BEAM TEST OF THE RFQ LINAC TALL

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Summary

Field tuning and beam test of the RFQ linac TALL were done. The machine is designed to accelerate heavy ions with charge to mass ratio of 1 ～ 1/7. The acceleration cavity is of four vane structure driven with a single loop coupler. The cavity is 58 cm in diameter and 730 cm in length. No vane coupling ring is used. A field uniformity was obtained within an error of ± 2% azimuthally and ± 5% longitudinally by use of side inductive and end capacitive tuners. The TE210 mode was tuned at 101.3 MHz, 0.9 MHz lower than that of the closest mode TE111. Beam test was done by using proton beam. Transmission exceeding 90% was obtained. Energy and its spread of the ouput beam were measured by an analyzer magnet as T = 825 keV and $\Delta T/T$ = 1.6% in FWHM. They agree with calculated values.

Introduction

The RFQ linac TALL was constructed as the first stage of an injector linac system for a heavy ion synchrotron 'TARN II' which is under construction at INS.[1] An RFQ linac is best for the stage because it can accept low velocity beam and has bunching function. The machine is designed on the basis of the experience of the test RFQ linac LITL.[2] The design parameters of the TALL are given in Table 1. The machine can accept ions with charge to mass ratio of 1 ～ 1/7. By using an ECR ion source it can accelerate heavy ions up to Xe and W.[3] Injected ions at 8 keV/u are accelerated up to 800 keV/u. For 100 MHz, the $\beta\lambda$ at the output energy is 12.4 cm and long enough to be accepted by the following drift tube linac.

Table 1. Design parameters of the TALL.

Ions (q/A)		1 ～ 1/7
Operating frequency (MHz)		100
Input energy (keV/u)		8
Output energy (keV/u)		800
Total number of cells		300
Cell number of radial matching section		40
Vane length (cm)		725
Cavity diameter (cm)		58
Characteristic bore radius, r_o (cm)		0.54
Minimum bore radius, a_{min} (cm)		0.29
Margin of bore radius, a_{min}/a_{beam}		1.15
Maximum modulation, m_{max}		2.5
Focusing strength, B_o		3.8
Maximum defocusing strength, Δ_b		- 0.075
Synchronous phase, ϕ_s (deg)		- 30
Intervane voltage for q/A = 1/7 (kV)		81
Maximum field (kV/cm)		205 (1.8 Kilpat.)
Rf power wall loss for q/A = 1/7 (kW)		180
Transmission for input beam	0 mA	0.94
with a normalized emittance	2 mA	0.91
of 0.6 π mm · mrad for q/A=1/7.	10 mA	0.63

Acceleration Cavity

The acceleration cavity is of four vane structure driven with a loop coupler. The cavity is 58 cm in diameter and 730 cm in length. The cavity is longitudinally separated into four sections, each of which is 1.8 m long.

Each section is assembled and aligned independently. The vane is mounted in a cavity cylinder with three base plugs. The cylinder is made of mild steel, copper plated to a thickness of 100 μm. Each section has 16 holes of 100 mm in diameter for side tuners, pumping ports and rf power feed. It also has one monitor loop in each quadrant.

The cylinders are jointed with rf contactors of silver coated metal O-rings. The vanes have no rf contact but narrow gaps of 0.2 mm to tolerate machining errors and unequal thermal elongation at the longitudinal joints. The vane separation effectively reduces L^2-dependence of the voltage variation, and allows vane positioning with realizable accuracy.

Vanes

Two sets of vanes are prepared for the TALL. One is for low power operation. It is made of aluminum and has no cooling channel. The other is made of oxygen free copper and has cooling channels for high power operation. The field tuning and beam test were done with the aluminum vanes. The vanes and cylinders are electrically contacted with C-shaped contactors made of stainless steel, silver coated to a thickness of 50 μm.

The transverse geometry of the vane tip is approximated by a circular arc with a varying radius, similarly to the LITL. The modulation was machined with a ball end mill of 30 mm dia. in most of the vane length. Mills of 12 and 20 mm dia. were used on the first section where the cell length is short and the modulation factor increases steeply. The modulation machining was checked to be within a tolerance of ± 30 μm by an inspection machine.

