Development of a Variable Energy RFQ for Cluster Acceleration*

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Abstract

An RFQ has been designed and built as a postaccelerator for the cluster accelerator facility at the IPN, Lyon. The 4-Rod RFQ resonator is designed for variable energy by means of a variable frequency of the resonator between 80-110 MHz. The properties of the RFQ for the typical cluster mass ranges of up to 50u are discussed and the status of the project is reported.

I. Introduction

At the IPN, Lyon, a cluster ion source in combination with an electrostatic Cockroft-Walton accelerator is used for various experimental studies concerning the inner structure of clusters or the interaction of clusters with matter [1,2]. Up to now the maximum cluster energy is limited by the highest operational voltage of the Cockroft-Walton, which is 500 kV. Higher cluster velocities would increase the resolution of the measurements and widen the field of research: the comparison of effects from cluster and heavy ion impact on solids or the physics of clusters of molecules could be studied e.g.. Therefore an upgrading program of the facility was started in collaboration between IPN (Lyon), KfK (Karlsruhe) and IAP (Frankfurt) [3,4], which includes an RFQ post-accelerator and new beam lines. The RFQ accelerates clusters up to a mass of ~ 50u to energies as high as 100 keV/u and provides at the same time a sufficient transverse focusing, which is lacking in normal rf accelerators at low ion velocities. Fig. 1 shows a schematic layout of the new cluster facility.

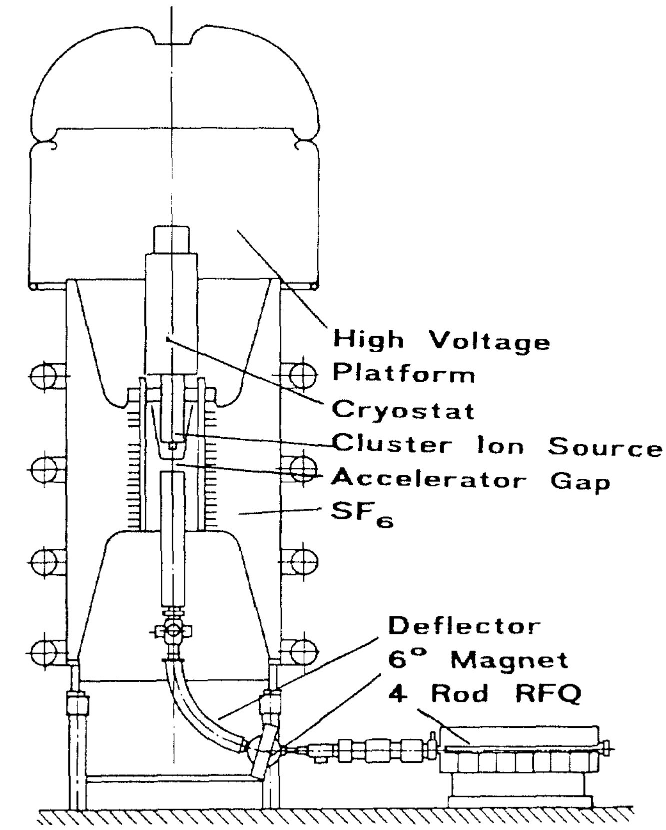

Fig. 1 : Schematic layout of the new cluster facility

II. The VE-RFQ Structure

RFQs are accelerator structures [5,6], which use electrical rf-quadrupole fields, generated by one set of electrodes, both for focusing and acceleration. But a fixed frequency accelerator is only capable to accept particles with one initial energy per nucleon and to accelerate them to one final energy per nucleon, because the velocity profile is also fixed. This can be changed by varying the cell length L_i or, as it is used in postaccelerator structures, by splitting up the structure into several individually phased units. Another way to fulfil the Wideroe resonance condition, $L_i=\beta_p\lambda_0/2=v_p/2f$, is to change the frequency f of the accelerator. Then a variation of the particle velocity v_p is possible, using the same fixed velocity profile of the electrodes : $v_p \sim f$.

The 4-Rod RFQ structure [7,8], developed in Frankfurt, has been modified such, that the frequency can be changed by a variation of the effective length of the stems and the corresponding inductivity with a movable tuning plate. Fig. 2 shows a schematic drawing of the structure.

The design of the VE-RFQ has to be made for the highest particle energy [9]. Both the input energy per nucleon E_{in} and output energy per nucleon E_{out} change with the frequency f : $E_{in},E_{out} \sim f^2$.

