A LIGHT ION FOUR ROD RFQ INJECTOR*

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Abstract

The four-rod RFQ has been developed in Frankfurt as an alternative solution for ion injectors. A 202 MHz resonator has been built with design parameters taken from the HERA injector (18keV- 750keV, 20mA H^-). Properties of this structure will described and applications as light ion accelerator for particles from an EBIS ion source will be discussed.

Introduction

The concept of spatial homogeneous focusing[1] has closed the low velocity gap of high frequency ion accelerators. The work has ignited numerous activities starting with the thoroughly work in Los Alamos[2]. While firstly the aim was improving high energy proton acceleratos, possible applications for heavier ions were seen very early and research started early too[3-6].

For protons and light ions the 4-vane RFQ is the structure mostly used: frequencies as low as 80-100 MHz, as chosen in FMIT[7] and TALL[10], seem to be the lower limit, however. For low charged heavy ions a frequency of 10 - 30 MHz must be chosen, which results in a too large diameter for the 4-vane resonator. Therefore at GSI, a split coaxial heavy ion RFQ is being built, in Frankfurt the four-rod RFQ structure has been developed for low frequency applications[4,11,12].

Criteria for RFQ structures are firstly to provide beam dynamics requirements like sufficient acceptance, current limits, small emittance growth, possibly high fields and small unwanted multipole components. The rf structure must supply the quadrupole voltage on the electrodes. The efficiency, described by the shuntimpedance R_P, is as important as a high group velocity that means strong coupling and good tolerances. This results in a flat field distribution without dipole components like assumed in the beam dynamic designs.

Like the shuntimpedance the tolerances are going directly into costs of the system. Simplicity and reliability mostly come together and are most important criteria for RFQs. A basic problem of the 4-vane structure is the high symmetry necessary to avoid dipole components of the axial fields. The split coaxial as well as the four-rod RFQ don't have the symmetry problems. Precision is only determined by beam dynamics requirements. So these structures are simplier and therefore cheaper.

Four rod RFQ

The 4-rod RFQ applies cylindrical rods with conical varying diameter as electrodes. The influence of higher field harmonics on beam properties has been investigated thoroughly [13] and is proven to be negligible as long as the full aperture is not used.

The resonators basic cell consists of two oscillators excited in the transversal π-mode to give the proper quadrupole field distribution between the electrodes. The accelerating structure consists of a chain of these cells operating in longitudinal 0-mode. Fig. 1 shows two cells of a linear version of this structrue. Optimizing this structure with respect to shuntimpedance results in an equidistant arrangement of the stems[12]. The impedance R_P of the four-rod RFQ is astonishingly high also for high frequencies. Several prototypes (108MHz, 18MHz)[11] have been built and operated. A four-rod RFQ for light ions has been designed and built to prove the attractive properties of the four rod RFQ. We took the HERA-RFQ[16] beam dynamic parameters allowing a good comparison of the structures characteristics and beam properties.[15]

Table I shows general parameters. The rf-structure consists of a massive water cooled ground bar with fourteen specially shaped stems to carry the electrodes. The copper plated vacuum tank has a steel base plate with fourteen bores to mount the rf-resonator and provide water cooling. Fig 2 shows a crossection of the resonator. The electrodes were made taking the HERA-RFQ data and approximating the sinusoidal shape by trapezoidal segments. Using abbreviations from fig.3 modulation and aperture values were tranformed into diameters of rod electrodes as follows:

$$r_1(N) = r_0 - (m(n)-a(n)) \qquad s_1 = (\beta(n)\lambda\,(1-2/\pi))/4$$
$$r_2(N) = r_0 - (a(n) + (a(n+1))/2 \qquad s_2 = \beta(n+1)\,\lambda/\pi$$
$$r_3^*(N) = (r_3(N) + r_1(N+1))/2 \qquad s_3 = s_1 + (\beta(n+1)\lambda(1-2/\pi))/4$$
$$\alpha = \mathrm{arctg}\,(a*(m(n)-1)/s_2) \qquad s_4 = \beta(n+1)\,\lambda/\pi$$
$$\gamma = \mathrm{arctg}\,(a*(m(n+1)-1)/s_4) \qquad s_5 = s_3 - s_1$$

The electrodes have been made on a lathe and brazed to the resonator. Fig.4 shows a view of the resonator and fig.5 a view of an electrode segment with full modulation. Tuning of the RFQ has been done with shorting plates in two cells at each end. Conditioning with rf up to 25 kW (5% dc) has been done in Frankfurt. High power operation (up to 150kW, $3x10^{-4}$dc) with beam has been done at DESY.

