PROPERTIES OF A 0-MODE RFQ STRUCTURE AND RECENT EXPERIMENTAL RESULTS*

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Summary

For low frequency operation of RFQ linacs a new rf scheme has been developed. The linac consists of a chain of resonators, electrically excited in the 0-mode, the fields being generated by four modulated rods. The construction allows direct cooling of the electrodes and therefore cw operation.
RF properties like R_p values, resonant frequencies, field distributions for systems with 4 and with 12 electrodes are presented.
With a coaxial $\lambda/4$ resonator sparking tests have been done at different pulse lengths and duty cycles.
Finally the status of our RFQ proton model, which uses the split coaxial structure as resonant cavity, is reported.

$\lambda/2$ RFQ Structure

The RFQ structure, which has been developed in Los Alamos, is very well suited for various applications like Pigmi, FMIT, proton injectors into synchrotrons and ion accelerators[1]. This design using the four chamber H-cavities is especially favourable for all cases, in which relatively high frequencies can be used. For the acceleration of heavy ions the corresponding RFQ structure must be run at low frequencies. Such a low frequency RFQ resonator is the coupled $\lambda/2$ structure[2,3,4], which has the advantage of small dimensions, simple construction, good rf properties with high duty cycle. Each pair of quadrupole electrodes consists of two copper rods connected to two radial stems forming a $\lambda/2$ oscillator. A front view of such a structure is shown in fig. 1. Two such resonators ar-

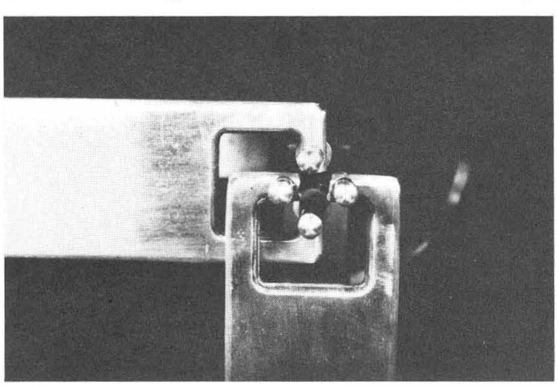

Fig. 1 Front view of the RFQ $\lambda/2$ structure

ranged at an angle of 90° and excited in π-mode produce the RFQ field. For the electrodes a design using circular rods with conical cylinders has been developed[4], which offers a relatively simple machining. Effective cooling, especially necessary for higher duty cycles, is maintained by direct water flow in the electrodes made of copper tubes. By axially adding an additional resonator the length of the RFQ structure can be increased stepwise. The accelerating mode is the $\pi 0$-mode, in which the second index indicates that the electrodes have the same phase along the structure.
Low field level measurements have been done to investigate the properties of these coupled resonators. One feature is the surprisingly good flatness of the axial fields.

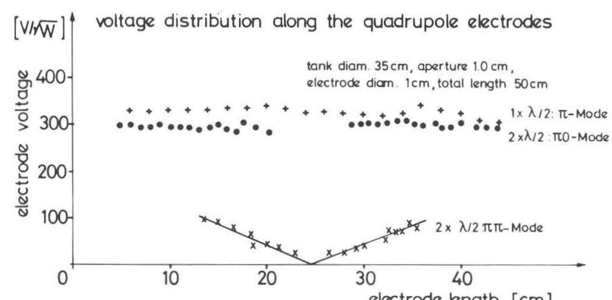

Fig. 2

Fig. 2 shows the voltage distribution along the electrodes for a single $\lambda/2$ and $2\lambda/2$ resonator in the π- respectively in the $\pi 0$-mode. While the $\pi\pi$-mode shows the expected linear dependence on the distance from the middle stem, for both other modes a nearly flat distribution could be measured. Measurements have been done by bead perturbation method using a drift tube arrangement displacable on the electrodes[5]. This well known method can be applied despite strongly varying fields in a narrow electrode system.
The R_p value, which is defined as the square of the electrode voltage divided by the rf power, was determined as a function of the electrode length (fig. 3). Although the Q value is only about 2000, the efficiency is very good. The resonator of our proton linac