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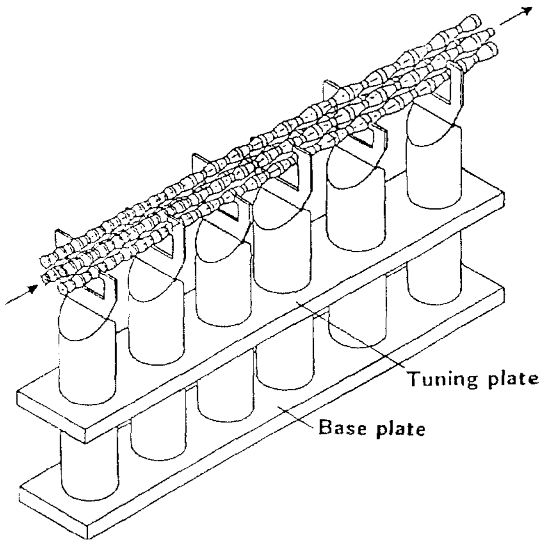

Fig. 2 : Scheme of the variable frequency 4-Rod RFQ

Consequently at a lower frequency it is possible to accelerate the same particle from a lower total input energy T_{in} with less electrode voltage U_Q : m=const $\rightarrow$ $U_Q \sim f^2$. Keeping the electrode voltage U_Q constant, heavier particles with the same input energy T_{in} can be accelerated at lower frequencies to the same total final energy T_{out} : U_Q=const $\rightarrow$ $m \sim 1/f^2$.

In table 1 the main parameters of the RFQ are summarized. For a short and compact structure the frequency should be chosen as high as possible, due to the low cluster masses < 50u and the preaccelerator voltage of 500 kV the highest operating frequency can be 110 MHz in this case. The total length is less than 2 m, the cluster energy is increased by a factor of 10. At a maximum electrode voltage of 80 kV the rf input power is less than 55 kW for 110 MHz. The designed tuning range in frequency from 80-110 MHz corresponds to a change in input and output energy by a factor of two resp., which is quite high. In addition a particle dynamics design had to be made for good beam quality taking into account the conditions mentioned before.

III. Beam Dynamics Calculations

The main design features for the RFQ have been a high acceleration rate for maximum energy gain, a short and compact structure and a low power consumption. At the input the electrode design started immediately with a modulation and a synchronous phase of 50°, the shaper part was omitted. Due to the high acceleration gradient the transverse focussing was lowered, both giving a transmission of 25% for the heaviest clusters at the highest frequency. For lower frequencies and masses the transmission is increasing to more than 70 %. The longitudinal output emittances are rather small, fig. 3 shows an example of calculated phase and energy spectra. The total phase width is about 40°, the total energy spread smaller than ~4% for the full beam [10].

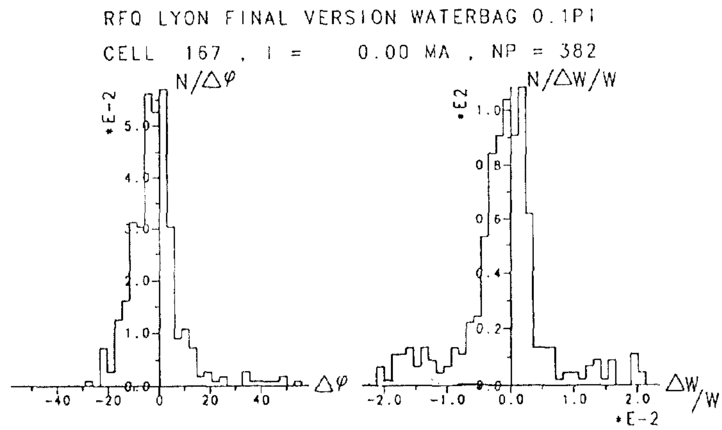

Fig. 3 : Phase and relative energy spectrum at RFQ output, mass 30, T_{out}=3 MeV, f=110 MHz

Recent work has been done on the transport of clusters through this RFQ: For masses < 10u the energy from the Cockroft-Walton is already as high as or even higher than the output energy of the RFQ. Therefore light clusters should only be transported to the target through the RFQ without loosing beam quality. The results of PARMTEQ calculations show, that this transport is possible, as long as the energy of the clusters is higher than the output or lower than the input energy of the RFQ [11]. Fig. 4 illustrates the different regions of transport and/or acceleration.

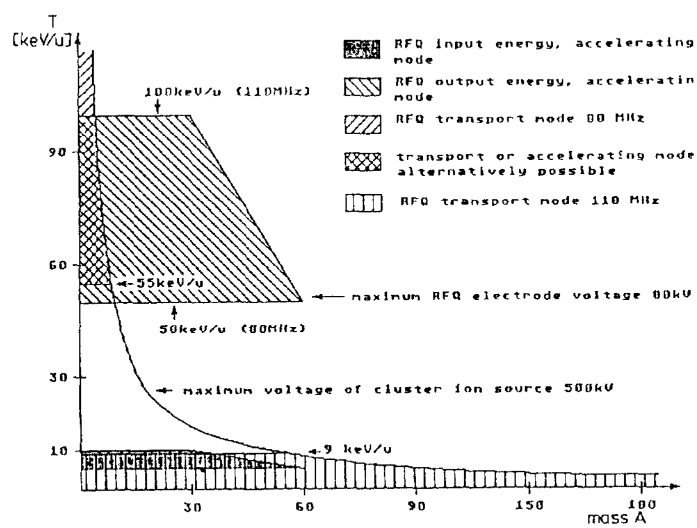

Fig. 4 : Regions of transport and/or acceleration through a modulated RFQ

The transverse beam behaviour for cluster mass 5, energy 500 keV, f=80 MHz is shown in fig. 5. At a normalized emittance of 0.1 π·mm·mrad the transmission is 95% for an electrode voltage of 6 kV only, the emittance growth being 10%. For larger input emittances the voltage can be raised. By proper adjustment of the voltage beam waists with minimum emittance growth can always be reached at the RFQ output. Depending on the voltage applied a small energy spread is introduced into the cluster beam.

