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ZERO-MODE-RFQ DEVELOPMENT IN FRANKFURT*

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Abstract

RFQ structures for low frequency high duty cycle operation have been investigated in Frankfurt. The zero-mode-λ/2-RFQ has been developed, which uses transmission-line-like RF structures and trapezoidal cylindrical electrodes. Prototype accelerators for 108 MHz have been built and tested with beam.

A high power cavity for low frequency (18 MHz), well suited for heavy ions, has been operated above 2 Kilpatrick in cw. Furthermore sparking tests to determine the basic design parameters and beam dynamic studies have been performed.

Zero-Mode-λ/2-RFQ Structure

The radio frequency quadrupole structure has been established as a solution for low energy ion acceleration structures. The 0-mode-RFQ developed as highly effective structure suited for high duty cycle operation combines easy manufactur and tuning. An essential feature is the possible use of circular rods for electrodes, which give good mechanical but also very good beam dynamic properties[1]. The basic structural cell can be described as two λ/2 transmission lines transversely excited in π-mode such that the RFQ electrode pairs have proper polarity. The 0-mode structure consists of a chain of such resonators longitudinally excited in 0-mode.

Fig. 1 shows a simplified circuit model and illustrates an advantage of this structure, the separated function of the structural parts, which p. e. allows variation of resonance frequencies by a factor of ∿ 3 for a given length and diameter of the structure just by using the inductance (legs) for tuning. Direct cooling of the cylindrical electrode and the stems and possible alignment on a bench outside the vacuum chamber are further advantages. The flatness of the structure is excellent and can be shaped by the choice of cell length. It hardly can be deteriorated by tuning errors. The unflatness is approximately given by $\omega l_o/2c$.

A prototype proton accelerator has been built and tested . The lay-out has been described in [2]. With the improved injection system (we now use two electrical einzellenses for matching the beam from the duoplasmatron) a maximum current of 1.1 mA (cw) has been achieved. Fig. 2 shows the block diagram of the new injection set-up. The einzellenses are a simple solution but with a proton fraction of < 20 % and no ion separation at injection the currents couldn't be further increased.

Spiral Resonators

RFQ linacs for heavy ion acceleration require frequencies in the range of 10 - 20 MHz. Only two types of resonators can be excited with resonance frequencies that low and still having feasable size: The "split coaxial structure"[4,5] and the spiral loaded "zero-mode-λ/2" structure. Several spiral and splitring resonators used for drift-tube acceleration of heavy ions have been constructed in Frankfurt and performed very satisfactorily having a good mechanical stability and reliability[6,7]. The spirals replace the straight stems in the 108 MHz-RFQ-modul giving a higher inductive load and a lower resonance frequency. Fig. 3 shows a scheme of the spiral RFQ. Fig. 4 gives a calculation of the R_p value versus the spiral tube diameter[7]. Optimization of such resonators leads to very high efficiencies. Our 18 MHz high power spiral RFQ resonator needed only 13 kW for U = 145 kV in cw operation[2].

Linear 0-Mode-λ/2-RFQ

The mechanical design of our RFQ resonators can be further simplified by arranging also the straight stems linearly. The RFQ is brazed on a massive rail and can be aligned and tuned outside the cavity on a bench and then screwed into the tank, which acts only as a vacuum vessel; the resonance frequency remains within 2 % the same as outside the cavity. Compared with the 90°-arrangement[2,3] the RFQ is now composed of a row of parallel dipoles perpendicular to the axis instead of a row of current loops (fig. 5). One basic cell now consists of two axially displaced λ/2-resonators excited in π-mode. The electrode length per cell is small compared to the vacuum wavelength, so for the calculation of frequency and shunt impedance L,C-circuit description can be used. The inductance of the stems L_S is described as a simple current loop, the coupling inductance L_C between the stem pairs and the inductance of the electrode L_Q is treated as small transmission-line pieces. Thus the resonance frequency for a 0-mode RFQ is given by

$$\omega^{-2} = \left(\frac{L_S + L_C}{n+1} + \frac{L_Q}{4n}\right)\cdot(C_Q + C_S)$$

