RFQ DEVELOPMENT AT INS

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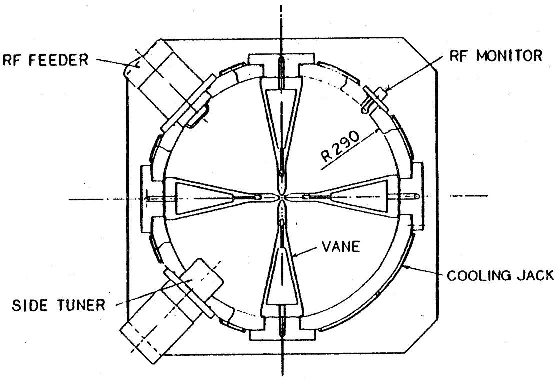
Abstract

The *100 MHz* RFQ linac is being constructed on the basis of the experience with the successful operation of the LITL. The cavity of 7.3 *m* long is a four vane structure and accelerates ions with $q/A \geqq 1/7$ to 800 *keV/u*. The cavity is separated longitudinally into four sections, each of which has a vane lengthof 1.8 it(m). A computer simulation shows that misalignments within 0.1 *mm* of the beam axes of the individual sections scarecely affect the transmission efficiency. The effect of longitudinal vane gaps of less than 0.2 *mm* is expected not so serious for the rf field.

1. Introduction

The RFQ linacs are being developed for acceleration of heavy ions at INS. A four vane structure at operation frequency of about 100 *MHz* is suitable for acceleration of heavy ions with medium mass number. For very heavy ions, the TEM mode resonators such as a split coaxial are preferable, since the four vane resonator becomes very large in diameter for these ions. Development of the RFQ for very heavy ions is presented in another paper[1]. The four vane resonator is a very simple structure with respect to fabrication, mechanical adjustment and cooling. However, it is not easy to stabilize the field, because the TE210 like mode is required for this structure, and a slight positioning error of the vanes and a variation of the intervane capacitance due to the modulation disturb the uniformity of the field. Feeding of rf power into the cavity with an inductive loop also disturbs the field. But it would be tuned with end capacitive tuners and/or inductive side tuners. The LITL has been constructed to test the feasibility of the loop coupling as well as to develop the method for vane positioning with a good accuracy.

The successful operation of the LITL led to construction of a longer RFQ, which permits a simple combination of a small-scale ion source, an RFQ and a drift tube linac for accelerating effectively heavy ions. This linac is separated into four sections for easy of fabrication. However, an acceptance of the linac is reduced by misalignments of the beam axes due to joining the four sections, and a vane surface field at the joint enhances with the longitudinal vane gap. Bisides, it is not easy to stabilize a voltage distribution in a long cavity, because the voltage tilt due to a longitudinal variation of the intervane gap is dependent of square of the vane length. These problems are discussed later.



2. LITL

The LITL was designed so as to accelerate heavy ions with medium mass number at an acceleration rate as high as possible. Operation frequency of 100 *MHz* gives reasonable acceptance and acceleration rate, and a power dissipation of the cavity is less than that of a cavity at a higher frequency. The cavity is of a four vane structure, and rf power is fed into the cavity with a single loop coupler. On each end wall, four capacitive tuners are mounted in face of the vane ends. A field uniformity within ± 2 % azimuthally and ± 3 % longitudinally is obtained with the end tuners. The measured unloaded Q value is 10,600, about 60 % of the SUPERFISH result for an infinitely long cavity and rf power of 22 *kW* is required to accelerate a $^7Li^+$ beam.

The acceleration test show that the LITL has the expected londitudinal and transverse acceptances and works stably for acceleration of ions with $q/A = 1 \sim 1/7$.[2]

3. 100 *MHz* Long RFQ Linac 'TALL'

3.1 Acceleration Cavity

The cavity of 7.3 *m* long and the vanes of 7.25 *m* long are divided into four sections, because it is not easy to machine the vanes of this length in a piece, and even if they can be machined in a piece, mounting them into a tank with a good accuracy have a complecated process. The structure of a section is similar to the LITL's as shown in Fig. 1. The cavity has cooling channels for a high duty operation, and has 16× 4 holes of 10 *cm* diameter on the side wall for inductive side tuners, evacuation and rf coupling. The vane tip of oxygen-free copper is welded to the base of mild steel, which is electroplated with copper. The vanes are positioned with an accuracy better than ± 0.05 *mm* in each section so that the beam axes of the sections are aligned within 0.1 *mm*. Misalignments of the beam axe within 0.1 *mm* has little effect on particle motions as discussed later. The vanes in a section and in adjacent