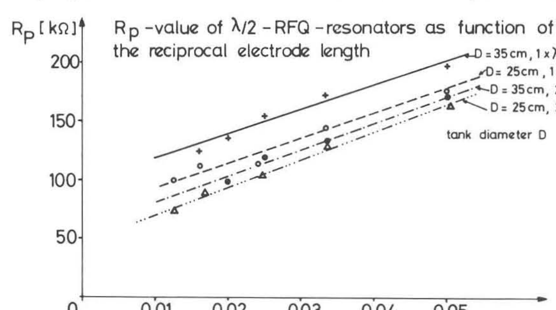

Fig. 3

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e.g.[4] has a R_p value of 75 kΩ, the design value of 25 kV electrode voltage can be achieved with only 10 kW. The low Q value facilitates rf control and cooling problems.

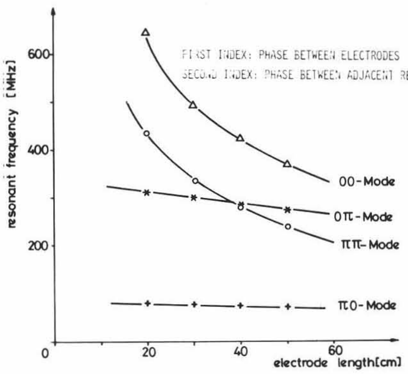


Fig. 4 Resonance frequencies of 2λ/2 quadrupole resonators as function of the electrode length

Fig. 4 shows the resonance frequencies for two coupled λ/2 RFQ resonators as function of electrode length. The lowest frequency always belongs to the π0-mode. The eigenfrequencies of the ππ-mode, for which the voltage has a node in the middle of the structure (s. fig. 2, lower curve), and the 0π- and 00-mode, for which the four electrodes have the same potential[4], are more than 100 MHz higher. This mode separation indicates the large tolerances with respect to rf properties. The length of both coupled resonators can be varied as much as 20 % without a significant change in field distribution.
Several λ/2 RFQ high power resonators have been built and operated successfully up to 72 kW corresponding to voltages between the electrodes of up to 97 kV (duty cycle 1-25%).
For lower frequencies a RFQ resonator using the λ/2 principle has also been built, consisting of twelve unmodulated rods (length 1100 mm, diameter 13 mm) forming an array of 5 independent RFQ channels (fig. 5). With

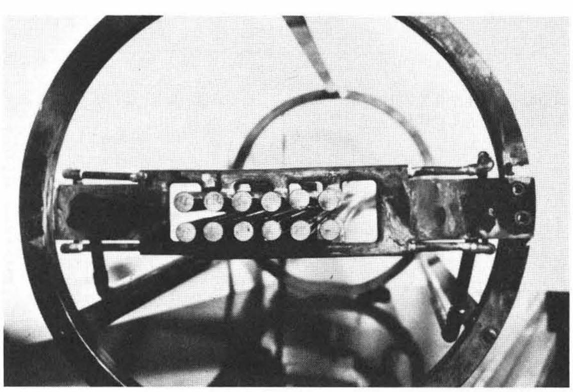


Fig. 5 Front view of twelve electrode RFQ

this high capacitive load a resonance frequency of 28 MHz was measured (tank diameter 35 cm, length 130 cm). The R_p value is 30 kΩ, Q value Q_0 = 1000. For an electrode voltage of 50 kV an rf power of 84 kW is needed. In spite of very long electrodes the voltage is almost constant being only 3 % greater in the middle of the resonator than near the radial stems. This array allows simultaneous acceleration of several beams, which might be important for the first part of a fusion accelerator; furthermore the funneling may be easier.
Similar principles of funneling are discussed at Los Alamos[6].

Sparking Experiments

As discussed in [3], the design and the capabilities of RFQ structures depend strongly on the maximum achievable field strengths. Therefore our sparking experiments have been continued. With the λ/4 coaxial resonator (R_p = 610 kΩ, gap width 1 cm, 108 MHz) voltages up to 350 kV can be produced. Fig. 6