Beam experiments

As envisaged at the start of the project a beam test has been done at DESY. After the transport to Hamburg in November 86 we installed the RFQ at the HERA injector beam line. Fig.6 shows the experimental set up. After carefully conditioning the four-rod RFQ for two weeks to get rf-power levels up to 80kw we had a first beam through the RFQ in early December. Starting with an injected beam of 40 mA we increased the rf-power up to 70kW and analysed a partly accelerated beam of 20mA. Fig.7 demonstrates the acceleration effects for different rf-powers resp. electrode voltages of the RFQ. For the determination of the impedance a beam of only 0.2mA has been used. The minimum power to accelerate ions to 750 keV was 60kW corresponding to a elektrode voltage of 61kV resulting in an impedance of the RFQ of RP=62 kΩ. This value is appr. 10% higher than for the 4-vane RFQ [16]. The maximum value of

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the accelerated current has been 35 mA, due to beam loading the rf-power had to be increased to appr. 105kW.
In a next step the microstructure of the accelerated beam pulse was analysed with a fast faraday cup. Fig. 8 shows the bunch structure for two values of the rf power. The bunchlength of approx. 1.0 nsec (FWHM) corresponds to the synchronous phase angle $\varphi = 30°$. Than the faraday cup has been replaced by a diagnostic box with a two plane emittance measurement device with a distance of 15cm between RFQ exit and the slit (slit - grid 5cm). In fig.9 emittace ellipses are shown for both x- and y plane for 80kW rf power and 20mA beam pulses. Fig. 10 shows the measured emittances as function of the rf-power level for an injected current of 25mA. The asymmetry in both planes is still the same as it was measured at the entrance of the RFQ. Due to problems with secondary electrons reliable measurements were only possible for power levels up to 90KW. This correspondes to 90% of the design voltage for this beam loading. Extrapolating to the design voltage of appr. 100kW and taken a emittance growth of 50% into account which has been calculated for this design [14] the emmittance of 1.6 and 2.3 mm mrad are in good agreement with the predicted values.

The tests of the four rod RFQ have been a great success. The results are close to the theoretical predictions. Even the time for measurement had been very short we were able to accelerate mor beam than the design value with proper longitudinal and radial emittance. Normally these values could be improved by fine tuning of the input matching, realignment and optimizing the emittance. The RFQ structure itself worked without problems.
The Four-rod RFQ is equivalent to the 4-vane RFQ but much cheaper.

Applications

The "HERA"-Four-rod-RFQ is a prototype for light ion accelerators. It could be used directly by increasing the electrode voltage U_a to 140kV and using fully ionized ions up to Neon from an EBIS source[17]. Exchanging the electrodes, specific charges e/m=.25 could be accelerated to 400keV/amu (U_a= 70kV) as an example. More flexibilty can be achieved with lower frequencies. With 108MHz specific charges down to e/m=.1 could be accelerated efficiently.
We work on a RFQ accelerator for the CRYRING project in Stockholm[8] where ions from an EBIS are accelerated to 300keV/amu and injected into a storage ring. The RFQ will have following parameters: Length 2.10 m, electrode voltage 70kV, aperture 3.mm. Ti 10.keV/amu. With an additional debuncher the energy spread will be as low as .15% while the transmission is still 90%.
The four-rod structure is favourably used there because of the efficient acceleration and the good vacuum properties needed for CRYRING and because of the relatively easy manufacturing and good operational stability.

