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PARMTEQ CALCULATIONS ON BEAM DYNAMICS IN A FREQUENCY VARIABLE RFQ*

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Abstract

An RFQ is built for postacceleration of clusters at the accelerator facility of IPN, Lyon. The frequency of the RFQ is between 80 and 110 MHz, which allows the acceleration of clusters in a wide range of masses and energies. Beam dynamics calculations are presented and their results are discussed for a few specific examples.

Introduction

During the last years the use of variable energy Radio Frequency Quadrupole (RFQ) accelerators has been proposed for various applications in ion implantation, postacceleration of light and heavy ions or clusters[1,2,3,4]. One project near completion is the upgrading of the Lyon cluster accelerator facility, which is carried out in cooperation between IPN, Lyon, KFK Karlsruhe and IAP Frankfurt/Main[5]. An energy variable RFQ serves for postacceleration of clusters with masses up to 55 to a maximum energy of 3 MeV, thus offering new possibilities for studies in cluster physics. Here a more detailed description of the beam dynamics properties of such an RFQ is given, whereas design criteria and the status of the project will be discussed elsewhere on this conference[6].

RFQ Beam Dynamics

The RFQ accelerator is a structure, which provides both acceleration and strong rf electrical focussing at the same time. From the RFQ potential linear equations of motion can be derived mostly for the case of ideal electrode profile[7,8]. A scheme of this profile is shown in fig. 1. These equations of motion

$$\frac{d^2 {x \atop y}}{d\tau^2} + (a \pm 2q\cos\tau){x \atop y} = 0$$

$$\frac{d^2 u}{d\tau^2} - 2au = 0, \quad \tau = \frac{1}{2}(\omega t - \varphi_s) \qquad (1)$$

are of Mathieu type, the coefficients given by

$$a = -\frac{\xi e V A_{10}\sin\varphi_s}{2Amv^2}, \quad q = \frac{2\xi e V A_{01}}{Amv^2k^2r^2} \qquad (2)$$

with ξ/A = charge to mass ratio, v = particle velocity, k = wave number, r = apertureradius and the RFQ parameters describing acceleration and focusing respectively.

$$A_{10} = \frac{M^2-1}{M^2 I_0(kr) + I_0(kr)}, \quad A_{01} = 1 - A_{10}I_0(kr) \qquad (3)$$

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For each kr the modulation M determines the ratio of acceleration to transverse focusing. Using smooth approximation as e.g. in [9] analytical expressions for longitudinal and transverse phase advances σ_{0l} and σ_{0t} resp., emittances and current limits, characteristic quantities in beam dynamics theory can be deduced:

$$\sigma_{0l}^2/\pi^2 = -2a$$

$$\sigma_{0t}^2/\pi^2 = q^2/2 + a \qquad (4)$$

$$\varepsilon = \bar{r}^2\sigma/\pi$$

RFQ design means to fix all these parameters along the RFQ, good beam quality being only one point of consideration besides rf properties, costs, power consumption, adjustment and fabrication tolerances. For a fixed design all parameters and mechanical dimensions are frozen, then (2), (3) and (4) give immediately the scaling rules for an energy variable RFQ

1.) $Amv^2 = \text{const} \;\; \rightarrow \;\; Am \sim v^{-2} \sim f^{-2}$
2.) $Am = \text{const} \;\; \rightarrow \;\; v^2 \sim f^2 \sim V$

In both cases the beam dynamics stays completely unchanged the values of (4) are not changed, i.e. the unnormalized acceptances, emittances and the transmission do not change with energy or cluster species. In case 2.) the electrode voltage can be varied in addition, but then (2), (3) and (4) are no longer constant.