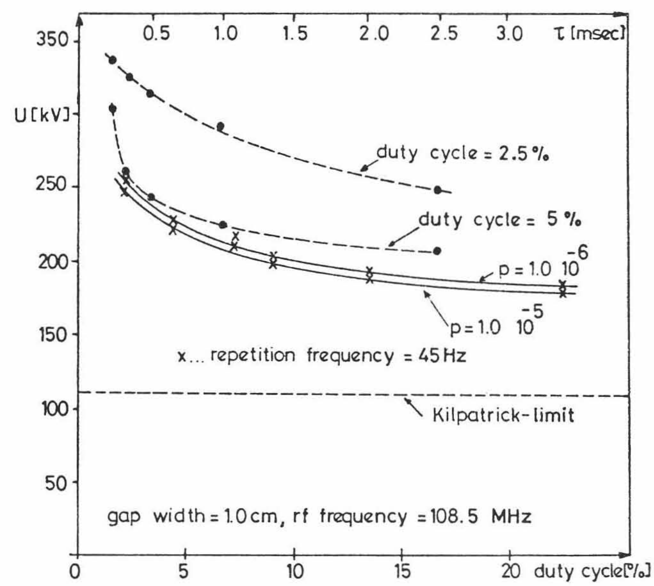


Fig. 6 Breakdown voltage as a function of duty cycle and pulse length

shows the breakdown voltage as a function of the duty cycle at two pressures and a constant pulse frequency of 45 Hz. A pressure

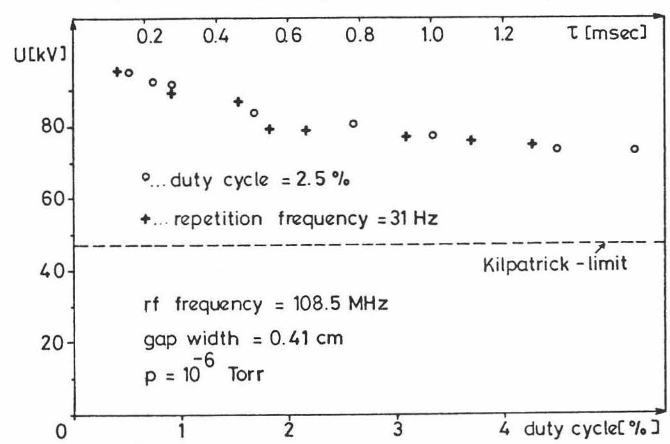


Fig. 7 Breakdown voltage for λ/2 RFQ

variation by a factor of 10 shows only a little effect . For a duty cycle of more than 5 % the breakdown voltage stays nearly constant. Varying the pulse width at constant duty cycles the steep increase in breakdown voltages for pulse widths smaller than 0.3 msec should be remarked. The measured values are by a factor of 2 to 3 higher than the Kilpatrick limit[7]. Experiments with a $\lambda/2$ RFQ at 108 MHz have been made. Results of sparking tests are shown in fig. 7. The maximum voltage between the electrodes has been 97 kV corresponding to a surface field of 26.2 MV/m.

Status of the Proton Model

At the 81 Washington conference we have presented the general properties of the split coaxial RFQ structure and the layout of the proton model[8]. In the meantime several im-

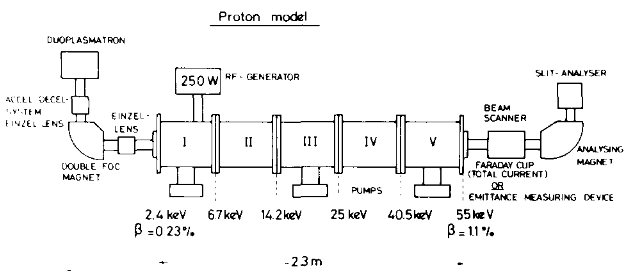


Fig. 8

provements have been made on the proton model: major parts of the injection system were modified, RFQ sections 2 and 3 were added and are running satisfactorily. The beam current was increased from 10 nA to 5 μA behind the third section. The measured (normalized) emittances behind sections 2 and 3 range from 0.1 to 0.4 mm mrad.