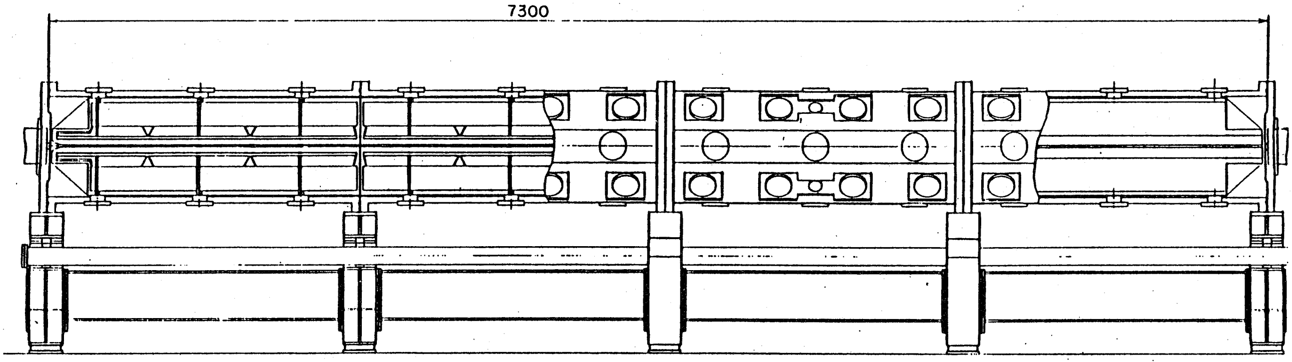


Fig. 1. Schematic drawing of the TALL.

sections are separated at $kz = 0$ or π, where a vane surface field is minimum, with a gap of about 0.2 *mm* to avoid their partial contact due to machining and positioning errors and thermal elongation. It is shown by rf measurements on a model cavity that the gaps scarecely affect on a field distribution and Q-value of a cavity3). The effect of the gaps on particle motions would be negligible for a very small ratio of the gap to the cell length, less than 0.01.

3.2 Field stabilization

In the TALL, three undesirable modes, TE110, TE111 and TE211 will exsist near the TE210 required, where the cross section of the cavity gives a resonant frequency of 100.6 *MHz* and that of the TE110 is 98.3 *MHz*. However, a simple equivalent circuit analysis shows that their frequency are separated from the TE210 more than 1 *MHz*, and little problem exists in the mode mixing.

It is not easy to excite a uniform field such as the TE210 in a cavity with a small value of *Diameter/Length*, because a longitudinal voltage tilt due to the axial variation of a intervane capacitance is dependent of square of a vane length as follows4).

$$\frac{\Delta V}{V} \propto \left(\frac{L}{\lambda}\right)^2 \frac{\Delta C}{C},$$

where λ is the wavelength in free space and nealy proportional to a diameter of a cavity, and C and ΔC are the intervane capacitance and its longitudinal variation due to the vane misalignment and other geometrical parameters. A good voltage distribution is obtained with only end capacitive tuners in cavity with a large D/L, but it will be not easy to tune a voltage distribution over the whole length with only end tuners in a cavity with a small D/L such as the TALL. Inductive tuners installed on the side wall of the TALL will compensate the intervane gap error and stabilize the voltage distribution together with end capacitive tuners.

3.3 Beam Dyamics Design

The design procedure is same as the LITL's. The machine accelerates ions with $q/A \geqq 1/7$ from 8 to 800 *keV/u*. The output energy is high enough to inject into a drift tube linac. The vane parameters are somewhat different from the LITL's:

i) The radial matching section has 40 cells, which permits beam injection with smaller divergence. With a 12 cell long radial matcher, as same as the LITL's, the divergence is 60 *mrad*, while it decreases to 43 *mrad* with 40 cells. Then the length of the section is 24 *cm*. Matching of an injection beam into the RFQ acceptance becomes easy with the decrease in divergence.

TABLE
Design parameters of the LITL and the TALL

		LITL	TALL
Ions (q/A)		$\geqq 1/7$	
Operating frequency (*MHz*)		100	100
Input energy (*keV/u*)		5	8
Output energy (*keV/u*)		138	800
Total number of cells		132	300
Vane length (*cm*)		122	725
Characteristic bore radius, r_0 (*cm*)		0.41	0.54
Minimum bore radius, a_{min} (*cm*)		0.25	0.29
Margin of bore radius, a_{min}/a_{beam}		1.10	1.15
Maximum modulation, m_{max}		2.1	2.5
Focusing strength, B_0		5.0	3.8
Maximum defocusing strength, Δ_b		−0.110	−0.075
Synchronous phase, ϕ_s (*deg.*)		−90 →	−30
Intervane voltage for $q/A = 1/7$ (*kV*)		62	81
Power dissipation (*kW*)		22*	180**
Normalized emittance (π*mm·mrad*		0.6	0.6
Transmission (%)	0 mA	94	94
	2 mA	92	91
	10 mA	64	63