Fig. 6 shows an example of calculations of resonance frequency as function of stem length and number of cells n. Using the same elements the shuntimpedance R_p can be calculated as well. Because the energy is instantly stored in the electrode capacity C_Q, the losses can be determined, assuming a constant quadrupole charging current I in the stem loops. The losses N can be calculated as function of the electrode voltage U_Q and so for $R_p = U_Q^2/N$

$$R_p = \frac{2(n+1)\cdot B\cdot f}{R_S\omega^2 C_Q^2(2H + D)\cdot K + N_Q}$$

With the same assumptions the Q value $Q = \omega W/N$ can be expressed in a simple way

$$Q = R_p \cdot \frac{\omega C_Q}{2}$$

Fig. 7 shows examples of R_p as function of parameters. High R_p value corresponds besides low losses to a small electrode capacity and low frequencies. The ratio R_p/Q is simply determined by the RFQ capacity and the resonance frequency.

With a short linear 0-mode structure without modulation first high power tests have been performed recently (L = 50 cm, aperture 9 mm, B = 5 cm, H = 8 cm, D = 5 cm, R_p = 300 kΩ, Q = 3000). In first tests within one hour high fields could be applied. In pulsed operation at 2.5 % dc 110 kV electrode voltage and in cw operation 55 kV have been measured. We have to install some radiation shielding before in a next step sparking tests with this structure will be done and the construction of a proton injector prototype 18 - 750 keV with circular cone shaped electrodes[1] will start.

For comparison calculation of the properties of a 4 vane RFQ cavity can be performed in a similar way. Assuming a lumped circuit model as shown in fig. 8, the resonance, shuntimpedance and Q value can be calculated:

$$\rho = \frac{U_{el}^2\cdot C_{cav}}{N} = \frac{8}{R_s\cdot U}\,\frac{1}{\omega^2 C_Q^2} \qquad Q = \frac{\omega C_Q}{2}\cdot R_p$$

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U being the circumference of all quadrants. The resulting values are for a 100 MHz RFQ ρ = 450 kΩ·m, Q = 19000, which correspond to Superfish results (no losses at contacts etc.). The free parameters for optimization are the shape of the cavity (obviously the circular form is optimal) and the electrode capacity C_Q. Contrarily to the 0-mode structure the choice of operation frequency determines most cavity parameters.

Sparking Experiments

The maximum applicable electrode voltage determines the accelerating and focussing fields. Therefore a number of sparking experiments have been done[2,9], which have shown unexpected high values of breakdown voltage so that for low duty cycle operation values of $U_e \geq 2$ K. are still safe.

To investigate the voltage holding capability for higher duty cycles up to cw operation and to apply special surface treatments a new sparker has been built. The electrode distance can be chosen under vacuum, so experiments with reproducable conditions can be done.

Besides calibrating our pick-up loop on low power levels we applied a method suggested by the Chalk River group[9]. In good agreement with the direct loops the bremsstrahlung measured with an intrinsic germanium X-ray spectrometer gives an independent value for the electrode voltage. Especially at high power and high duty cycle the pick-up characteristic might change.

The gap region has been observed with a TV-camera and glow points[9] could be observed at 2 K. still below sparking level (gap 1 cm, electrode diameter 1 cm).

The maximum voltage applied up to now was 150 kV in cw operation and 320 kV with 15 % dc. With careful conditioning we hope that we will be able to achieve still higher values.

Applications

There have been numerous RFQ accelerator projects described in literature[11]. We are working on a proton and on a heavy ion injector. In addition we plan a new application, which will also make use of the specific RFQ properties.

The deceleration of heavy ions has an increasing importance. Highly charged ions at low energies are a new tool in atomic physics and experiments will give information about heavy ion cooling, an essential feature in HIF.

Using the small postaccelerator in the IKF [6,7,12] we will install our proton RFQ in the beam line, injecting with 300 keV/N (p, Ne^{9+}) from the 7 MV Van de Graaff and a matching postaccelerator cavity. Calculations (fig. 9) show the advantage of such a system. With a transmission efficiency of approximately 50 % ions of energies as low as 10 keV/N can be delivered to the experiment; even this is not a system optimized for deceleration. Tandem-postaccelerator combinations have a very poor transmission for the very low energy ions[13]. The spatial homogeneous focussing of the RFQ can be used to decelerate the ions to "arbitrary" energies. Energy variation could be done with a short additional postaccelerator type section, even with a short finger drifttube RFQ cavity with an improved TT-factor.