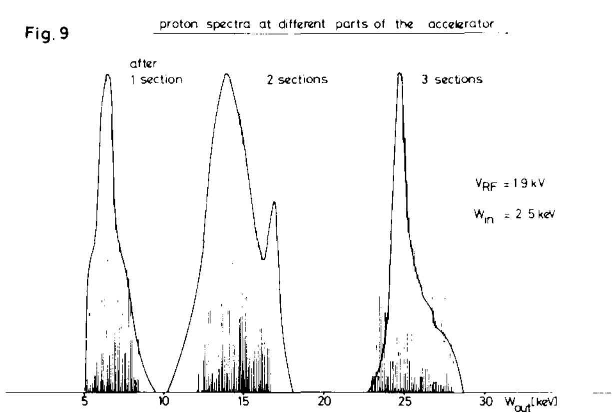
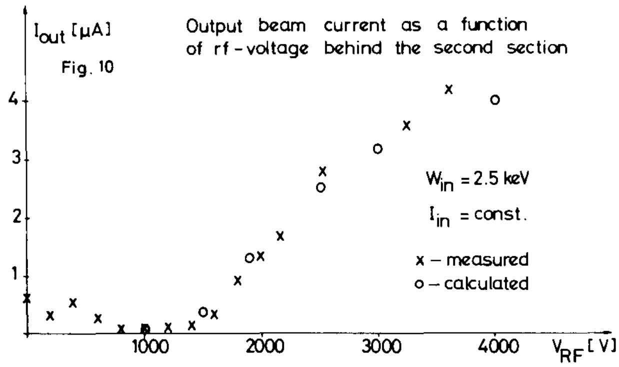
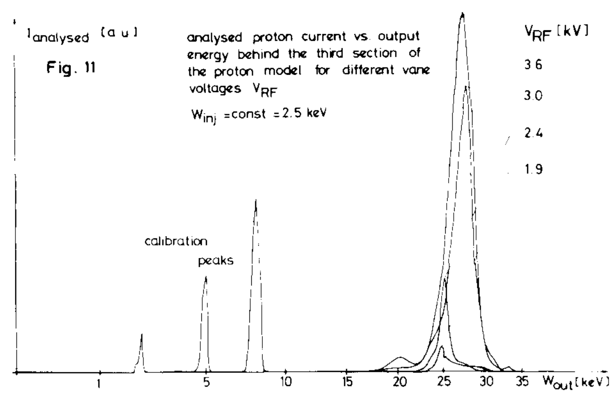


Fig. 9 shows calculated and measured spectra behind sections 1, 2 and 3. The proton currents had to be normalized due to different analysing methods. The calculations were done for a dc beam ($\Delta\phi$ = 360°) and an energy spread of ± 10 % corresponding to the width of the calibration peak. The current distribution over the calibration peak was used to weight the number of particles per energy deviation of the calculated spectra.
Fig. 10 shows theoretical and experimental



beam currents behind the 2nd section as function of the rf voltage. The current increases with the transversal acceptance due to lower phase shifts and the axial capture efficiency. For the future this offers a possibility to study space charge effects at high tune depressions ($\cos\mu_0$ can experimentally be varied between 1 and 0). Fig. 11 shows the measured energy spectra behind section 3. The transmitted current again rises steeply towards higher electrode voltages. The 2-3 mA beam extracted from the source contains 35 % H^+, 50 % H_2^+ and 15 % H_3^+ with a proton current behind the bending magnet of roughly 300 μA. This current is already sufficiently high to observe space charge effects (Ilim predicted: 0.5-1 mA), but the beam emittance is still much larger than the RFQ acceptance. Consequently the source extraction system has to be modified to achieve a higher brilliance.



Computations have been done at the Hochschulrechenzentrum.

References

1 R.H. Stokes, T.P. Wangler, K.R. Crandall, IEEE Trans. Nucl. Sci., Vol. NS-28, No. 3, Part 1 (1981) p. 1999
2 P. Junior et al., IEEE Trans. Nucl. Sci., Vol. NS-28, No. 2 (1981) p1504
3 H. Klein et al., IEEE Trans. Nucl. Sci., Vol. NS-28, No. 3, Part 2 (1981) p. 2865
4 P. Junior et al., this conference
5 A. Schempp, A. Schönlein, Inst. f. Angew. Physik, Univ. Frankfurt/Main, Int. Rep. 81-2 (1981)
6 D. Swenson, R.H. Stokes, priv. commun. 1980
7 W.D. Kilpatrick, Rev. Sci. Instr., Vol. 28, No. 10 (1957) p. 824
8 R.W. Müller et al., IEEE Trans. Nucl. Sci., Vol. NS-28, No. 3, Part 2 (1981) p. 2862