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Table 1

Four-Rod-RFQ Design Parameters

RF frequency	202.560 MHz
energy	18 - 750 KeV
aperture radius	5.0 - 3.5 mm
RF voltage	70.5 KV
nom. current	20 mA
energy width	± 11 KeV
normalized emittance	<1πmm mrad
duty factor	2.5 10
Length	118 cm
number of stems	14

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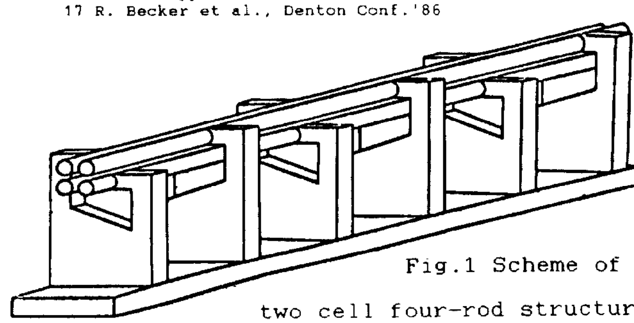

Fig.1 Scheme of a two cell four-rod structure

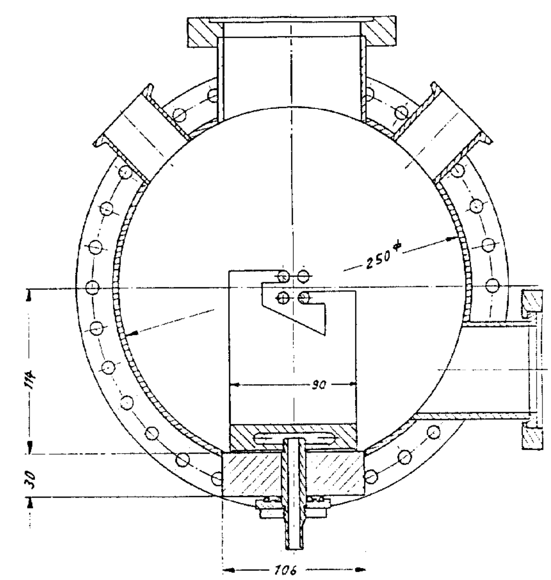

Fig.2 Cross-section of the four-rod resonator

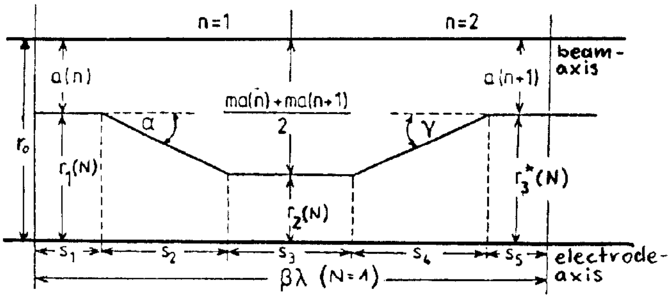

