DESIGN STUDY ON AN 80MHz RFQ LINAC FOR HEAVY IONS

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Abstract

An intense heavy ion linear accelerator system at Tokyo Institute of Technology (TIT), which consists of a four-vane RFQ linac and an IHQ (Interdigital H structure with rf Quadrupole focusing) linac, is to be applied for researches on heavy ion pumped laser and heavy ion inertial fusion[1]. The four-vane type RFQ linac accelerates particles with charge to mass ratio (q/A) of 1/16 up to 200keV/amu. The design of the RFQ and preliminary results of its model test are reported.

INTRODUCTION

The four-vane RFQ linac is designed for acceleration of particles with $q/A \geq 1/16$ from 5keV/amu to 200keV/amu. The planned maximum beam current is 10mA for $^{16}O^{+}$. This output energy is necessary both for heavy ion pumped laser and for injection of particles into the IHQ linac. The computer code PARMTEQ was used to simulate the particle motion in the RFQ. The computer code GENRFQ, generator of the vane parameters for PARMTEQ, which was programmed at INS,was used for the optimization of vane parameters. Design parameters are summarized in Table 1. The total vane length is 394 cm which corresponds to 272 cells including a radial matching section with 20 cells. The beam transmission is expected to be 92% for the beam current of 0mA and 72% for 10mA.

A high shunt impedance is required because the available rf power for the RFQ linac is limited to 100kW. In order to obtain a high shunt impedance, a thin vane with a small vane-top curvature is preferable. This configuration, however, tend to distort the linearity of the intervane electric field.

Wall loss and multipole components have been calculated for various vane-top geometries by using the computer code SUPERFISH. After a compromise of these two conditions, a half-scaled model has been constructed in order to investigate the end cut structure including end tuners and the longitudinal distribution of TE_{210} electric field, as well as other fundamental rf characteristics.

OPTIMIZATION OF VANE-TOP CONFIGURATION

Fig.1 shows the configuration of vane-top for analytical survey. The curvature radius ρ and angle θ were varied while the width of 20mm and angle of 15deg. were kept constant. A straight line connects the curvature and 20mm wide flat portion. The larger θ becomes, the thicker the vane-top becomes. This thickness grows maximum at the θ of 75 deg., because the straight line becomes tangential to the curvature. A thick vane-top makes the capacitance high and a large tank diameter makes the inductance low. When the vane-top becomes thick, the tank diameter becomes small in order to fix the resonant frequency to be 80MHz. That is the reason why the wall loss increases in accordance with the larger θ.

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)		200
Normalized emittance(cm·mrad)		0.05π
Vane length(cm)		394
Tatal number of cells		272
Characteristic bore radius, r_0(cm)		0.49
Minimum bore radius(cm)		0.30
Margin of bore radius, a_{min}/a_{beam}		1.1
Maximum modulation, m_{max}		2.1
Focusing strength, b		3.2
Maximum defocusing strength, Δ_b		-0.048
Synchronous phase, ϕ_s(deg.)		-90 → -30
Intervane voltage(kV)		84
Maximum field(Kilpat.)		2.2
Transmission(%)	(0mA input)	92
	(5mA input)	83
	(10mA input)	72

Neglecting the acceleration term, the electric potential in the Q channel ,U is expressed in cylindrical coordinates as

$$U = \frac{V}{2}\sum_{m=1}^{\infty} A_{0m}\left(\frac{r}{r_0}\right)^{2m}\cos 2m\psi,$$

where V is the intervane voltage. Due to the synmetrical property as

$$U(r,\psi,z) = U(r,\psi\pm\pi,z),$$

only the even terms in ψ are nonzero. The two lowest order terms, A_{01} and A_{03} are quadrupole and dodecapole coefficients, respectively. The dodecapole component can be a reason of the beam transmission degradation.

Calculation results of wall loss and A_{03} are shown in Fig.2 as a function of ρ and θ. In the case of $\rho = r_0$ (r_0 :characteristic bore radius), required rf power including beam loading exceeds 100kW, while A_{03} is small. On the other hand, rf power decreases by a factor of 10% and A_{03} becomes doubled in the case of $\rho=0.75r_0$. The multipole components are already analyzed by K. R. Crandall,[2] and A_{01} and A_{03} obtained from the calculated azumuthal electric field show a good agreement with his results. The curvature radius of $0.75r_0$ is chosen mainly from the viewpoint of rf power though the influence of the dodecapole component on the beam dynamics is not clear at present.

The structure of one quadrant is shown in Fig.3. The vane-top configuration was finally determined as represented in Fig.3 considering further reduction of wall loss and easiness of machining. This configuration allows two dimensional machining but makes its mechanical design difficult, especially the cooling structure. The two dimensional machining contributes to much reduction of machining cost. Main rf specifications of the RFQ linac is summarized in Table 2. A high shunt impedance and allowable peak surface electric field of 2.0 times Kilpatrick were achieved without any increase of A_{03}. It seems to be pretty difficult to machine the 4m long vane with sufficient accuracy. Therefore, the cavity will be devided into two tanks with 2m long vanes.

