LOW FREQUENCY HIGH DUTY CYCLE HEAVY ION RFQ

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Abstract

A new RFQ structure for low frequency and high duty cycle operation is proposed. Due to its merits this structure has potential applications for heavy ion acceleration. As an example, a 27 MHz RFQ for a UNILAC upgrading is studied. The main RFQ parameters and results of beam dynamics simulations demonstrate the performance of the structure. Additionally, a new matching approach between the RFQ and conventional linac structures is presented.

Introduction

For acceleration of high intense heavy ion beams, well suited RFQ structures are needed. At ITEP a so called 4-ladder structure has been developed which has promising features. The new structure is in competition with other types of RFQ accelerators in a wide frequency range.

Within the upgrading program at GSI, the linear accelerator UNILAC has to be modified to a high intensity injector for the synchrotron SIS. For beam dynamics reasons, the operating frequency of the foreseen RFQ structure should be near 30 MHz. Thus the 4-ladder structure is a promising candidate for GSI applications.

As an intermediate step, a modification of the first part of the UNILAC has been discussed:
Keeping the dc preinjector for U^{10+} and the low energy beam transport line, the first tank or only one part of it will be replaced by an RFQ accelerator. Parameters of the RFQ and beam dynamics calculations will show that the current limit of the UNILAC can be increased considerably.

Performance of the RFQ structure

A detailed description of the new RFQ structure is given in Ref. [1]. A schematic view of the 4-ladder structure (or also called 90^o-apart- stem structure) is shown in Fig. 1.

The electrodes in this structure are short vanes; each vane is supported by its own stems. Thus this stucture can be considered as the 4-vane structure with window cuts in vanes or the symmetric 4-rod structure [2]. The arguments for the choice of this type of resonant structure - based on the MAFIA code simulations and cold model measurements - are the following:

- This structure has a good rf efficiency, which was confirmed by MAFIA code simulations made in a wide frequency range (27÷400 MHz). The diameter of the resonator is considerably less than for the 4-vane structure. These facts make the described structure very attractive for low frequency heavy ion RFQ's.

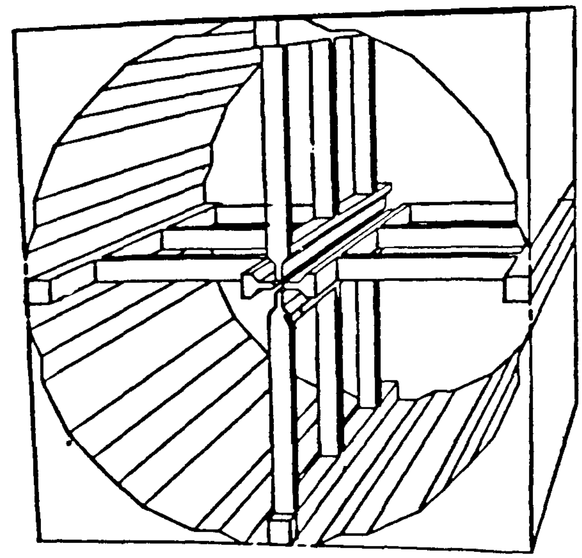

Figure 1: Schematic drawing of the 4-ladder structure

- The need to have a good field distribution, both azimuthaly and longitudinaly, requires first of all reliable separation of the operating quadrupole mode from the dipole and high order modes. It is known that a 4-rod RFQ has a good separation of the quadrupole mode from dipole mode, so f_{dip} is quite higher then f_{quad} - even doubled. On the contrary, in a 4-vane RFQ the frequency difference between operating mode and undesired ones is only a few percent and vane coupling rings (VCR) or other coupling mechanism have often to be used to reject undesired dipole modes.

In the described structure, the mode separation is better than in the 4-vane resonator due to the strong magnetic coupling between neighbouring quadrants through the windows. The measurements at the 108 MHz cold model show that the dipole mode frequencies are more than 20 MHz higher than the quadrupole mode; this separation is enough to guarantee good azimuthal stabilization of the operating quadrupole mode.

Furthermore, recent investigations [3] showed that 4-rod RFQ's have an E_z component on the beam axis in the gap between end plate and electrodes. This effect can be completely eliminated in the proposed structure provided that horizontal and vertical stems will have the same longitudinal position. It allows to avoid any contact problems for the resonator consisting of separated parts, because there are no currents flowing along the electrodes.

