

RF SPARKING IN ACCELERATOR CAVITIES

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Abstract

For high beam currents, high focusing and accelerating gradients in RFQ accelerators electrode voltages near the breakdown limit have to be applied. The rf breakdown limit depends for instance on electrode geometry, gap width, electrode material, frequency and duty cycle. The influence of these parameters has been investigated and some new experimental results will be presented.

Introduction

In RFQ's the rf fields are used both for focusing and acceleration, therefore high fields well above the Kilpatrick criterion [1] are required in many cases. To ensure the reliable operation with these high voltages sparking experiments have been done.

Usually the gap voltage is measured by a pick up loop; for its calibration Q-value and field amplitude in the gap have to be known. For more precise measurement of the gap voltage a computer based x-ray detector system has been used in addition. After careful collimation and attenuation of the x-rays the maximum energy could be measured with a germanium detector with an accuracy of about 1 % during high power operation [2]. This method has the great advantage that the maximum voltage can be measured independently of the cavity parameters, e.g. of the Q-value.

As resonators quarterwave coaxial resonator structures and 4-rod RFQ's are being used operating at resonance frequencies of 26.7 MHz, 108.5 MHz and 216 MHz. The 108.5 MHz resonator is a normal quarterwave coaxial structure [3], whereas the 216 MHz resonator [4] is

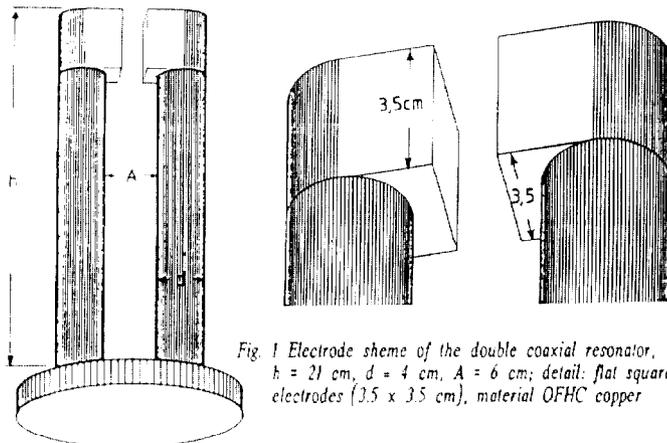


Fig. 1 Electrode scheme of the double coaxial resonator, $h = 21$ cm, $d = 4$ cm, $A = 6$ cm; detail: flat square electrodes (3.5 x 3.5 cm), material OFHC copper

a double quarterwave coaxial resonator as shown in Fig. 1. The two arms of this structure are brazed to the tank end plate.

A 4-rod RFQ operating at 108.5 MHz [5] is shown in Fig. 2. The RFQ for 26.7 MHz is a 4 rod spiral RFQ and described by A. Schempp [6, this conference]

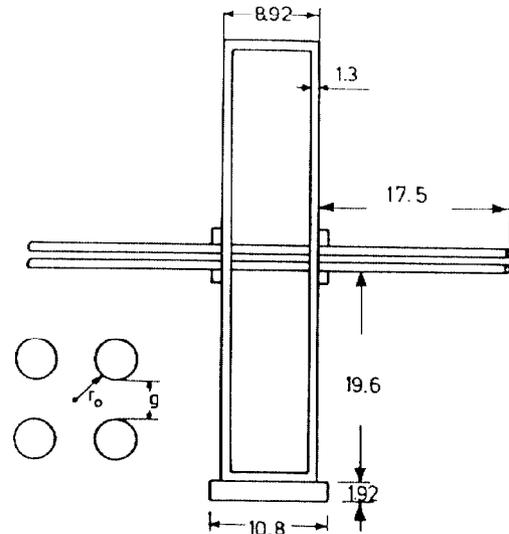


Fig. 2 Scheme of the 108.5 MHz RFQ, dimensions in cm, gap 6.5 mm, $r_0 = 6.5$ mm, rod diameter 12.7 mm

Experimental Set up

In all experiments the electrodes were made of standard industrial OFHC copper. The electrodes of the quarterwave coaxial structures have been polished with polishing paste, cleaned in an ultrasonic bath with methanol. In all investigations the gap voltage was measured via bremsstrahlung spectrum. The number of breakdowns of the rf amplitude during the rf pulses were counted automatically. The value of the breakdown voltage was arbitrarily defined by a spark rate of one per rf-minute. The rf-time can easily be calculated from the product of operating time and duty cycle. The vacuum pressure varied during operation from 1×10^{-7} hPa to 2×10^{-6} hPa.