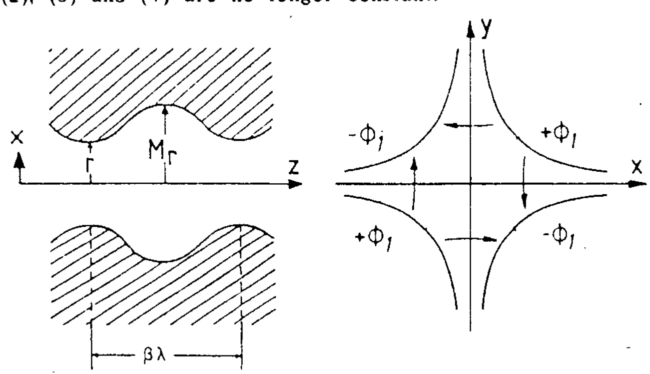
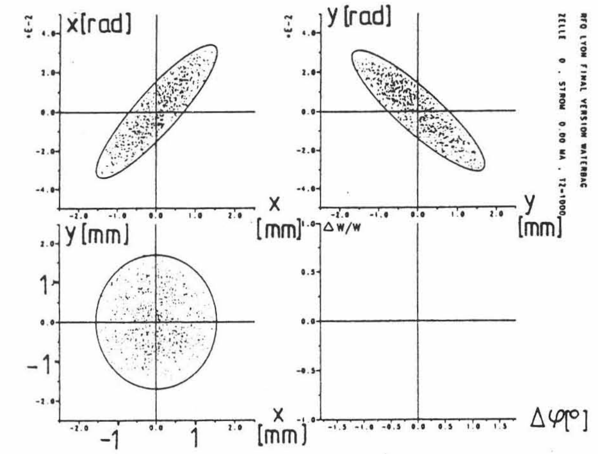


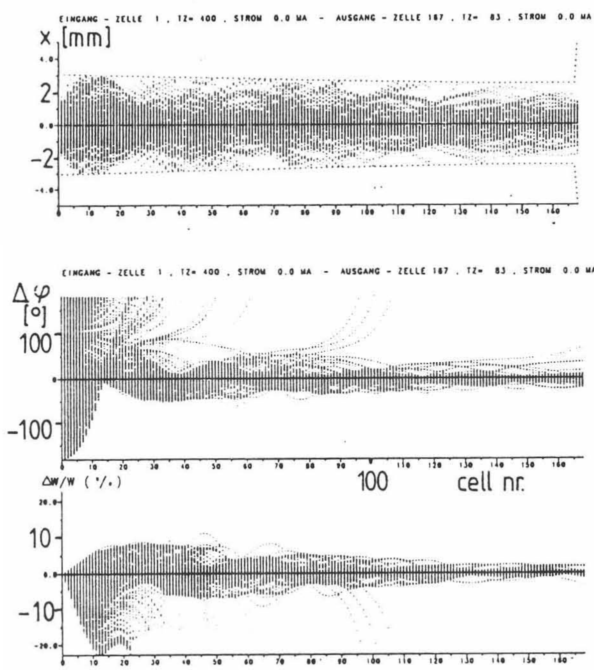
Fig. 1 Scheme of ideal RFQ electrode profile

VE-RFQ Parameters

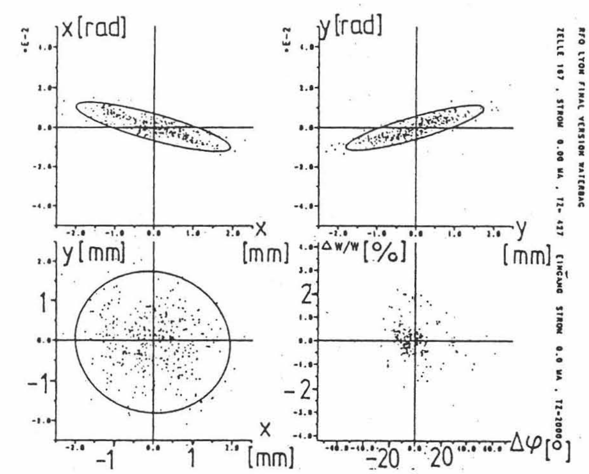
The Lyon cluster postaccelerator RFQ was designed for high energy gain and compact dimensions. Table I summarizes main parameters, some of them being plotted in fig. 2. Maximum electrode voltage is 80kV, a shaper was omitted. Fig. 3 gives the range of masses and energies covered by the RFQ.



