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Sparking Tests and Design Considerations for RFQ - Structures *

H. Klein, H. Deitinghoff, K. Halfmann
P. Junior, A. Schempp, A. Schönlein

Institut für Angewandte Physik, Universität Frankfurt, Germany

Abstract

The design of a heavy ion accelerator using the RFQ principle is mainly determined both by particle dynamics - and rf - requirements.

Particle dynamic calculations lead to very low frequencies of 9-13 MHz for initial particle energy of ≈ 2 keV/N. The acceptance of the RFQ structure is limited by the maximum obtainable accelerating and focusing electrical fields. Sparking experiments to determine this important parameter and design of a RFQ - structure with coupled λ/2 - resonators have been started.

The investigations of the RFQ-principle have been concentrated on the construction of a proton model [1] for beam dynamic studies, preparation of RFQ high power tests and the development of particle dynamic codes for optimisation of the RFQ-structure and space charge calculation.

Since the accelerating electric field is directly connected to the focusing field, the maximum electrode voltage for a given beam aperture limits the acceptance of the structure. This voltage is limited by sparking. Very few experimental data on sparking and no good theoretical descriptions at all exist. So work has been done to prepare high power cavities for sparking test. When frequencies as low as 9 MHz shall be considered, a resonator like the Los Alamos type resonator does not seem suitable. Also the expense for a resonator of the "split coaxial type" (tank diameter ca. 2 m) is high, and - in addition - it is not flexible enough to perform tests with different frequencies, electrodes and electrode distances easily. Therefore two relatively simple arrangements have been prepared for our sparking tests.

A coaxial λ/4-resonator will be used for measurements with variable gap geometries and different gasload. The R_p-value of this resonator was measured to 0.8 MΩ at 108.5 MHz. High power experiments are in preparation.

The second arrangement, better adaptable for lower frequencies, uses RFQ-shaped electrodes which are exited as coupled λ/2-resonators[2]. Each pair of quadrupole electrodes consists of two copper rods with sinusoidal modulation which are connected to two common stems forming a λ/2-resonator. Two of these resonators arranged in an angle of 90° and excited in π-mode produce the RFQ-field.

Fig. 1 shows the resonator. The resonant frequency is mainly determined by the capacity of the 4 rods and the inductivity of the stems. The distributed capacity has been measured to 1.6pF/cm, which is much higher in comparison to conventional accelerator structures. The RFQ-electrodes had been machined on a turning lathe. No additional surface treatment has been done. The vakuum tank has a glass flange so we are able to see sparking directly and to identify the position where sparking occures by help of a television camera.

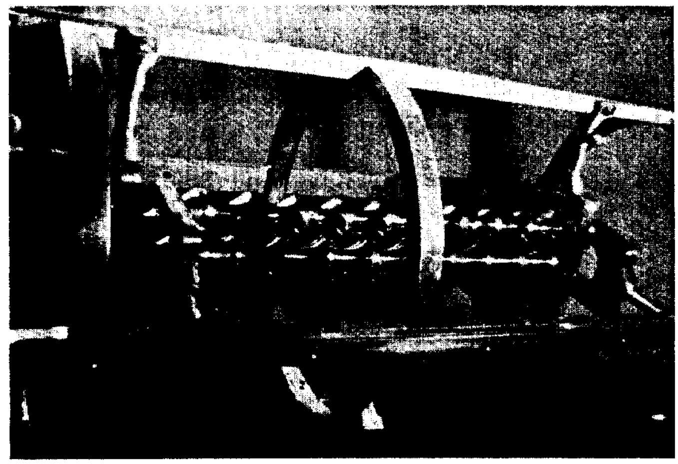

Fig. 1 The λ/2 RFQ - Resonator

First results of experiments at 108 MHz are shown in fig. 2 and 3. Sparking was observed at an electrical field of more than 14 MV/m at 10^{-6} Torr (12 MV/m at 10^{-5} Torr). Between 14 and 16 MV/m there is a constant spark rate of approximately 1-3 sparks/minute. For higher than 16 MV/m the spark rate is increasing linearly with the field. The applied RF-power of up to 80 kW (0,5% dc) corresponds to an average accelerating field of 1.76 MV/m (electrode voltage 93 kV). Fig. 3 demonstrates the increase of sparking rate with duty cycle. Sparking always is located at the regions of ideal quadrupole symmetry, where the radii of the four electrodes are the same.

