PERFORMANCE TEST OF AN 80 MHz RFQ LINAC AT TIT

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Abstract

A four vane type heavy ion RFQ Linac was constructed at Tokyo Institute of Technology (TIT). The first acceleration test was accomplished with low intensity He^+ ion beam in late 1993. In this report, optimization of the vane parameters, the characteristics of RF cavity and results of acceleration tests are presented.

Introduction

The 80 MHz RFQ was designed[1-3] to accelerate particles with charge to mass ratio (q/A) of 1/16 from 5 keV/amu to 214 keV/amu for plasma experiment. In order to gain high acceleration efficiency and to save RF-power and costs, small beam-margin and two-dimensional (2D) machining for cutting of the RFQ vane-tips were applied. The beam optics was simulated including effects of higher order harmonics in the intervane potential for optimization of the vane parameters.

Vane parameters optimized considering higher order mode.

To design vane configuration, the GENRFQ[4] and a modified PARMTEQ were used. The MOD12 was used to revise acceleration force diminished by 2D machining. The modified PARMTEQ, called PARMTEQ-H, has been improved in precision of intervane electric fields at INS. By using tables presented by K.R.Crandall[5-6] that potential is expressed as the sum of multipole components. That potential is given by:

$$U(r,\psi,z) = \frac{V_0}{2}\left[F_0(r,\psi) + \sum_{n=1}^{\infty} F_n(r,\psi)\cos nkz\right]$$

$$F_0(r,\psi) = \sum_{m=1}^{\infty} A_{0m} r^{2m} \cos 2m\psi$$

$$F_n(r,\psi) = \sum_{m=0}^{\infty} A_{nm} I_{2m}(nkr)\cos 2m\psi$$

$$k = \frac{2\pi}{L} = \frac{2\pi}{\beta_s\lambda}.$$

Then the values of the eight coefficients, A_{10}, A_{01}, A_{12}, A_{03}, A_{30}, A_{21}, A_{32} and A_{23}, were taken into account in the PARMTEQ-H.

Fig. 1 shows beam transmissions as designs of various Δrf. With the calculation neglecting higher order mode, Δrf=-0.57 indicates the highest transmission. With the calculation including an influence of higher order harmonics, however that transmission is given about 20% lower value at high current. The higher order mode of the inter-vane field seems to have great influence on the design of RFQs with vanes with non-hyperbolic cross sections, and small margin of beam size. Therefore to calculate the precise optics including higher order mode is useful to optimaize vane-parameters.

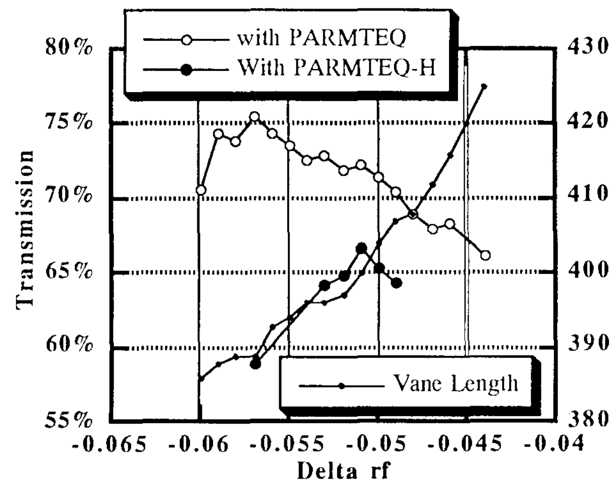

Fig. 1 Transmissions and vane length versus defocusing force, Δ_{rf}, for 10 mA beam injected.

Improved vane-parameters

By using elaborate calculation with multipole components in the RFQ channel, we can see closely the distribution of the particles in separatrix. We are able to determine vane-parameters of TIT-RFQ not only indicated by the computer code to generate the vane-parameters but also improved by consulting the numerical distribution of the particles. When a parameter table of an RFQ is generated by GENRFQ, particles are accelerated to required energy on the condition of constant synchronous phase in the final section called *accelerator section*. In the design of TIT-RFQ, we raised the synchronous phase gradually from -30° to -20° within the separatrix in the final section to gain higher efficiency of acceleration. Applying this method the output energy increases from 207 keV/amu up to 214 keV/amu without reduction of transmission efficiency. This increase corresponds to 5% of the energy gained in the acceleration section.
Table 1 shows designed performance parameters of the RFQ.