COLD MODEL DESIGN[3]

A half-scaled cold model without vane modulation and a radial matching section was fabricated to examine the field stabilization and to determine end structures. Vanes are made of aluminum but tanks are made of commecially available steel pipe for cost reduction. The tank length and diameter are about 1.7m and 32cm, respectively as shown in Fig.4. The same two-tank structure as the actual cavity was adopted in order to investigate the influence of the tank connection. The gap between vanes in different modules has theoretically no electromagnetic effect, because no current flows across the gap.

The vanes with ρ of 1.55mm were two dimensionally machined using a numerically controlled (NC) mill and the tolerance of vane-top was within ±0.02mm. The vanes are bolted to the tank with rf contacts. Alignment of four vanes is carried out using two end jigs and reamer pins instead of an optical method.

The vane end cuts are triangular and the tuning plates can be attached as shown in dotted lines in Fig.4. Four capacitive end tuners (C-tuner) are also inserted from each end plate. The optimization of the end cut geometry and the C-tuners will produce fairly uniform distribution of the rf field at the four quadrant cavities. In addition to the C-tuners, each quadrant has six inductive side tuners to tune the rf field distribution more precisely.

Other auxiliary components such as an antenna and pick-ups are also installed. A loop type antenna is employed and each quadrant has one pick-up for monitoring internal field strength.

RF FIELD MEASUREMENT

The measured resonant frequency is 187.99MHz which is a little lower than the value predicted by SUPERFISH. Q-value from this measurement is meaningless because material of vanes and tanks are different. Only Q-value measured after copper electro-plating can be used for quantitative estimation.

The electric field strength near the beam axis is measured with a bead-perturbation mehtod. Through two halls bored at the center of both end plates, a perturbator, ceramic bead with a diameter of 10mm, is introduced into the cavity. The perturbator slides on the surfaces of neighboring two vanes by means of a guiding thread. This measuring technique allows exact positioning of the perturbator without special holding devices. The diameter of center halls is reduced to be 12.5mm

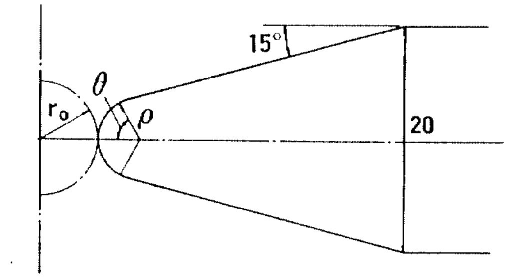

Fig.1 Vane-top cross section for analytical survey

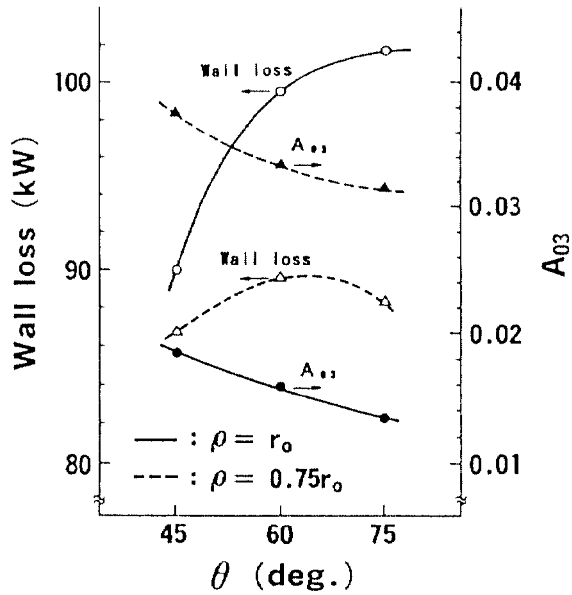

Fig.2 Wall loss and A_{03} as a function of ρ and θ

Table 2

Main rf specifications of the TIT RFQ

Resonant frequency(MHz)	80
Calculated Q value(SUPERFISH)	21600
Wall loss(at nominal intervane voltage, kW)	81.0
Shunt impedance(MΩ/m)	29.8
Maximum field(Kilpat.)	2.0
A_{01}	0.97
A_{03}	0.033
Vane radius(cm)	0.37
Cavity diameter(cm)	76.6
Cavity length(cm)	400

in proportion to beam halls of the actual machine. The end plates have other four halls near the bottom of vanes to measure the magnetic field of each quadrant cavity.

