Design and experiments of the RFQ Linac at Kyoto University

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Abstract

At Kyoto University, the RFQ linac has been operated. The normalized acceptance of the RFQ is 1.5 π·mm·mrad and the beam size is 4.0 mm at the entrance. To focus the beam at the entrance of the RFQ, an electric solenoid lens and a permanent magnet symmetrical lens are inserted. An emittance and profile monitors are also inserted in the beam transport. In the results, the output current of 1.5 mA is obtained from the RFQ when the beam current is 5 mA at the Faraday cup at the entrance of the RFQ.

Introduction

The ICR proton linac consisting of a 2 MeV RF-Quadrupole (RFQ) linac and a 7 MeV Alvarez linac, has been operated at Kyoto University [1]. The layout of the accelerators is shown in Fig. 1. The main specification of the RFQ linac is shown in table 1. The RFQ linac is a 4-vane type. The designed beam current is 50 mA and the duty factor is 1 %. The RF resonant frequency is 433 MHz. The choice of this frequency has merits of a compactness of the cavity size and an availability of the klystrons. On the other hand, it causes difficulties of the beam injection into the RFQ because of the small bore radius. The low energy beam transport between the ion source and the RFQ linac consists of an Einzel lens and electro-static quadrupole lenses [2]. The final focus system is needed at the entrance of the RFQ to match the beam ellipse to the acceptance of the RFQ.

In this paper, we present the acceptance calculation of the RFQ linac and the status of the beam injection.

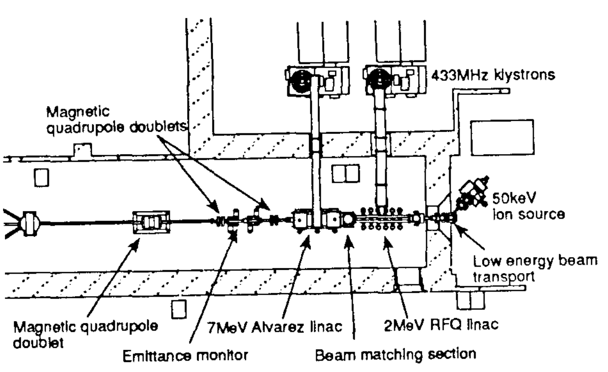

Fig. 1 Layout of the ICR proton linac.

Table 1 Main specification of RFQ linac

Ion species	H^+
Input and output energy	50 keV - 2 MeV
Vane length	2195 mm
Characteristic bore radius	3.0 mm
Resonant frequency	433.00 MHz
Required RF power	540 kW
Intervane voltage	80 kV (1.8 Kilpatrick limit)

Beam acceptance of the RFQ linac

The RFQ linac is designed by PARMTEQ code [3]. The two-term potential is used for the beam simulation in PARMTEQ. The general potential function U in the RFQ is

$$U=\sum_{n,m=0}^{\infty}U_{nm}=\frac{V}{2}\sum_{n=1}^{\infty}A_{0m}\left(\frac{r}{r_0}\right)^{2m}\cos 2m\theta \\ +\frac{V}{2}\sum_{n=1}^{\infty}\sum_{m=0}^{\infty}A_{nm}I_{2m}(nkr)\cos 2m\theta\cos nkz \qquad (1)$$

V is a vane voltage and r_0 is a characteristic bore radius. I_{2m} is a modified Bessel function. If the cross section of the RFQ vane tip is ideal, the potential is

$$U_{01}=\frac{V}{2}\left(\frac{r}{r_0}\right)^2\cos 2\theta$$
$$U_{10}=\frac{V}{2}\frac{m^2-1}{m^2I_0(ka)+I_0(mka)}I_0(kr)\cos kz \qquad (2)$$
$$U_{nm}(n,m\geq 2)=0$$