Table 1. Design parameters of the TIT RFQ

Charge to mass ratio	≥1/16
Operating frequency (MHz)	80
Input energy (keV/amu)	5
Output energy (keV/amu)	214
Normalized emittance (cm·mrad)	0.05π
Vane length (cm)	422

Total number of cells	273
Characteristic bore radius, r_0 (cm)	0.466
Minimum bore radius (cm)	0.294
Margin of bore radius, a_{min}/a_{beam}	1.1
Maximum modulation, m_{max}	2.05
Focusing strength, b	3.4
Maximum defocusing strength, Δ_{rf}	-0.051
Synchronous phase, ϕ_s (degree)	-90 → -20
Intervane voltage (kV)	79
Maximum field (Kilpat.)	2.2
Calculated Q value	20000
Wall loss (at nominal intervane voltage, kW)	89
Shunt impedance (MΩ / m)	29.5
Cavity diameter (cm)	72.5
Cavity length (cm)	425
Transmission (%)	(0 mA input) 91.8
	(10 mA input) 68.4

The resonant cavity

In order to confirm RF characteristics designed by the computer code SUPERFISH and to determine the end geometry of the cavity, a cold model was fabricated and tested. The practical cavity is divided into three tanks. The four vanes were installed on each cavity using a coordinate measuring machine. The opening between the vanes on adjacent modules is 0.4 mm. These gaps absorb thermal deformation of the vanes. Alignment error at the vane tops is within ±50 μm. The cavities are made of steel plated by copper, and the vanes are made of forged oxygen free copper (OFC). There are 24 manifolds to mount the RF coupler, inductive tuners, pick up couplers, windows and vacuum pumps. Each manifold has a same flange in order to change positions of these devices.

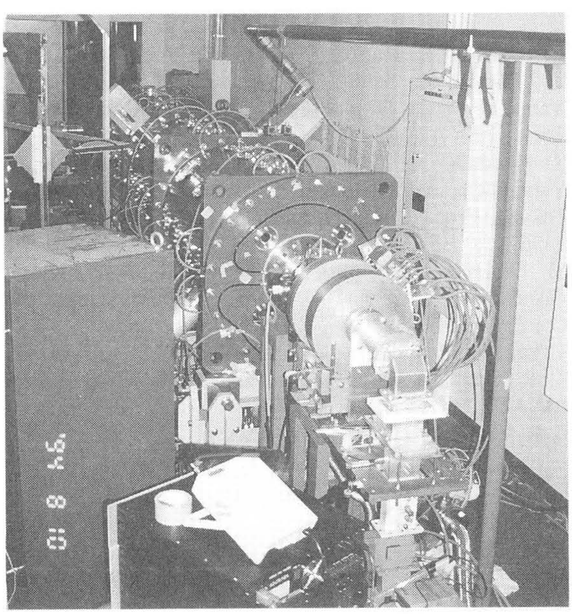

Fig. 2 The cavity of the TIT-RFQ

Tuning of the resonant cavity was accomplished by frequency perturbation methods. The frequency shift, which is proportional to the square of the electric field, caused by Teflon perturbater was measured. The bead pull was done through the strong electric fields near the vane-tip region along the axis. Fig. 3 shows the results of bead pull in all four quadrant after tuning. The differences in field strength between each quadrant are within ±1.5% and the longitudinal field deviation is within ±5%.

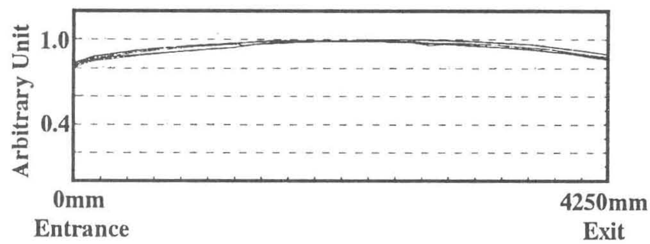

Fig. 3 The results of bead pull in the four quadrants.

The measured resonant frequency and Q-value are 80.9 MHz and 10700 respectively. The resonant frequency was indicated 900 kHz higher than the predicted (SUPERFISH) frequency.

Acceleration test for low current

Arrangement of the RFQ linac and its equipment for He^+ acceleration is shown in fig. 4. A small ECR ion source, which uses 2.45 GHz magnetron, was producing of several decades μA with a He^+ ion fraction of up to 72%. The beam was focused by einzel lenses, and injected to RFQ linac. An emittance monitor system consisting of movable two pairs of slits was arranged immediately in front of the RFQ. The accelerated beam was analyzed by dipole magnet, and measured by faraday cup behind slits as a current.

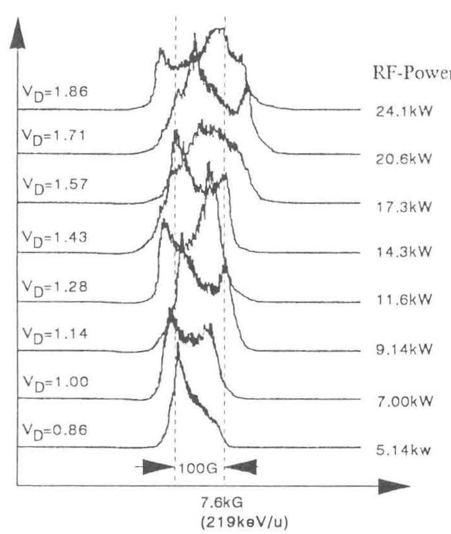

Fig. 5 The momentum spectrum of the output beam.