Acknowledgement

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References

1 P. Junior et al., this conference
2 A. Schempp et al., IEEE Trans. Nucl. Sci., Vol. NS-30, 4 (1983) p. 3536
3 P. Junior et al., HIF-Symposium, Tokyo, January 1984
4 R.W. Müller, this conference
5 W. Neumann et al., this conference
6 A. Schempp et al., BNL 51134 (1980) p. 159
7 H. Klein et al., Nucl. Instr. Meth. 220 (1984) p. 200
8 A. Schempp, LANL-AT1-Note 2.8.83
9 H. Klein et al., GSI-82-8 (1982) p. 150
10 R. Hutcheon et al., this conference
11 H. Klein, IEEE Trans. Nucl. Sci., Vol. NS-30 4(1983) p. 3313
12 A. Schempp, Univ. Frankfurt/M.,Inst. f. Angew. Physik, Int. Rep. 84-1
13 M. Grieser et al., IEEE Trans. Nucl. Sci., Vol. NS-30, 4(1983) p. 2099

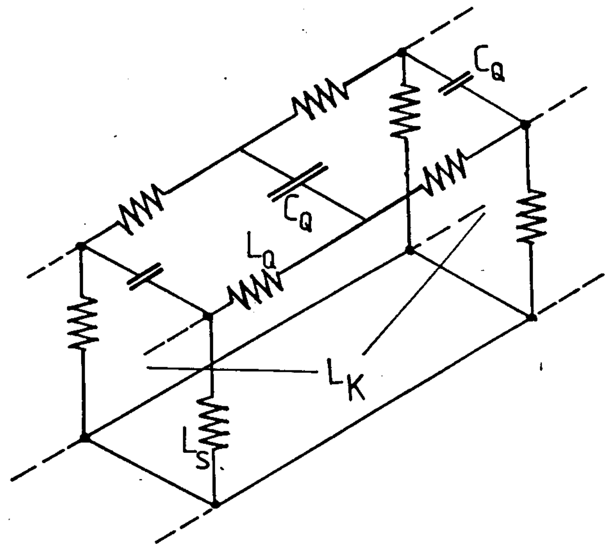