- The 90^o - apart - stem structure allows to have the same mechanical design of the resonator as for the 4-vane resonator. It means that it is possible to keep the merits of a 4-vane resonator as there are mechanical stability, rigidity, possibility of a good electrode cooling and relative simplicity of manufacturing. It is important for high duty cycle operation.

- Mechanical tolerances for the RFQ resonant structure are determined by field perturbation appearing if the local resonant frequency is changed. This frequency variation depends on the changing of the inter-electrode capacitance and inductance of the resonant structure. The requirements for the accuracy of electrode positioning are determined mainly by beam dynamics considerations and they are the same for all types of resonant structures. The changing of inductance of a 4-vane structure is determined by variation of the cross-section of the quadrants. There are quite strong requirements on the cylindrical surface of the resonator and accuracy of positioning of the vanes on it.

  The inductance of a 4-ladder structure is determined mainly by stems and the requirements on resonator geometry are relaxed. The estimate of the resonant frequency by a semi-empirical formula shows, that the accuracy of electrode basement positioning is considerably lower then for the 4-vane resonator.

Some basic parameters of a 27 MHz RFQ resonator are given in Table. 1

Inner tank diameter	1500 mm
Diameter of the stems	80 mm
Height of the stems	680 mm
Distance between the stems	860 mm
Specific shunt-impedance	1.1 $M\Omega m$

Table 1: Some Basic Resonator Parameters

RFQ Design for the UNILAC

The main requirements for RFQ design are the following:

- Charge-to-mass ratio of ions corresponds to existing Wideröe part of the UNILAC (U^{+10} with possible change to U^{+8}).

- Normalized acceptance ≥ 1 mm·mrad, maximum capture of injected beam, transmission close to 100% with beam current up to 10 mA.

- The RFQ output beam parameters have to fit the transverse and longitudinal acceptance of the Wideröe section.

The chosen input energy of 1.878 keV/u is the lowest value suitable for the preinjector beam transport system. The voltage between adjacent electrodes and average distance between opposite electrodes have been chosen to obtain he required acceptance with the transverse phase advance of $\sigma_0 \approx 50^o$. The maximum field strength is quite low, it does not exceed 1.5 of the Kilpatrick criterion. The calculated parameters of the RFQ and some results of beam dynamics simulations are given in Table 2. The parameters are given for two different values of the RFQ output energies. The first energy corresponds to particle energy at the output of 14 accelerating gaps of tank 1. The second value assumes the complete replacement of tank 1.

Average radius	R_0	$8.0mm$
Voltage	U_l	$84kV$
Phase advance	σ_0	$0.837\ldots0.701$
Aperture	a	$8.0\ldots6.3mm$
Acceptance (norm, min)	V_k	$1.3mm\cdot mrad$
Input energy	W_{in}	$1.878keV/u$
Relative input velocity	β_{in}	0.002
Output energy	W_{out}	$66.2/217keV/u$
Cell number	N	206/287
Length	L	$4.73/13.73m$
Phase width at output	$\Delta\Phi$	$\pm20^0/\pm16^0$
Energy spread at output	$\frac{\Delta W}{W}$	$\pm3.2\%/\pm2.8\%$
Transmission at $\epsilon_{in}=0.5V_k$; $I_{in}=0$		100%
Transmission at $\epsilon_{in}=0.5V_k$; $I_{in}=10$ mA		$\geq 95\%$

Table 2: Main RFQ Parameters

With a safe shunt-impedance value of 800 $k\Omega m$, the rf power will be 45 kW for the short section, 125 kW for the 13.7 m section, beam loading is not included.

The particle dynamics in the RFQ section was tested by simulations using the codes PARMTEQ and PROTON (ITEP code for simulations of beam dynamics in different accelerating structures). In Fig. 2 the RFQ transmission in dependence on input current at an input emittance of $\epsilon_{in} = 0.5$ mm·mrad is shown.

Matching of RFQ's to Drift Tube Structures

Conventional transverse and longitudinal matching by magnetic lenses and separated rebunching cavities are costly and critical especially in case of high beam intensity. Therefore a direct coupling of the RFQ with the following drift tube structure has been studied.