a is a minimum bore radius and m is a modulation factor. The potential function in eq. (2) is the two-term potential. In our RFQ, the cross section of the vane tip has a constant curvature because of the technical reason. The potential function is different from the two-term potential [4]. The fundamental terms of U_{01} and U_{10} are decrease and the higher order components of U_{nm} is not equal to 0. Fig. 2 (a) is simulation results to show the relation between the beam transmission and the input beam emittance under some conditions. In the case 1, the effect of the decrease of U_{01} and U_{10} are considered in the calculation without the effect of the higher order components. In the case 2, the vane voltage is increased by 10 % to compensate the decrease of the potential. The voltage increase is very effective and we can obtain the large acceptance. The discharge does not occur by the 10 % voltage increase in our RFQ linac. In the case 3, the effects of the potential function of U_{03} and U_{12} are added to the condition of the case 2. Other higher order components of the potential are negligible. The functions of U_{03} and U_{12} are

$$U_{03} = \frac{V}{2} A_{03} \left(\frac{r}{r_0} \right)^6 \cos 6\theta \qquad (3)$$

$$U_{12} = \frac{V}{2} A_{12} I_4(kr) \cos 4\theta \cos kz$$

The electric force by the potentials of U_{03} and U_{12} becomes strong when the beam size is large. Fig. 2 (a) shows that the beam transmission becomes worse if the input normalized emittance is larger than 1.5 π·mm·mrad.

Fig. 2 (b) shows the relation between the beam transmission and the input beam emittance at the various beam current. The condition is the same in the case 3 of Fig. 2 (a). Even if the beam current is 50 mA, the enough beam transmission is obtained if the input normalized emittance is smaller than 1.5 π·mm·mrad. The input beam

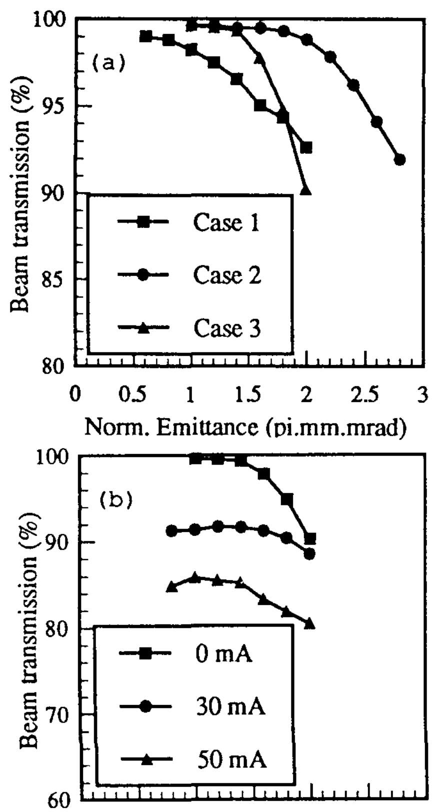

Fig. 2 (a) : Relation between the input beam emittance and the transmission in the RFQ in three conditions.
Case 1 - Decrease of U_{01} and U_{10} are calculated.
Case 2 - Vane voltage is increased by 10 %.
Case 3 - Effect of U_{03} and U_{12} are calculated.
(b) : Relation between the input beam emittance and the transmission at the various beam current.

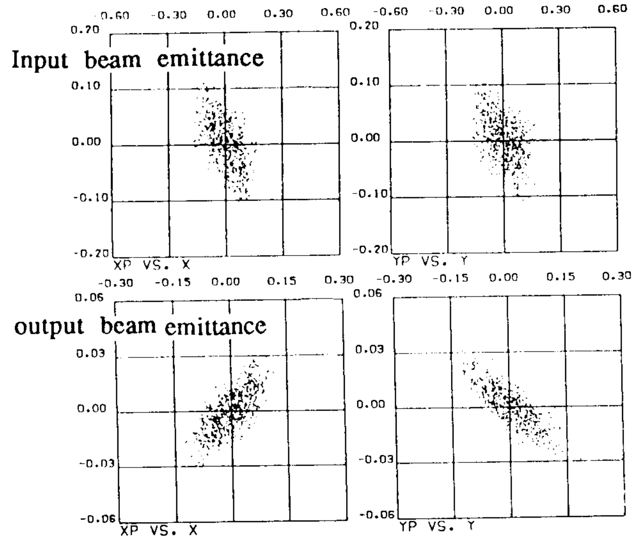

Fig. 3 Input beam emittance and the output beam emittance of the RFQ in the simulation. The input unnormalized emittance is 145 π·mm·mrad. The beam current is 0 mA.

emittance and the output beam emittance in the simulationare shows in Fig. 3. The input unnormalized emittance is 145 π·mm·mrad and it corresponds to the normalized emittance of 1.5 π·mm·mrad. The 95 % output normalized emittance is 1.7 π·mm·mrad.