Alignment

The cylinder has square flanges on both the ends. The vertical and horizontal rims of the flanges are the fiducial planes for the alignment.

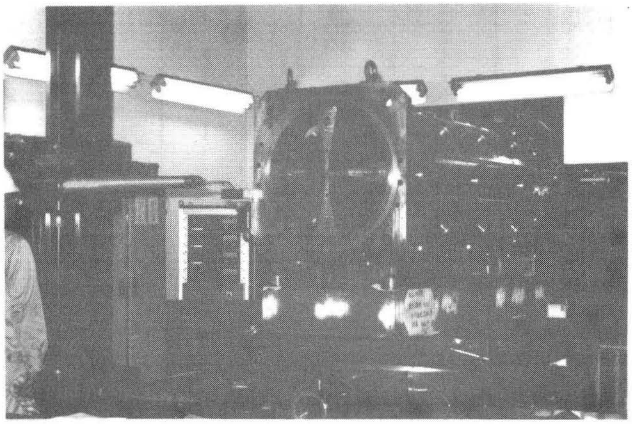

Fig.1. Inspection of the vane alignment.

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Both the vane ends have fiducial holes near the vane tip. They were used to measure the radial positions of the vane tips. The side flats of the vanes near the tip and base were used as the azimuthal fiducial planes. The accuracy of the vane positioning was checked with an inspection machine (Fig.1).

The vanes were assembled first with no rf contactor and no vacuum seal. After the vanes were aligned within an error of ± 50 μm , the positions of the vanes, base plugs and cylinders were fixed with locator pins. Then the cavity was disassembled and cleaned up. Guided with the locator pins, the vanes were assembled with rf contactors and vacuum seals. Again the vane position was measured with the inspection machine and re-aligned when necessary.

The four section was jointed on a bed. The bed has five support flats. They were leveled within an error of ± 20 μm. The square flanges were jointed so that there remained no clearance between the horizontal fiducial planes and the flats, and so that the vertical fiducial planes were in a plane.

The beam axis was aligned within an error of 200 μm over the length of 7.3 m. The steps between the longitudinally adjacent vanes are within 100 μm at the joints. A computer simulation shows that alignment errors of the beam axis of 100 μm at three joints do not decrease the transmission significantly.

Field Tuning

On the input and output ends, a part of each end of the aluminum vane is removable in order to vary the inductance of the cavity ends. The end wall has four movable capacitive end tuners. They are aluminum rods of 25 mm in diameter. Each quadrant has 4, one for each section, movable side tuners. They are water cooled copper cylinder 100 mm in diameter driven with stepping motors in a stroke of 50 mm. They will compensate the resonant frequency shift due to thermal elongation. Aluminum cylindrical blocks of 100 mm in diameter and various thicknesses are inserted through the side holes to obtain uniform field.

