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CONSTRUCTION OF THE RFQ "TALL"

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Summary

An RFQ linac "TALL" is constructed. The machine is designed to accelerate heavy ions with charge to mass ratio of 1 to 1/7 from 8 up to 800 keV/u. It will be used as the first stage of an injector for a heavy ion synchrotron "TARN II" which is under construction at INS. The acceleration cavity is of four vane structure driven with loop coupling at 100 MHz. The cavity is 58 cm in diameter and 730 cm in length. No vane coupling ring is used. A field uniformity was obtained easily within an error of ± 6% azimuthally and ± 5% longitudinally by use of side and end tuners. The TE210 mode has a resonant frequency of 101.78 MHz, 0.93 MHz lower than that of the closest mode TE111.

Introduction

The long RFQ "TALL" is constructed as the lowest energy stage of an injector linac system for a heavy ion synchrotron "TARN II" which is under construction at INS.[1] 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 charge to mass ratio q/A of acceptable ions is chosen at 1 to 1/7. This choice will cover ions of a lot of elements in the periodic table. With a hot cathode PIG type ion source, a few hundred microamperes of $^{40}Ar^{6+}$ will be obtained. One of the best ECR ion source will supply a few microamperes of $^{84}Kr^{12+}$.[3]

The injection energy was chosen at 8 keV/u instead of 5 keV/u of the LITL. The space charge limited current in the injection line will increase by two times compared to the LITL. The output energy is 800 keV/u. At this energy, the $\beta\lambda$ is 12 cm for 100 MHz and it gives sufficient drift tube lenghts for focusing elements to a following linac.

The radial matching section has 40 cells instead of 12 cells of the LITL. The envelope angle of the input beam decreases to 43 mrad from 80 mrad of the LITL. The higher injection energy and the smaller envelope angle will make easy the matching of high intensity beam to the RFQ. The output vane ends have no matching section.

Construction of the Acceleration Cavity

Structure

The acceleration cavity is of four vane structure. 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 (Figs.1 and 2).

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 joinned 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. A model study shows that the gaps have little effect on the field distribution, resonant frequency and Q factor for the TE210 mode.[4]

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 for high power operation with cooling channel. Now the cavity is equipped 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.

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_0 (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_0		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

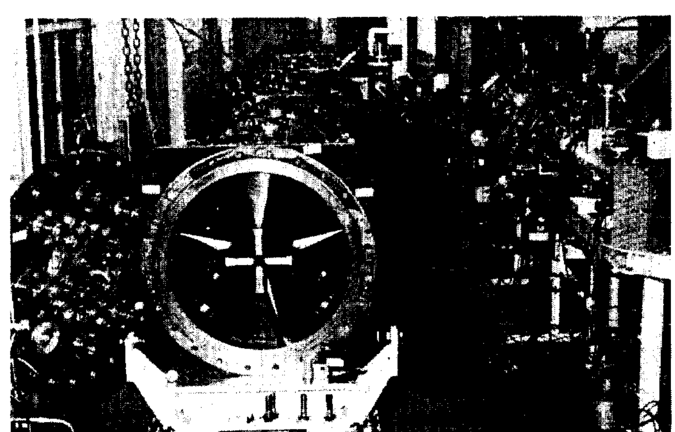

Fig.1. Photograph of the TALL.

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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 $\pm$ 30 μm by an inspection machine.

Alignment

The cylinder has square flanges. The vertical and horizontal rims of the flanges are the fiducial planes for the alignment. The both vane ends have fiducial holes near the vane tip. They are used to measure the radial position 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 is checked with the inspection machine.

The vanes were assembled first with no rf contactor and no vacuum seal. After the vanes were aligned within an error of $\pm$ 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 TALL was laid on a bed (Fig.2). The bed has five support flats. They were leveled within an error of $\pm$ 20 μm. The four sections of the TALL were joinned 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.[5]

Tuners

The end wall has four movable capacitive end tuners. They are aluminum rods of 25 mm in diameter. An the input and output ends, the vanes have removable inductive tuners. 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.