ig. 4 a) Input emittance, ε^{tr} = 25 mm mrad



b) Transverse and longitudinal beam behaviour



c) Corresponding output emittances

f = 110 MHz, A = 30, T_{in} = 300 keV, U = 80 kV

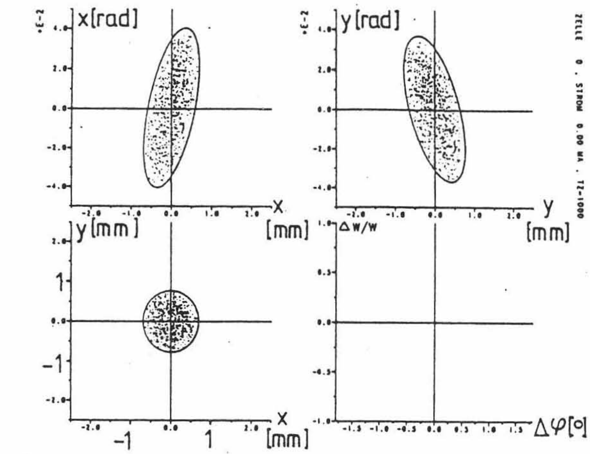
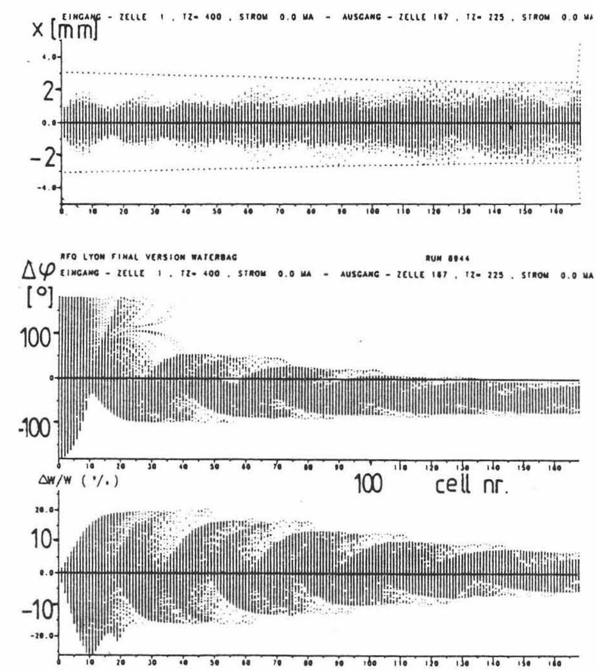
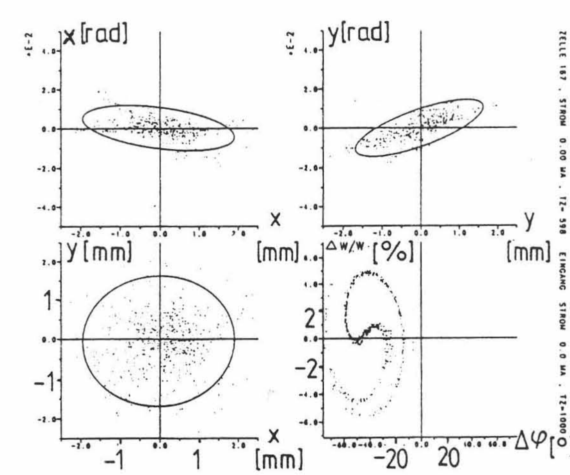


Fig. 6 a) Input emittance, ε^{tr} = 25 mm mrad



b) Transverse and longitudinal beam behaviour



c) Corresponding output emittances

f = 80 MHz, A = 30, T_{in} = 160 keV, U = 80 kV

Table I RFQ parameters

f [MHz]	80 - 110
U [kV]	80
T_{in} [keV]	≤ 300
T_{out} [keV]	≤ 3000
charge state/mass	≥ 1/56
l [m]	1,96
cell number	167
modulation	1.1 - 2
φ_s [°]	50 - 15.5
a [mm]	3.1 - 2.5
σ_{ot}^{min} [°]	8.2 - 7.2