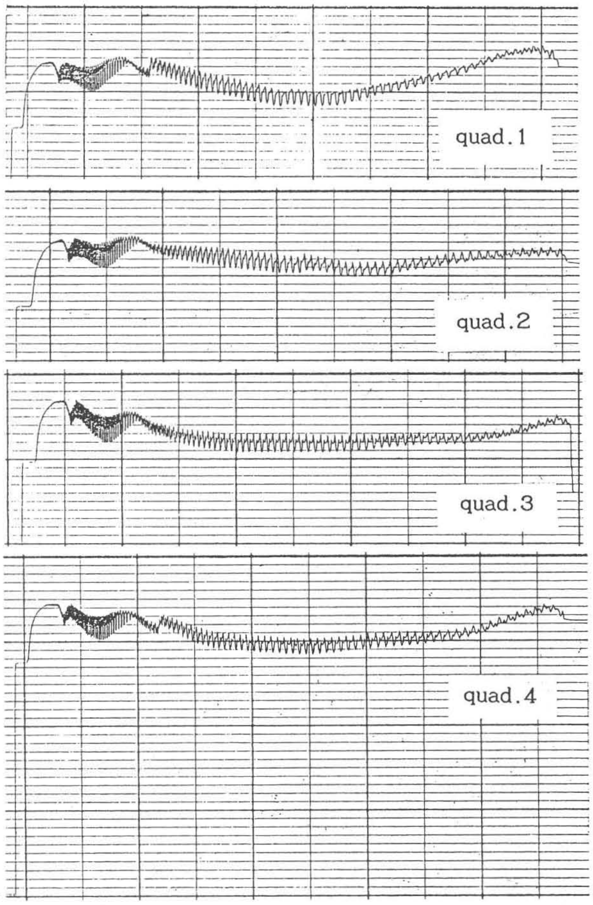

Fig.2. Electric field distribution between the vane tips. Ordinate: shift of the phase difference between the cavity field and input signal (arbitrary scale). Abscissa: position of a dielectric perturbator.

Resonant frequencies of various modes were measured with the vane ends shorted to the both end plates. From the dispersion relations the cutoff frequencies were determined at 97.6 and 101.1 MHz for the dipole and quadrupole modes, respectively. The calculated ones by SUPERFISH for the cross sectional geometry at the quadrupole symmetrical plane are 98.3 and 100.6 MHz, respectively.

The field distribution was tuned roughly by varying the shape of the vane ends. Then fine tuning was done by using side inductive and end capacitive tuners. The electric field distribution between the vane tips was measured by use of a dielectric pertubator moving guided by the vanes. A field uniformity within a deviation of ± 2% azimuthally and ± 5% longitudinally was obtained, by using two dozen side tuners of fixed length and three end capacitive tuners(Fig.2). Slight potential jumps were measured in the quadrants 1 and 4 at the joint of the first and second sections. The distribution does not depend on the position of the coupling loop. The separation of 0.93 MHz between the TE210 and the closest TE111 mode is satisfactory.

Beam Test

Ions extracted from a microwave ion source at 8 keV are transported to a magnet with two einzel lenses. Protons are separated from other ions with the magnet. They are focused into the RFQ entrance with a triplet of electric quadrupole lenses and an einzel lens.

The accelerated ions are focused with a triplet of quadrupole magnets on an object point of an analyzer magnet.

The energy of the output beam was measured by the magnet as T = 825 keV/u. Considering that the frequency is tuned at 101.3 MHz, the measured energy dose not cotradict with the design value. The energy spread was measured as ΔT/T = 1.6% in FWHM. It agrees with a computer simulation by PARMTEQ.

Transmission efficiency was measured for input proton beam of 10 μA. The emittance and intensity of the input beam were measured just in front of the entrance or, downstream of the final einzel lens. The intensity of the output beam was measured at the object point. Transmission exceeding 90% was obtained.

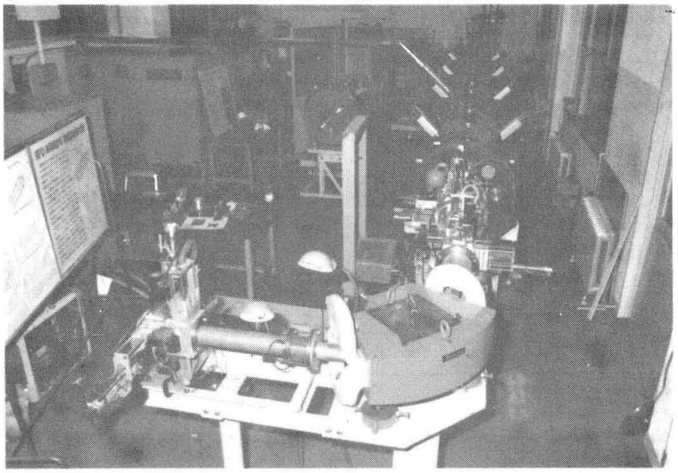

Fig.3. View of the beam test stand from output side.