Rf Characteristics

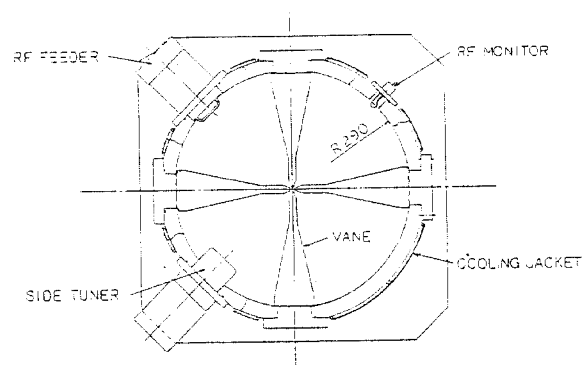
Cutoff frequencies

The resonant frequencies were measured with the vanes shorted to the end walls before tuning (Fig.3). The dispersion curves give the cutoff frequencies averaged over the length. They are 97.6 MHz for dipole mode and 101.1 MHz for the quadrupole mode. The calculated ones with SUPERFISH are 98.3 and 100.6 MHz for the cross section at the quadrupole symmetry.

Mode separation and field uniformity

The cavity was driven with a single loop coupler. The field distribution was measured with perturbation method. The electric field distribution near the vane tops was measured by use of a table tennis ball moving guided by the vanes. The magnetic field near the cavity wall was measured with an aluminum perturbator of 12 cc inserted through the holes for the monitors. Figure 4 shows that both measurements agree. The field was tuned so that the magnetic field might become uniform. Then the electric field was measured.

When the end inductive tuners gave too large end inductances, the fundamental of the quadrupole mode was mixed with the second harmonic of the dipole mode. After the shape of the tuners was varied to give lower end inductance, the separation between the TE210 and TE111 became 1 MHz. A field uniformity within a deviation of $\pm$ 5.7% azimuthally and $\pm$ 4.9% longitudinally was obtained, by using two dozen side tuners of fixed length and three end capacitive tuners (Fig.6). The distribution does not depend on the position of the coupling loop. The interim tuning gives the resonant frequencies of 99.24 for the TE110, 101.78 for the TE210 and 102.71 MHz for the TE111 (Fig.5). The separation of 0.93 MHz between the TE210 and the closest TE111 mode is satisfactory.



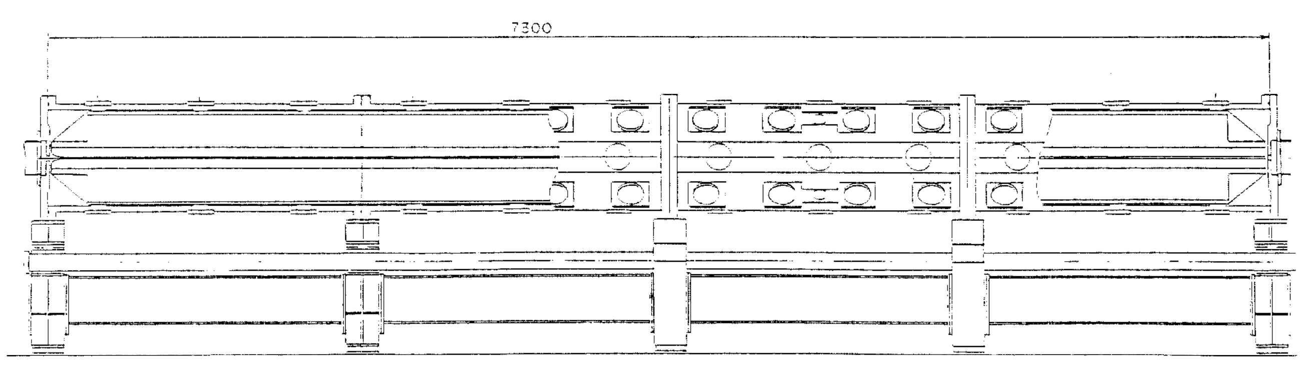


Fig.2. Schematic drawing of the TALL.

Conclusion

So far, we easily obtained a field uniformity within an error of ± 6% both azimuthally and longitudinally. The TE210 mode has a resonant frequency 101.78 MHz. The frequency of the closest mode TE111 is 0.93 MHz higher. Fine tuning will give a better field distribution with a satisfactory mode separation.

The cavity has a length of 2.4 times the wave length. It is driven with a loop coupler. It has no vane coupling ring. The vane separation is another answer for a long RFQ to get a field uniformity and mode separation. It makes much easy the vane machining and assembly.