Beam injection into the RFQ linac

The proton beam is transported from the ion source by the Einzel lens and the electro-static quadrupole lenses in the low energy beam transport. At the entrance of the RFQ, the strong lenses are needed because the beam size of the acceptance of the RFQ is 4.0 mm. As the acceptance of the RFQ is axially symmetric, the symmetric lens is

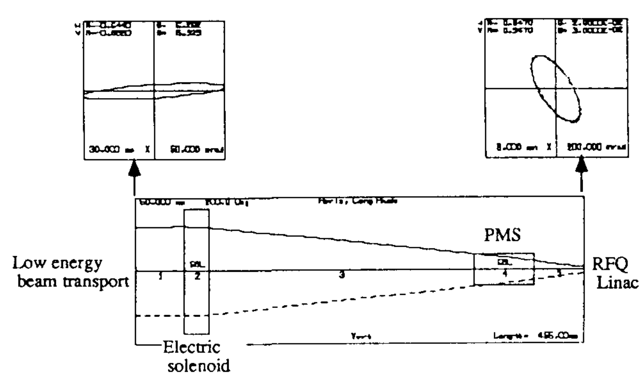

Fig. 4 Beam ellipse at the entrance of the RFQ and the beam optics calculated by Trace-3D. The beam current is 0 mA and the unnormalized emittance is 145 π·mm·mrad

desirable. We adopt the electric solenoid and the permanent magnet symmetrical lens (PMS). Fig. 4 shows the beam ellipses at the entrance of the RFQ and the beam optics calculated by Trace-3D. The beam current is 0 mA and the unnormalized emittance is 145 π·mm·mrad in the calculation. The current of the electric solenoid is 25 A and the magnetic field is 0.63 T. The magnetic field in the PMS is 1.15 T and the length is 60 mm. The focal length of the PMS is 162 mm.

The emittance monitor consists of a view screen and movable slits [5]. The input beam emittance in the vertical direction is shown in Fig. 5. The emittance is measured at the 456 mm before the RFQ. The normalized emittance is 1.8 π·mm·mrad. The aberration is found in the beam distribution. It is caused by the Einzel lens and electrostatic quadrupole lenses in the low energy beam transport. The acceptance ellipse of the RFQ at the same point is also shown in Fig. 5. The acceptance is 1.5 π·mm·mrad.

The accelerated beam current by the RFQ linac is 1.5 mA in this condition. It is measured by the toroidal core monitor in the beam matching section.

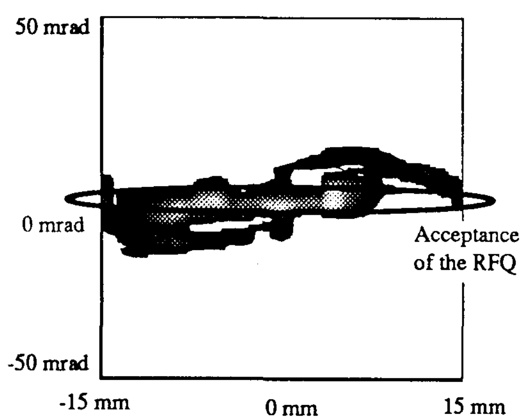

Fig. 5 Beam emittance at the 50 cm before the RFQ linac. The normalized emittance is 1.8 π·mm·mrad. The beam current is 5 mA.

Conclusion

The acceptance of the RFQ is 1.5 π·mm·mrad in the simulation including the effects of the higher order components of the potential function. The acceptance is enough large because the beam emittance of 1.0 π·mm·mrad is desirable to accelerate and transport the beam by the following accelerators.

In the present, we can accelerate 1.5 mA by the RFQ linac when the beam current at the entrance of the RFQ is 5 mA. The present beam emittance is 1.8 π·mm·mrad and the matching condition for the RFQ injection is not fully satisfied. We are going to modify the low energy beam transport to decrease the beam aberration and also improve the matching condition by installing the new PMS [6]. It has a larger bore radius and the stronger focusing force than the present one.

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