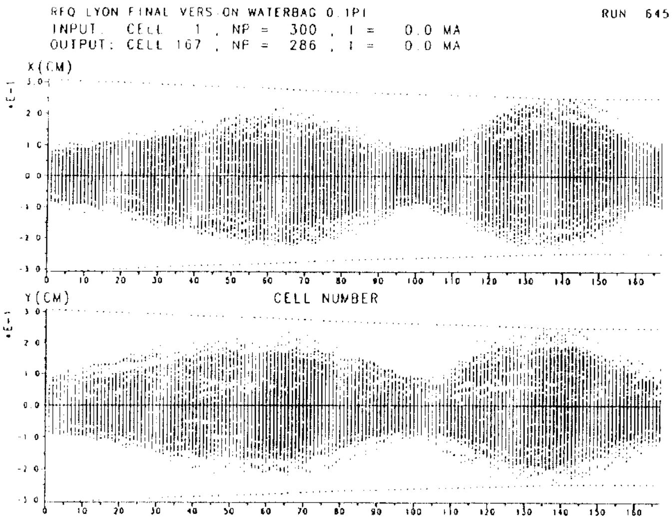

Fig. 5 : Transport of mass 5 at 500 keV through the RFQ, U_Q=6 kV, f=80 MHz

IV. First Experimental Results

First rf measurements on the completed RFQ have been carried out since the beginning of 1991. In fig. 6 the frequency is plotted as a function of the distance between the tuning plate and the base plate. The frequency range is shifted to higher values due to changes of the electrode geometry.

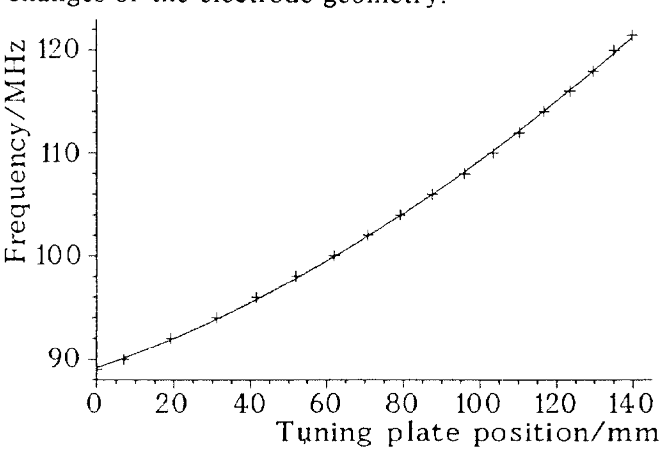

Fig. 6 : Tuning range of the resonator

The Q-value of the resonator and the Rp-value, which is a measure of the structure efficiency depend on resonator inductivity and are changed corresponding to the frequency. In fig. 7 the measured dependence of both parameters are plotted versus frequency. The curves are in good agreement with the theoretical values [4].

In first high-power tests an input power of 50 kW could be reached for a frequency of 90 MHz and a duty cycle of 1%, which is higher than required by the cluster source. First beam tests are scheduled for June.

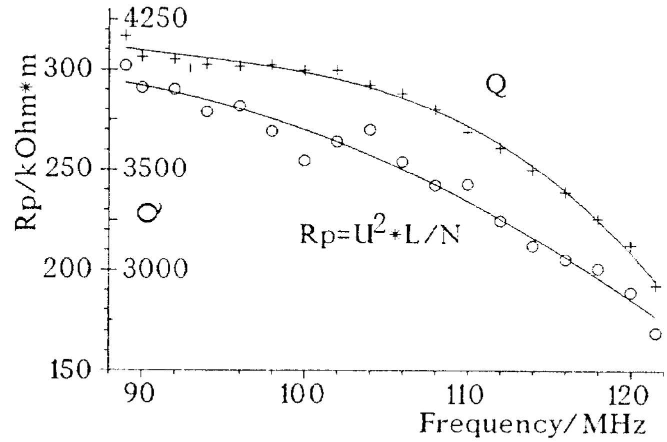

Fig. 7 : Measured Q- and Rp-values versus frequency

Table 1
RFQ parameters

Max. initial/final energy [keV/u]	10/100
Min. initial/final energy [keV/u]	5/50
Number of cells/modulation	167/1.1-1.98
Aperture [mm]	3.1-2.5
Transmission [%]	25-70
Transverse phase advance [°]	8.2-7.2
Synchronous phase [°]	50-15.5
Long. final emittances(95%)[keVnsec]	20-60
Max. electrode voltage [kV]	80
Frequency [MHz]	80-110
Length/diameter of structure [m]	2.0/0.5
Rp-value [kΩ·m]	180-300
Q-value	3000-4100

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