Acknowledgements

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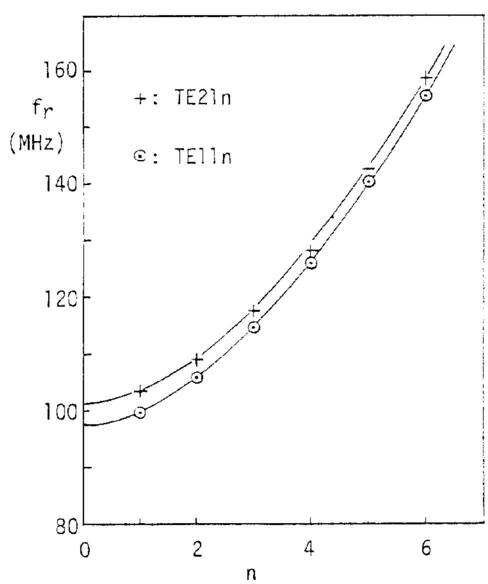

Fig.3. Resonant frequencies when the vanes are shorted to the end walls.

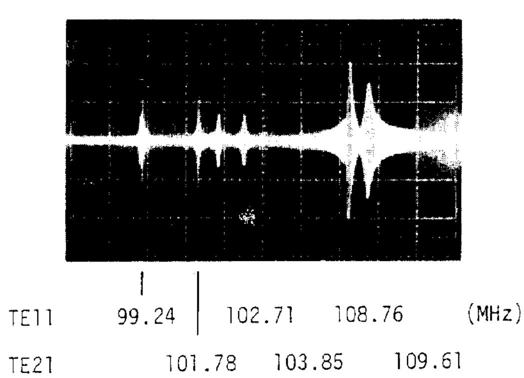

Fig.5. Resonances of various modes for the interim tuning.

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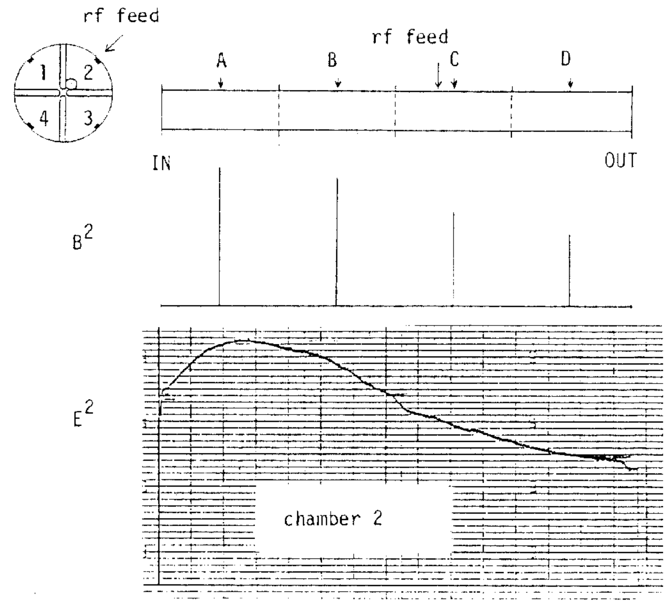

Fig.4. Electric and magnetic field distribution before the tuning.

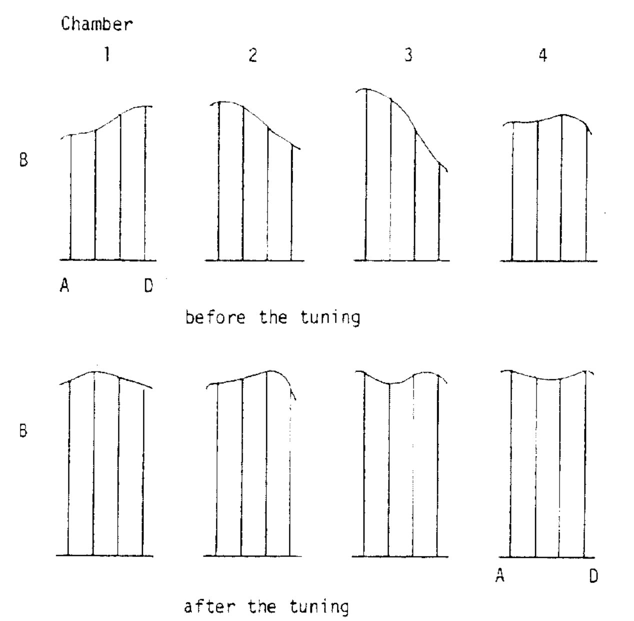

Fig.6. Magnetic field distribution before and after the interim tuning.