*measured value, **SUPERFISH result.

ii) The focusing force B is chosen at 3.8 to give a higher acceleration rate. In an RFQ linac with a longer accelerating section, an acceleration rate increases linearly with a decrease in B, when tne rf defocusing force is optimized and the longitudinal and transverse acceptances are fixed. Then we should note that wall loss of the cavity increases at the inverse square of B and the larger modulation factor m due to the decrease in B results in distortion of a field in an acceleration bore for a circular approximation of a vane tip shape. An acceleration rate of 800 *kV/m* is given at $B = 3.8$ for the TALL parameters. A field distribution at $kz = 0$, where the distortion is largest, is shown in Fig. 2 for the maximum m of 2.45 in the TALL. A good field distribution is, of course, given with unmodulated vanes with a cross section at $kz = \pi/2$. The figure shows that the field stronger than the identical one is applied in the acceleration bore. Beam loss due to this distortion would be negligible, since the TALL is designed to be stable both transversly and longitudinaly to a stronger field.

iii) The ratio of the minimum aperture to the beam envelope is chosen at 1.15 in consideration of misalignments of the beam axes due to joints of four sections.

The vane parameters and the PARMTEQ results are listed in Table in comparison with those for the LITL.

3.4 Beam loss due to misalignments of the beam axes

Misalignments of the beam axes due to joining the four sections reduce the transverse acceptance of the TALL. The beam axes coincided at the joints have not serious problem even if the beam axes are sloped in undesirable directions as illustrated in Fig. 3(a), while discreteness at the joints purturbs particle motions even if the axes are parallel (Fig. 3(b)). Slope of the axes in the x or y-direction means that an acceptance of a section moves parallel in the x' or y'-direction on a phase diagram, and the discreteness means movement of the acceptance in the x or y-direction. A beam emittance on the x-x' plane at the last joint has $|x'| \leqq 10$*mrad* at $x = 0$, and has the same value on the y-y' plane. Therefore a slope as large as 0.5 *mm*/1.8 *m* = 0.28 *mrad* causes a mismatching of only about 1.4 %. The axes are practically aligned to a slope within 0.11 *mrad*. On the contrary, the emittance has only $|x| \leqq 1.5$*mm* at $x' = 0$ and a discreteness of 0.5 *mm* causes a mismatching as large as 17 %. Computer simulations were, therefore, performed only for the case

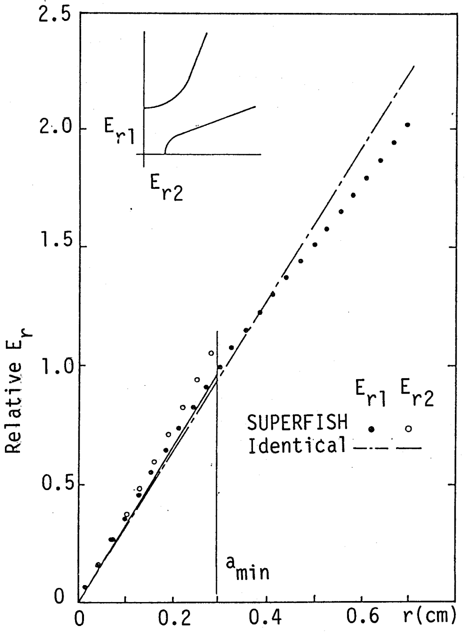


Fig. 2. Field distribution at kz = 0.

that the beam axes are not coincided at the joints but parallel. The results are shown in Figs. 4 and 5. The misalignments within 0.1 *mm* we expect, have little effect on particle motions as shown in the figure.

3.5 Enhancement of the surface field due to the longitudinal vane gaps

The vanes are separated into four sections at $kz = 0$ or π with a gap of about 0.2 *mm*. The vane surface field will enhance at the vane edges. The surface field near the edge might be estimated by a surface field in an infinitely long cavity with a cross section as shown in Fig. 6, which can be calculated by SUPERFISH. The surface field are calculated for three kind of edge shapes as illustrated in the figure. The smallest enhancement of the surface field is given with the edge of the circular shape and the maximum field is 1.24 times the surface field without the gap. On the vanes without the gaps, the maximum surface field at $kz = 0$ is calculated to be $1.24V/r_0$ at the last joint cell by SUPERFISH. Therefore, the maximum surface field at the edge of the vane separated would be $1.54V/r_0$, and it is nealy equal to that at $kz = \pi/2$, estimated to be about $1.6V/r_0$.