The momentum spectrum of the RFQ output beam is shown in fig. 5. The observation of fig. 5 indicates that inter vane voltage (V_D=1 is designed voltage) varies the phase of

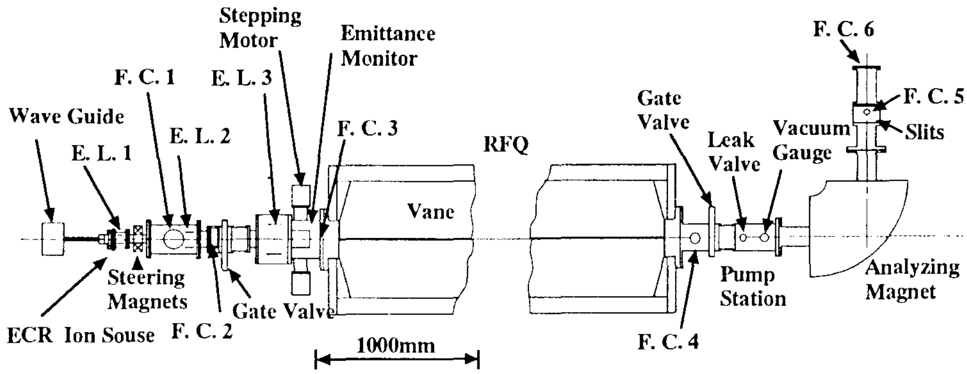

Fig. 4 Layout of RFQ Linac for He^+ acceleration

synchrotron oscillation. Because of higher resonant frequency than predicted one, the measured beam energy was 5 kev/u higher than designed one. Relation between output beam current and fed RF-power is shown in Fig. 6. The designed intervane voltage given by measured Q-value corresponds to 6.7 kW RF-power. We can get good transmission at designed intervane voltage. The current in the acceptance of the RFQ measured by the emittance monitor was 42% of injected current. Considering acceptance, duty factor and fraction rate of He^+ ion, the transmission efficiency was estimated more than 89%.

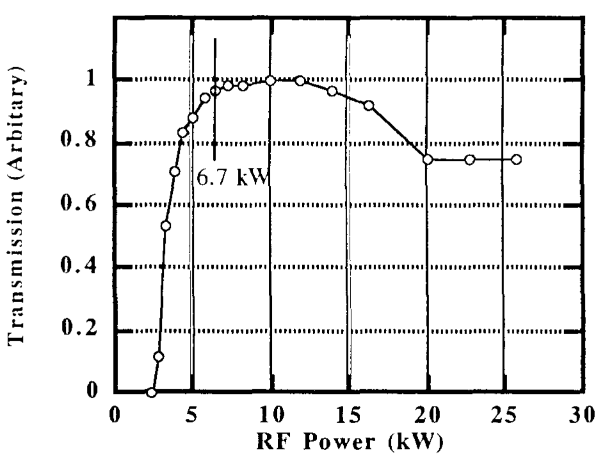

Fig. 6. Relation between output beam current and fed RF-power.

Conclusion

The TIT-RFQ linac was completed. The results of the acceleration tests with low current He^+ and C^{2+} beam agree well with the numerical prediction. In order to evaluate the performance of TIT-RFQ, however, high current acceleration tests are being required. We are planning to accelerate a few mA He^+ ion beam using a new ECR ion source.

References

[1] M. Okamura, T. Hattori, Y. Oguri, T. Aida, K. Takeuchi, O. Takeda, K. Satoh, Y. Tanabe, N. Tokuda and S. Yamada, Proc., The 8th Symp. on Acce. Sci. and Tech.,(1991)131-134

[2] O. Takeda, K. Satoh, Y. Tanabe, S. Kawazu, M. Yamaguchi, M. Okamura, T. Hattori, Y. Oguri and N. Tokuda, Proc., European Particle Acc. Conf.,(1992)1334-1336.

[3] M. Okamura, Y. Oguri, Y. Takahashi, T. Hattori, O. Takeda, K. Satoh and Y. Tanabe, Proc, Linear Acc. Conf.,(1992)67-69.

[4] S. Yamada, Proc., LINAC Conf.,(1981)316.

[5] K. R. Crandall, R. H. Stokes and T. P. Wangler Proc., LINAC Conf.,(1979)316.

[6] K. R. Crandall, LA-9695-MS (1983)