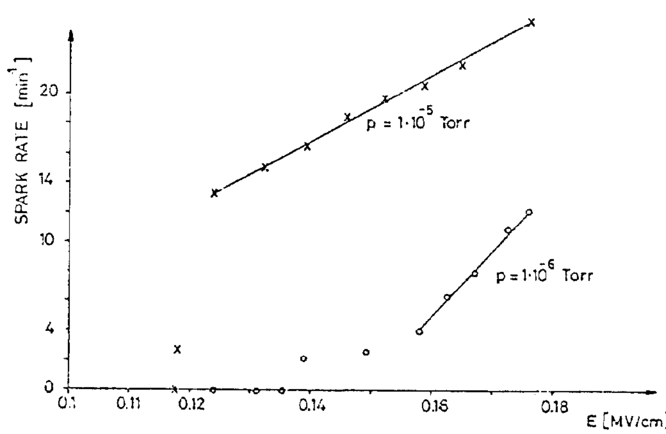

Fig. 2 Spark rate as function of the electrical field E

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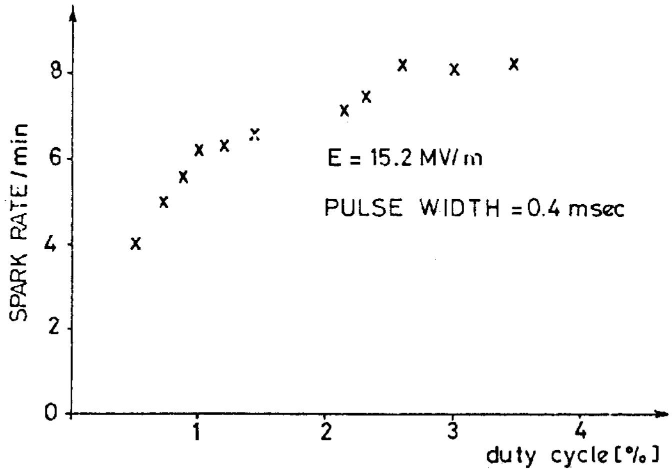

Fig. 3 Spark rate as function of duty cycle

Cooling can be easily done with water flowing through the electrodes made out of a 30 x 10 mm copper tube.

Further tests will be done with higher duty cycle, specific surface treatment and different gas load (e.g. caesium). For frequencies between 9 and 27 MHz such $\lambda/2$-RFQ-structures will be used. RF-power up to 100 kW, 25% d.c., can be applied. The lower frequency is adjusted with longer RFQ electrodes resulting in a structure length of 60 cm for 20 MHz (Ø 25 cm).

Further studies concern calculations of such $\lambda/2$ resonator systems (fig. 4). For this a computer code has been developed which fastly displays geometrical data of circular RFQ rods necessary for their machining on a lathe. As input data the programme is satisfied with linac- and buncher parameters: frequency ω, electrode voltage V, inner aperture R, transverse phaseshift, input and output energy and synchronous phases φ_s.

A corresponding system then consists of circular rods the principle being shown in fig. 4. All even Fourier coefficients in the potential

$$\phi = \frac{V}{2} \left(C \, \frac{x^2 - y^2}{R^2} + \sum_N A_N \cos Nkz \, \frac{\mathrm{ch}Nkz + \cos Nky}{2} \right) \cdot \sin (\omega t - \varphi_s)$$

(C and A_N field parameters defined by proper RFQ boundary conditions, k wave number)

vanish, when the profile is taken uneven with respect to coordinates $\beta\lambda/4$ resp. $3\,\beta\lambda/4$.

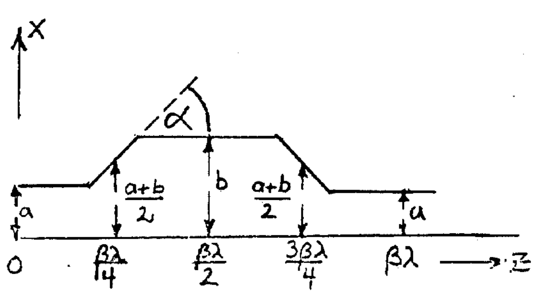

Fig. 4 Scheme of electrode profile minimizing higher Fourier-coefficients in the potential

The "Klirrfactor" $\sqrt{(A_3^2 + A_5^2 + \ldots)/A_1^2}$ with respect to uneven Fourier coefficients is minimized when the inclination angle α is properly chosen, depending on section length $\beta\lambda$ and modulation b/a.[4]

In order to prove our construction principle, a small proton linac (frequency 108 MHz, electrode voltage 25kV, acceleration from 20 to 300 keV, transverse phaseshift $\cos\mu = 0.8$, synchronous phases from 60^o to 30^o, overall length less than 1 m) is under construction. Our principle is presently taken as a calculation basis of heavy ion RFQ linac examples, where the influence of parameters is being studied. Primary results favour an U^{++} accelerator driven at a lower frequency than 13.5 MHz. At corresponding overall length's (~20 m) and transverse acceptances (~0.7 cm mrad) focusing turns out stronger and this is displayed by $\cos\mu = 0.5$ at 9 MHz compared to $\cos\mu = 0.9$ at 13.5 MHz, thus permitting rather higher beam currents.

For the purpose of obtaining quantitative information on this improvement as well as on beam behavior under space charge conditions in the gentle buncher, a two dimensional space charge programme [5,6] is presently extended to three dimensions and accordingly fitted to RFQ situations.

Calculations have been done at the HRZ, Universität Frankfurt.

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