Experimental Results

Recently tests have been made, to investigate the effect of edges of electrodes to the sparking limit at different gap widths. The watercooled electrodes are disks with a diameter of 40 mm and thickness of 10 mm. Three different edges were used with radii of curvature of 5 mm, 2.5 mm and ~ 0.1 mm (sharp edges).

In Fig. 3 the gap voltage and the electrical field gradient is plotted as function of the gap width. For sharp edges the breakdown voltage is much smaller compared with the results of the edges of curvature of 2.5 and 5 mm, certainly due to the increased field enhancement at the sharp edges. But surprisingly enough for the larger radius of curvature of 5 mm the breakdown voltage decreases by about 10 % compared with the 2.5 mm curve. A possible explanation may be that the sparking probability is higher, since the high field region is larger. This indicates the existence of an optimum edge profil [7].

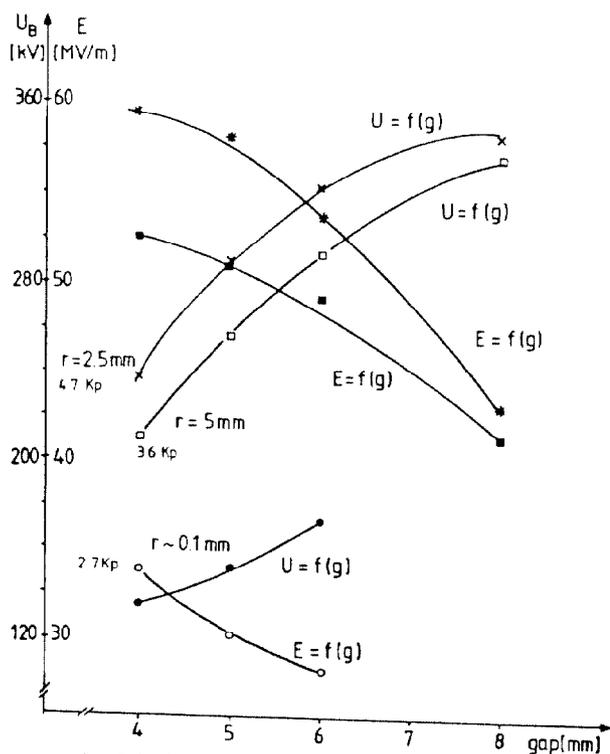


Fig. 3 Breakdown voltage and electrical field versus gap width for plane electrodes (disks, 4 cm diameter, thickness 1 cm)
 O: sharp edge (radius of curvature ~ 0.1 mm)
 X: rounded edge with a radius of curvature of 2.5 mm
 □: rounded edge with a radius of curvature of 5 mm
 frequency 108.5 MHz, pulse length 1 msec, pulse repetition rate 100 Hz, Kilpatrick voltage at 4 mm 50 kV, at 5 mm 60 kV, at 6 mm 71 kV and at 8 mm 94 kV.

In agreement with previous measurements [3] an influence of the pulse length on the breakdown limit was observed. In this experiment the pulse length was varied from 0.5 msec to 5 msec at a constant repetition frequency of 100 Hz, and then the breakdown voltage was measured at cw. Then the measurements were repeated with a constant pulse length of 1 msec at an increasing repetition frequency until 100 % duty cycle. In that cases nearly identical results were achieved, so the breakdown voltage depends only on the duty cycle. The field gradient also decreases, indicating that sparking is not caused by field emission only. The small decrease of the breakdown voltage between 0.5 and 1 msec and a more significant decrease between 1 and 2 msec pulse length could already be shown [8] at