The beam test was done in pulse operation. The duty factor was 16.7% (2 ms duration/ 12 ms repetition period). The proton acceleration required rf power of 4.6 kW (peak). The unloaded quality factor Q_0 was measured at 7100. It is about 70% of a caluculated value for the aluminum vanes. With the loop coupler the cavity was stably operated up to the full power of 25 kW of a power supply now available. Multipactoring was observed in three ranges below the proton acceleration rf level. On the first power test they were easily surmounted after a few hour outgassing.

The cavity is pumped with two turbo-molecular pumps of 500 l/s. The vacuum pressure was $1 \cdot 10^{-6}$ Torr with no rf power. It increased to a range of 10^{-5} Torr on the outgassing process.

Replacement of the Vanes

After the beam test the aluminum vanes were disassembled in order to replace by the copper vanes. Sparking marks were observed on the end surfaces of the vanes between the first and fourth quadrants at the joint of the first and second sections. It corresponds to the potential jumps measured on the field tuning (Fig.2).

The end shape of the high power vanes were determined on the basis of the field tuning. The vanes are contacted with copper rods at the longitudinal joints to eliminate the potential jumps. The vanes and cylinder are contacted with O-shaped contactors instead of the C-shaped ones for the aluminum vanes, because higher contact force becomes possible.

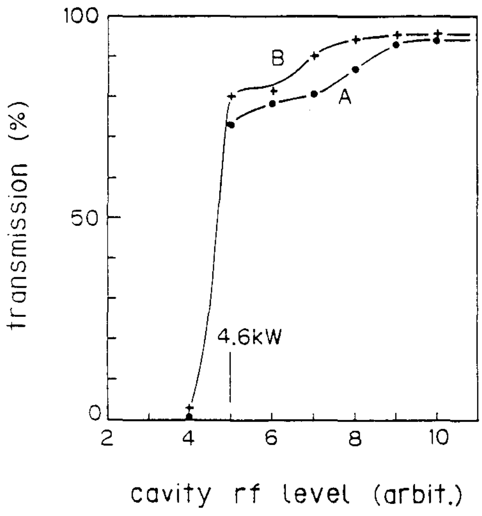

Fig.4. Transmission vs. cavity rf level for input H⁻ beam of 10 μA. Input beam emittance for A and B is given in Fig.5.

Conclusion

We obtained a field uniformity within an error of ± 2% azimuthally and ± 5% longitudinally with a loop coupler. No vane coupling ring was used. The TE210 mode was tuned at 101.3 MHz. The closest mode TE111 has a suffiecient separation of 0.9 MHz. Transmission exceeding 90% was obtained. The measured energy and its spread agree with the calculation. Field tuning and beam test with the new vanes will begin in June.

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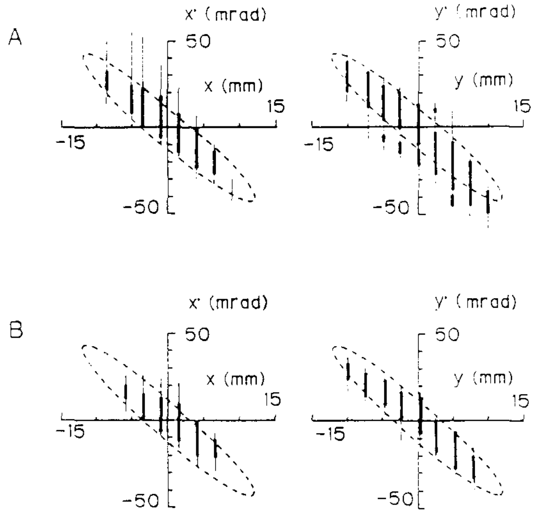

Fig.5. Emittance of the input H⁻ beams of 10 μA measured at 21 cm upstream of the RFQ entrance. Thick and thin bars cover 95% and 100% of the beam, respectively. The ellipses are ones for RFQ acceptance at the design voltage. The area is 145π mm · mrad, or 0.6π mm · mrad normalized. A and B are for beams limited by apertures of 13 and 8 mm dia., respectively, inserted between the electric quadrupole lenses.