On the other hand, a voltage variation along the beam axes jumps discretely at the gap, and a field of V_g/g is excited in the gap. A voltage jump of 10 % corresponds to a gap field of 20 *MV/m* in the TALL. However, V_g depends on dV/dz at the joint without the gap, and the jump of 10 % would be caused by a very large voltage variation along the axis[3] . Tuning of the voltage distribution will reduce V_g within 1 %.

4. Conclusions

As an extended version of the LITL, a long RFQ to attain 800 *keV/u* is under construction. The beam axes of the four sections are aligned within 0.1 *mm*, and it has little effect on particle motions. The maximum surface field at the joints of the vanes separated with a gap of 0.2 *mm* will be nealy equal to that at $kz = \pi/2$.

Acknowledgments

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References

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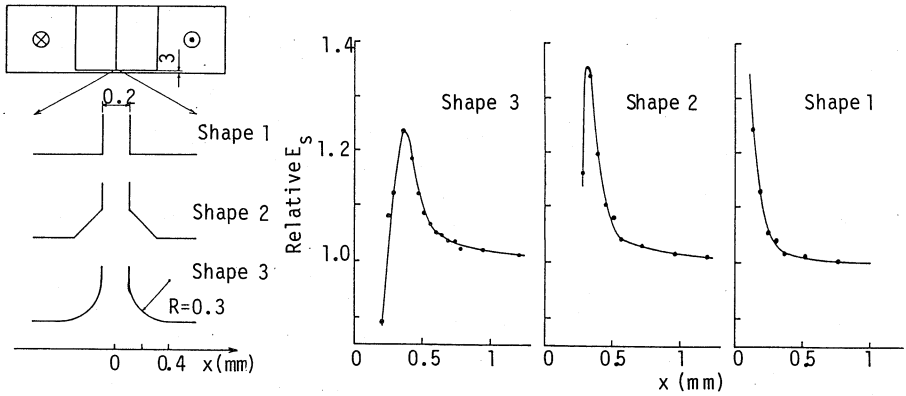

Fig. 6. Surface field near the gap. The resonant frequency is 100 MHz.

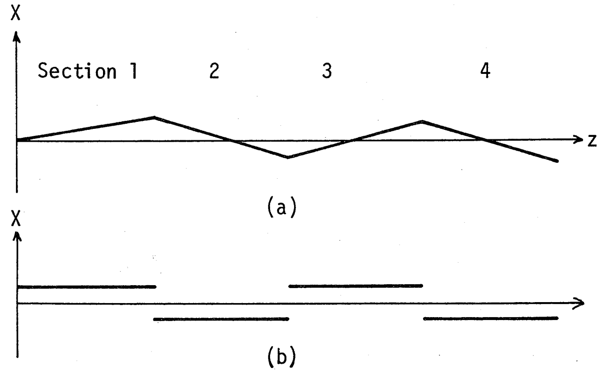

Fig. 3. Misalignments of the beam axes of four sections.

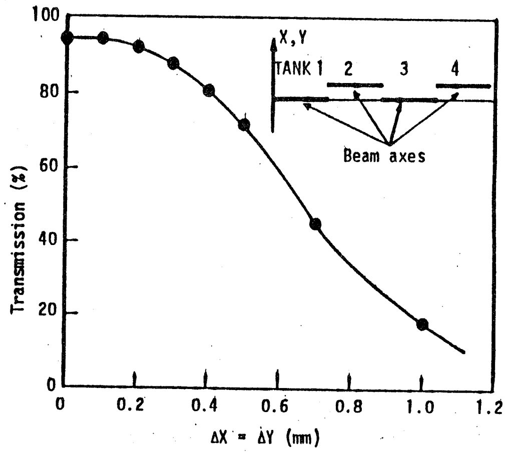

Fig. 4. Computer simulated transmission vs. errors of the beam axes.

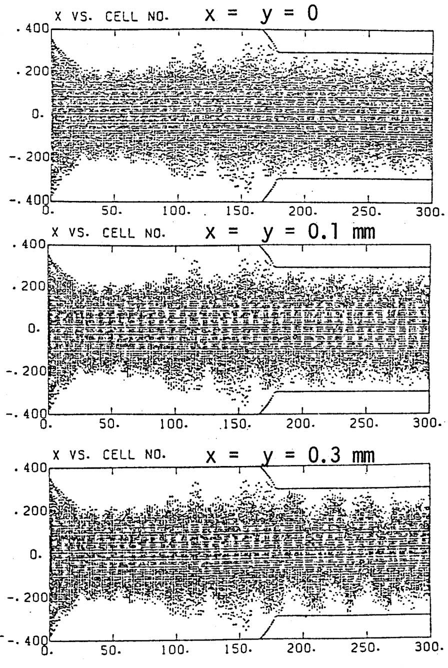

Fig. 5. x-beam profiles.