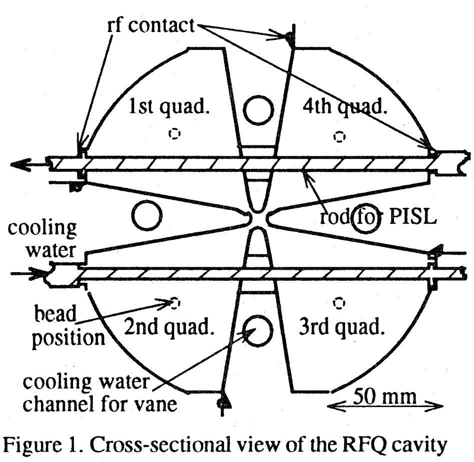
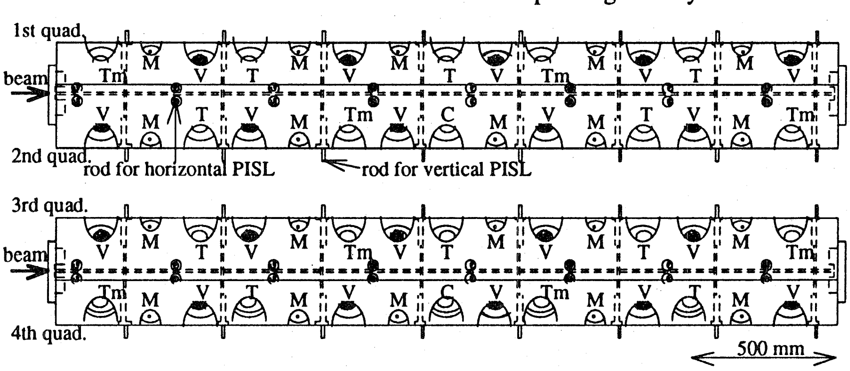


Figure 1. Cross-sectional view of the RFQ cavity in the plane of a pair of horizontal PISLs.



V:vacuum port, T:stab tuner port, Tm:movable tuner port, C:coupler port, M:loop monitor port

Figure 2. Longitudinal outside view of the cavity before installing tuners, couplers and monitors.

IV. References

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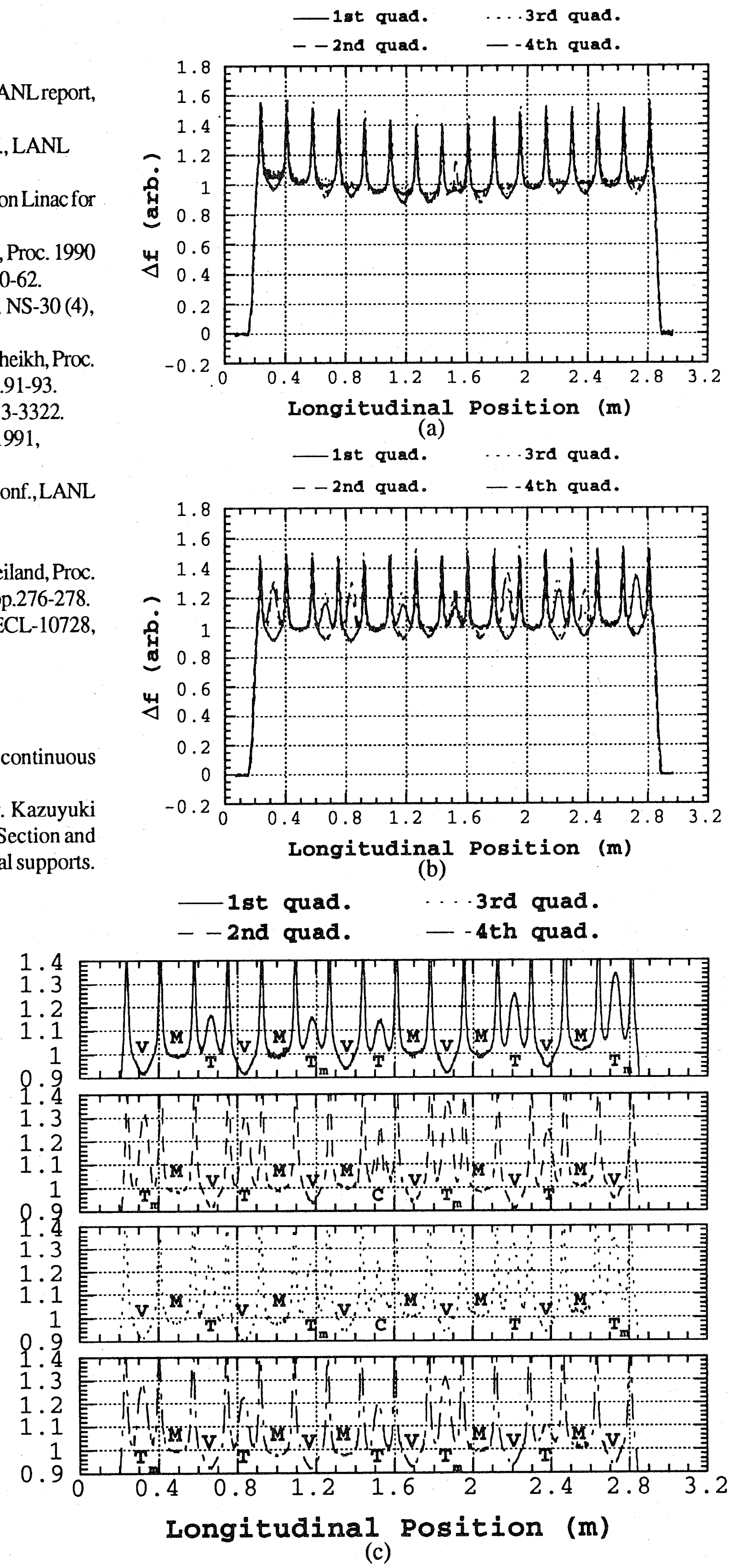

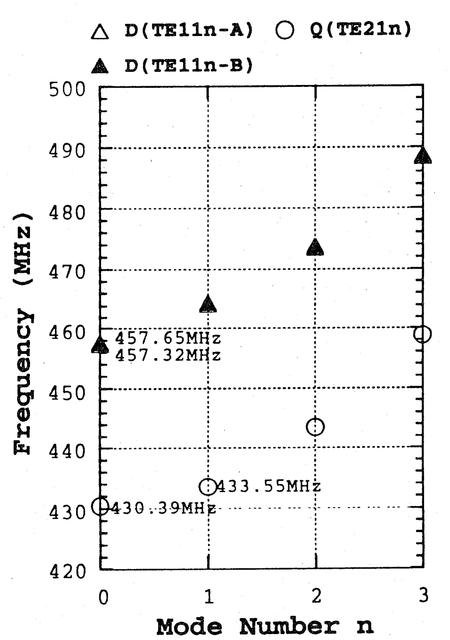

Figure 3. Measured dispersion curves of the quadrupole modes (TE21n) and the two degenerated dipole modes (TE11n-A and TE11n-B) before tuning the dummy tuners.

Figure 4. Distributions of the squares of magnetic field strengths in the four quadrant cavities.
a: Distributions before adjusting the dummy tuners.
b, c: Distributions after adjusting the dummy tuners. In Figure 4c, each distribution is shown separately and the vertical axis is expanded in order to show details.