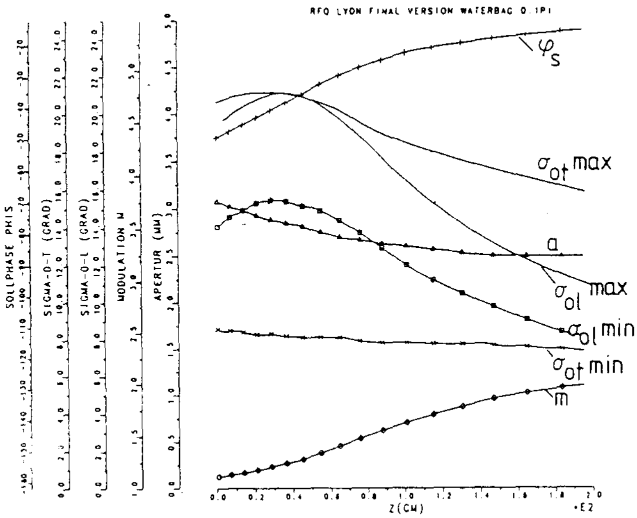


Fig. 2 VE-RFQ parameters vs. length

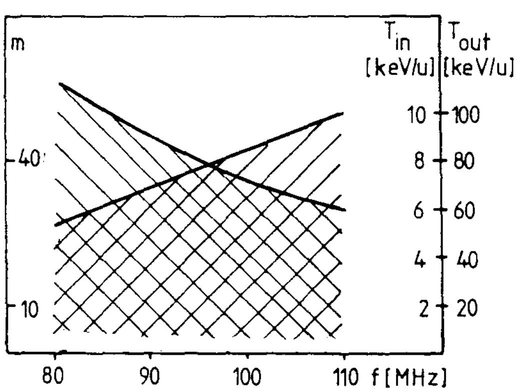


Fig. 3 Range of cluster masses and energies

Results of PARMTEQ Calculations

From (4) follows that for the heaviest particle at the highest frequency and velocioty phase advances are at minimum. Here mass 30 at 110 MHz and 10 keV/N input energy and all other masses scaled corresponding to rules 1) and 2) gives a transverse phase advance of ~7.5° and a synchronous acceptance of 52 mm·mrad (not norm.).

For an injected dc beam with this transverse emittance the transmission is ~ 17 % due to the omitted shaper and the rather low focusing strength. Emittance growth is about 25 %, the longitudinal output emittance is very small with < 2° keV/u (rms). The transmission is increasing to ~ 22 % for 25 mm mrad, figs. 4 a-c show input and output emittances and the beam behaviour along the RFQ. Fig. 5 illustrates for mass 30 the gain in focusing and transmission as function of electrode voltage for a lower frequency of 80 MHz, corresponding to an input energy of 160 keV. Figs. 6 a-c show input and output emittances for mass 30, U = 80 kV and f = 80MHz and the transverse and longitudinal beam behaviour.

As can be seen, particles are changing the synchronous phase along the RFQ, some additional emittance growth up to an factor of 2 seems to follow from this effect. The transverse input ellipse parameters were adjusted to maximum transmission, some flexible transverse matching should be provided[10].

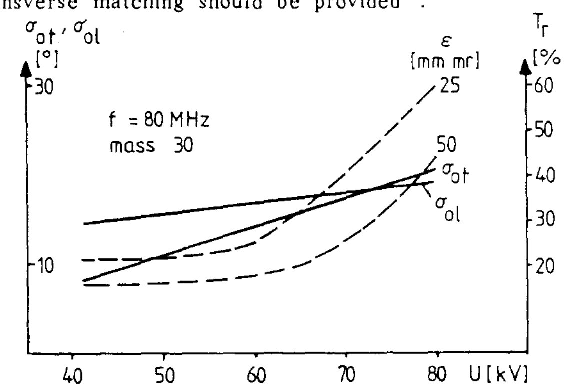


Fig. 5 Phase advances and transmission vs. electrode voltage, parameter transverse emittance ε,

Conclusion

An effective postaccelerator for cluster masses up to 56 has been designed and built, providing a high energy gain. PARMTEQ calculations proved scaling rules from linearized equations of motion. Work on optimization of beam optics and overall transmission from cluster source to the experimental area is in progress[11].

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