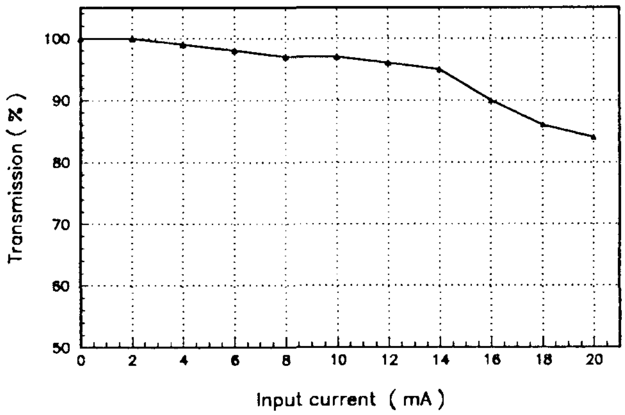

Figure 2: RFQ transmission in dependence on input current. $\epsilon_{in} = 0.5$ mm·mrad

Due to the different transverse focusing periodicity of both structures, the ratio of the beam radius has to be

$$(\frac{\rho_x}{\rho_y})_{Wid} \approx 1.7(\frac{\rho_x}{\rho_y})_{RFQ}$$

An asymmetric RFQ section has been proposed for this transverse matching. The mean aperture radius of the electrodes is different in both transverse planes. R_{ox} and R_{oy} increase within this RFQ section slowly in order to have adiabatical changing of the phase advance. The matching section consists of 46 cells at a length of 1.5 m, the mean aperture radius changes from 8 mm up to 12 mm for the x-plane, up to 9.9 mm for the y-plane.

For the longitudinal focusing, the modulation in each plane was calculated approximately to equalize the transit time factors T_x and T_y. More accurate calculations should be done with existing 3D-codes.

The results of the beam dynamics simulations are shown in Fig. 3. The beam envelopes of both transverse planes are plotted in the RFQ matching section and the first Wideröe tank starting at 66 keV/u. Even at a high beam intensity no losses occurred.

Conclusion

The proposed RFQ structure combines the advantages of the compact 4-vane structure and the 4-rod structure. The structure can be built in a wide range of frequencies. Thus a low frequency design for high intense heavy ion beams is feasible. As an example, a 27 MHz section for the UNILAC upgrading was designed. A 10 mA U^{10+} beam can be accelerated without loss, only moderate modifications of the Wideröe tank 1 are necessary. A special matching section between RFQ's and conventional drift tube linacs will be of importance for high intensity beams.

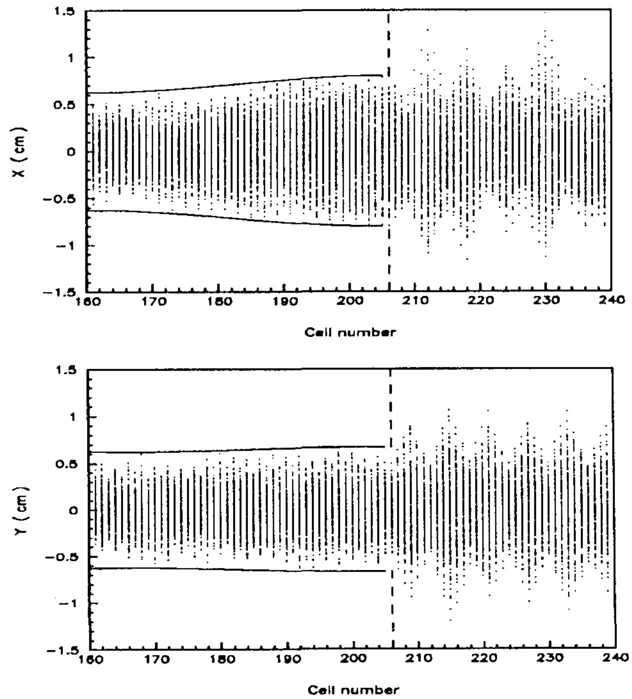

Figure 3: Particle distribution along the RFQ matching section and Wideröe Tank 1 for X and Y planes. $I_{in} = 10$ mA; $\epsilon_{in} = 0.50$ mm·mrad (norm).

Acknowledgement

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References

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