Fig.3 Parameters of the trapezoidal rod modulation

Fig.4 View of the HERA Four-rod RFQ

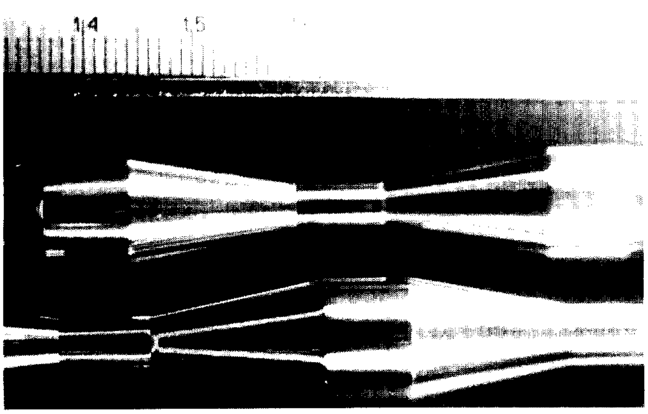

Fig.5 Four-rod electrodes

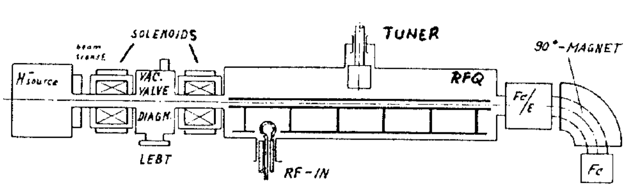

Fig.6 Experimental set up at DESY

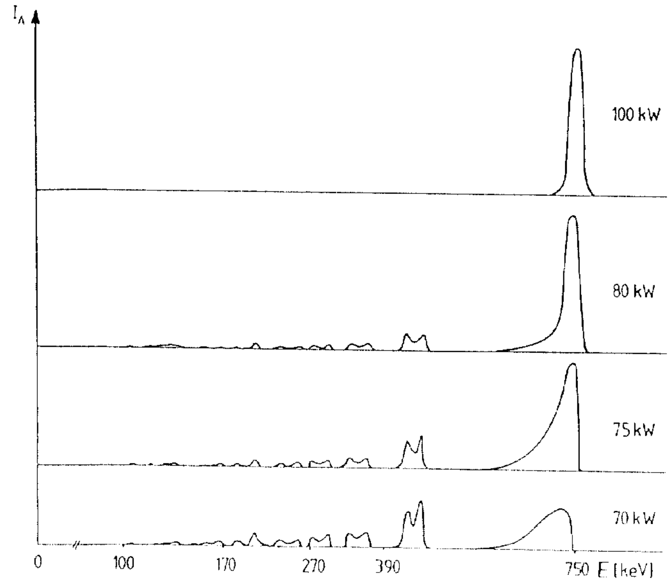

Fig.7 Energy specta for different rf powers

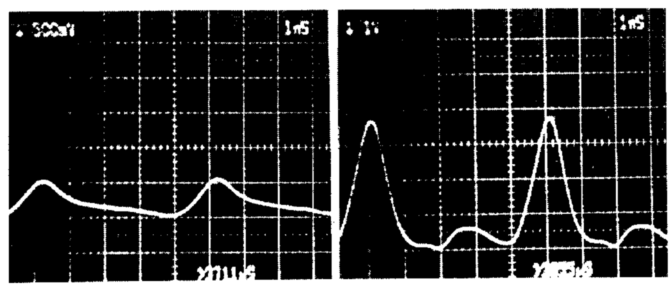

Fig.8 Bunch structure (70 and 100 KW RF power)

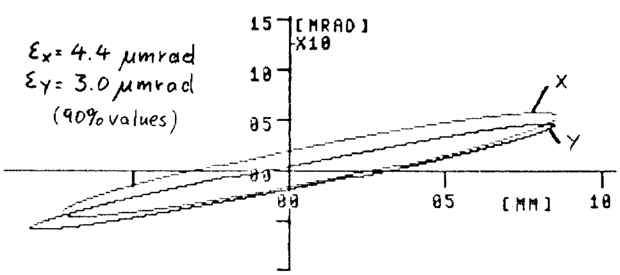

Fig.9 Emittances in x- and y-plane (80KW,25mA)

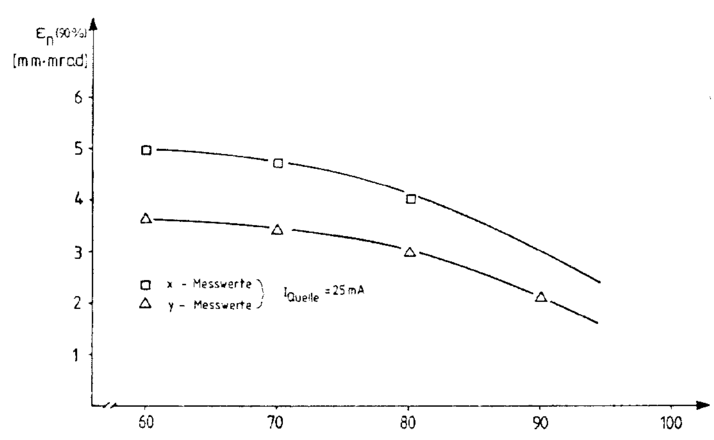

Fig.10 Measured beam emittances vs. rf power