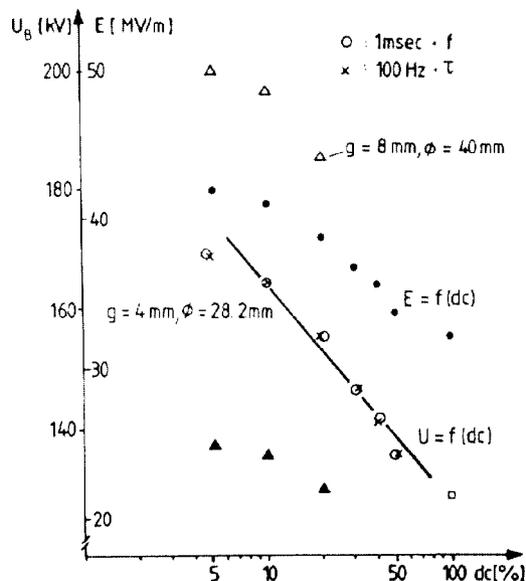


Fig. 4 Breakdown voltage and field gradient versus duty cycle gap width: 4 mm (O, ● and x) and 8 mm (Δ , \blacktriangle), disk diameter: (O, ●, x) 28.2 mm; (Δ , \blacktriangle) 40 mm, frequency 108.5 MHz, pulse length: (O, ●) 1 msec with increasing repetition rate from 50 Hz up to 500 Hz; (x) 0.5 up to 5 msec and a constant repetition rate of 100 Hz; Δ , \blacktriangle 1 msec and with a repetition rate of 50, 100 and 200 Hz. □ = cw

the electrodes with a diameter of 40 mm at a gap width of 8 mm. This is plotted also in Fig. 4. No more sparking could be observed at one rf-minute by reducing the gap voltage by 8 kV to 120 kV at cw. With the 216 MHz quarterwave coaxial resonator sparking experiments have been performed at a gap width of 5 mm. The electrodes have the shape of flat squares [9] with an edge length of 3.5 cm. Fig. 5 show the results. Two edge profiles with radii of curvature of 2 mm and 0.1 mm (sharp edges) were used. For sharp edges the breakdown voltage is lower compared with results achieved using edges with radius of 2 mm. This behaviour is similar to the result of 108.5 MHz, see Fig. 3. A remarkable preliminary result at all sparking measurements seems to be, that the electron current, given by the integral over the bremsstrahlung spectrum, is about 1 mA before a spark occurs [8].

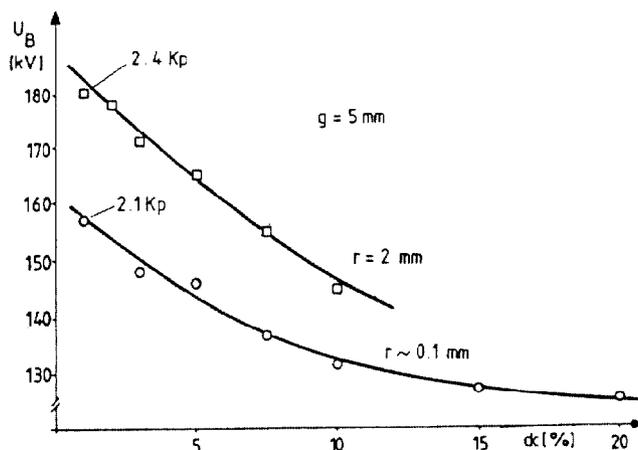


Fig. 5 Breakdown voltage versus duty cycle, gap width 5 mm. f_{res} 216 MHz, pulse length 1 msec O sharp edges. □ edges with radius of curvature of 2 mm.

According to the Kilpatrick criterion [1] the breakdown limit should increase by 30 %, if the frequency is changed from 108 to 216 MHz. But our experiments [9] do not confirm this prediction, the breakdown voltage stays appr. constant.

Therefore the tests at 108 MHz for flat square electrodes will be repeated to check these results.

After construction, tuning and testing at low field level at Chalk River [5], the 108 MHz 4-rod RFQ was shipped to Frankfurt. At low field levels conditioning was started and carefully increased up to the breakdown limit. The R_p -value of 408 k Ω was determined by the measurements of the gap voltage via bremsstrahlung spectra, and the rf power by a power meter.

In Fig. 6 the breakdown voltage is plotted versus duty cycle. The measurements have been done with a constant pulse length of 1 msec and an increasing repetition frequency, starting at 20 Hz. In a certain range between 4 and 50 % duty cycle the breakdown voltage shows an exponential decrease. This decrease could be measured with electrodes formed as disks (see Fig. 4), too, using the quarterwave coaxial resonator at 108.5 MHz. Using the original RFQ breakdown measurements could only be done up to 8.5 % duty cycle. For greater duty cycle the RFQ showed a thermal instability. For a greater stability the rods were fixed with four rings [10], two on every side near the end of