Fig. 1 Circuit model for 1 cell of λ/2-RFQ-structure

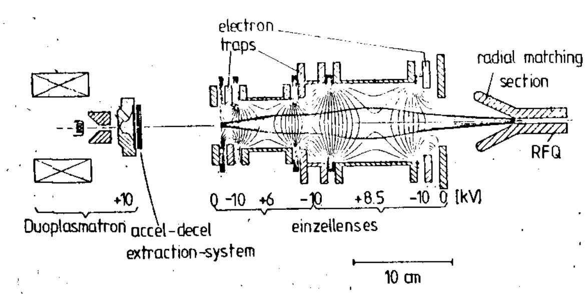

Fig. 2 New injection system

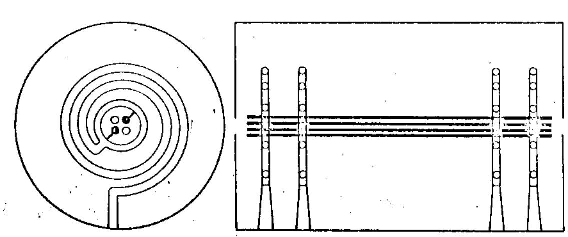

Fig. 3 Scheme of spiral RFQ

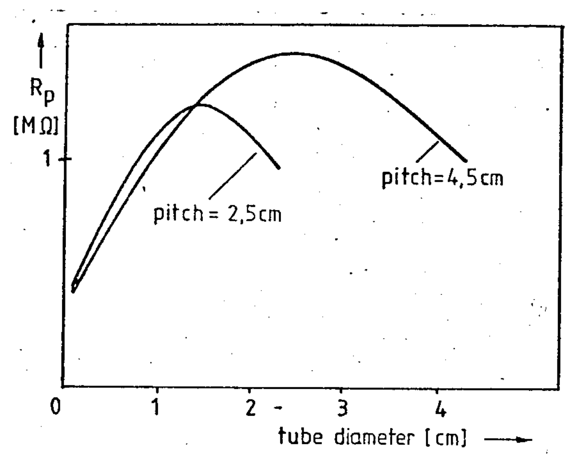

Fig. 4 R_p value as function of spiral tube diameter

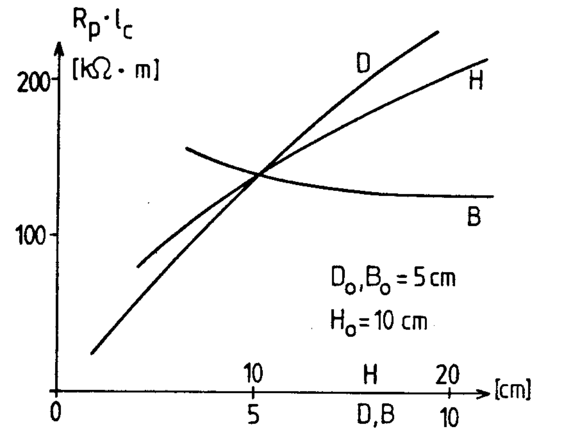

Fig. 7 R_p as function of structure parameters

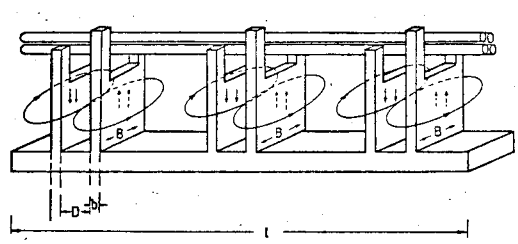

Fig. 5 Scheme of linear λ/2-RFQ

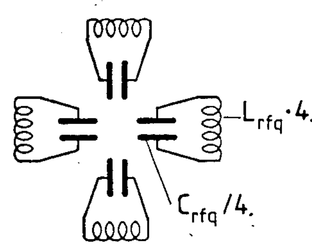

Fig. 8 Simple lumped circuit representation of 4 vane RFQ

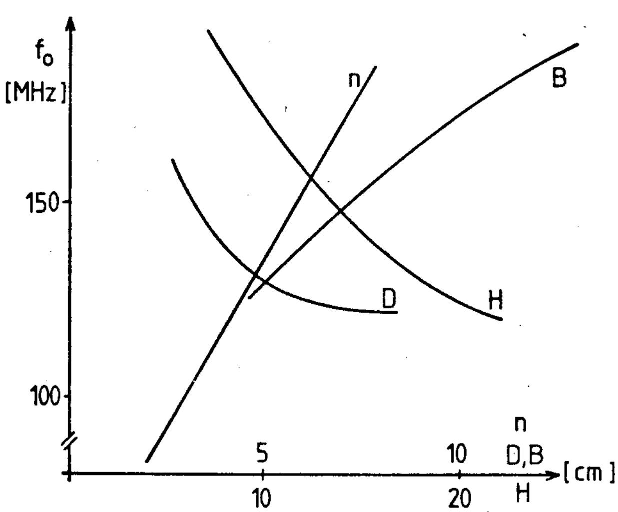

Fig. 6 Frequencies of linear λ/2-RFQ as function of geometric parameters

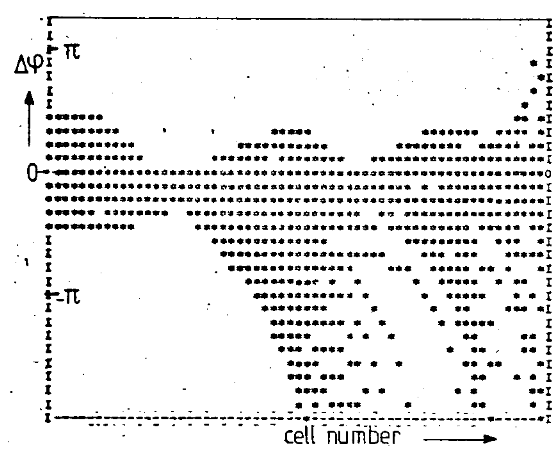

Fig. 9 Phase distribution in a deccelerating RFQ T_i = 300 keV, T_F = 50 keV, ΔT_m = 9 keV, transmission 58 %