The opposite vanes had to be short-circuited in order to suppress the dipole mode (TE_{110}-mode), because the accelerating quadrupole mode (TE_{210}-mode) could not be separated from the dipole mode by adjusting the end tuning plates and end tuners. Fig.5 shows the measured frequency perturbations in four quadrant cavities which correspond to the squares of the electric fields near the beam axis. The field uniformity is insufficent and a droop is found near the end cut region. The electric field strengths of the third and fourth cavities are a little larger than those of the first and second cavities. This is understandable as a results of the mixing of the quadrupole mode with the dipole mode. The measured phase differences among four cavities also indicate this mode mixing.

CONCLUSION

An 80MHz RFQ linac was designed to achieve the intervane voltage of 84kV with the limited available rf power of 100kW. As a consequence, 4m long thin vane with its top radius of $0.75r_0$ was adopted. In order to study the field stability of this RFQ, a half-scaled cold model without vane modulation and a radial matching section was fabricated. A field uniformity, however, is not sufficient at present due to the mixing of the quadrupole mode (TE_{210}) with the dipole mode (TE_{110}).

We have been concentrating on the elimination of the mode mixing which will be achieved by inserting interstitial vanes and by adjusting the side tuners. Other rf characteristics will be also measured after copper electro-plating of the cold model. Moreover, the structural and thermal designs are also in progress including the R&D concerning machining procedure.

REFERENCE

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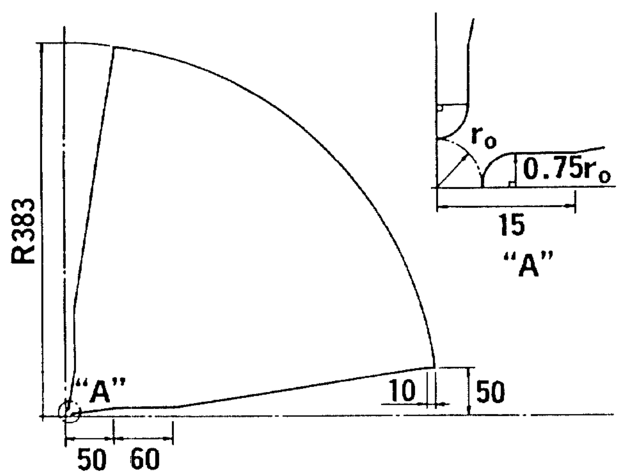

Fig.3 Cross section of one quadrant

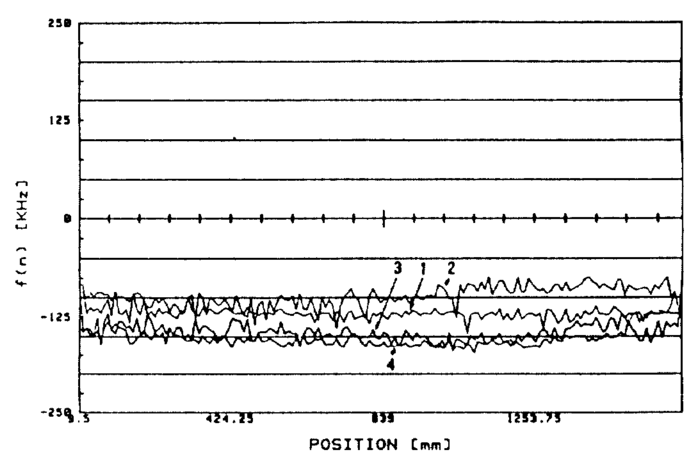

Fig.5 Electric field distributions in four quadrants

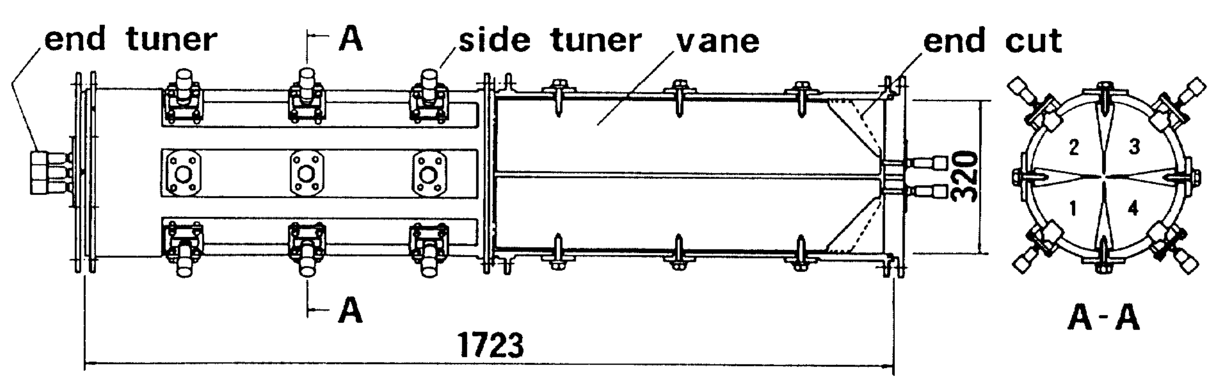

Fig.4 Half-scaled cold model