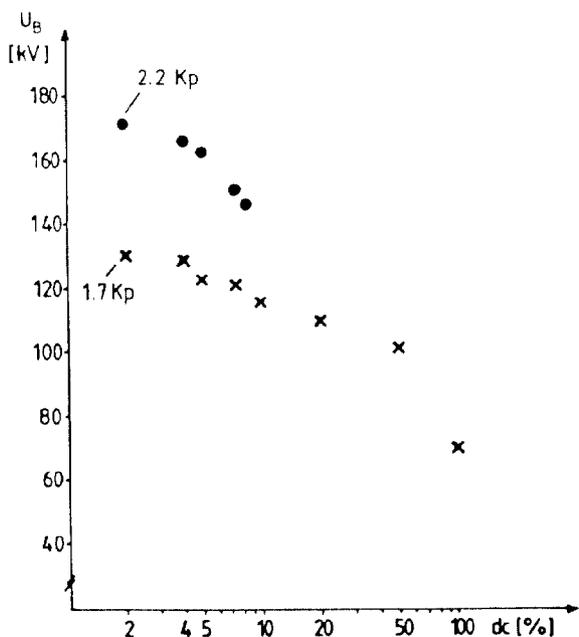


Fig. 6 Breakdown voltage versus duty cycle for the 108.5MHz RFQ, pulse length 1 msec, before (O) and after (X) mechanical changes. $U_{kp} = 77$ kV

the rods. But surprisingly the breakdown voltage is about 25 % lower for the stabilized RFQ. A possible explanation for this behaviour may be that the surface was rougher than the original one, because after brazing of the rings the RFQ was treated by a sand blasting equipment. Therefore the results seem not to be significant and will be repeated.

First sparking test have been done with a 27 Mhz spiral 4 rod RfQ [6] also with a pulse length of 1 msec and repetition frequencies of 30 and 150 Hz. Fig.7 shows the breakdown of the rf field in the cavity measured by the pick up loop and the trigger signal for the oscilloscope. The average duration of the breakdown is similar to the measurements in another cavities and is in a range of 10 μ sec. The gap voltage collapses within 200 nsec, i.e. 5 rf cycles. Table 1 shows the results.

pulse length [mm]	duty cycle [%]	$U_{Kilpatrick}$ [kV]	U_B [kV]
1	3	39.2	138
1	15	39.2	114

Table 1: Breakdown and Kilpatrick voltage for 27 Mhz RFQ

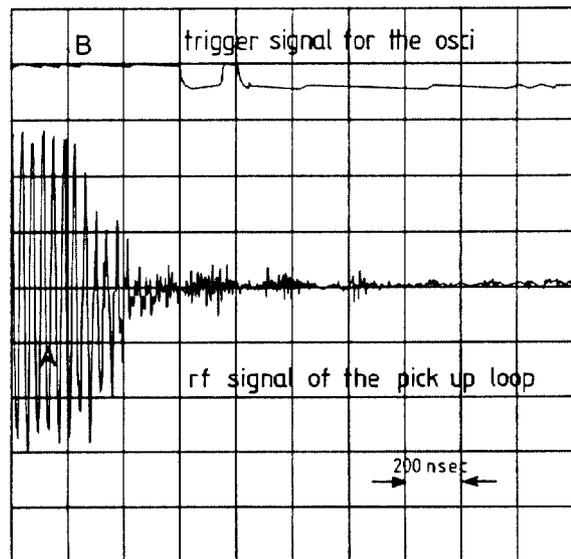


Fig. 7 Rf signal of the pick up loop (A) and trigger signal (B) of the oscilloscope during sparking, $U_B = 138$ kV, $f_{res} = 26.7$ Mhz, pulse length 1 msec, $p_f = 30$ Hz, $\Delta t_{spark} = 10 \mu$ sec.

References:

- [1] W. D. Kilpatrick Rev. Sci. Instr. 28 (1957) p. 824
- [2] J. Brutscher et. al. GSI anual report 1987
- [3] A. Gerhard, et. al. IEEE EL- 20 (1985) p. 709
- [4] M. Kurz diploma thesis, Frankfurt 1988
- [5] R. Hutcheon et.al. IEEE No. 87 CH 2387-9 PAC 87 1987
- [6] A. Schempp, this conference
- [7] J. D. Cockroft J. IEE 66, 385 (1928)
- [8] A. Gerhard et. al. XIIIth International Symposium on Discharges and Electrical Insulation in Vacuum Paris June 1988 to be published
- [9] A. Gerhard, et. al GSI-86-13 (1986) p 31