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DESIGNING RFQ LINACS WITH ARBITRARY ELECTRODE PROFILES*

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For a couple of years now RFQ linacs have been designed in our institute using electrodes, which disagree with the ideal shape. Two such linacs proved successful with proton beams, where the electrodes consisted of circular and trapezoidal rods. While such electrodes are easy to manufacture, the determination of the appropriate geometry requires considerable computational efforts. In this paper we present a practicable design process, which only needs a fair amount of computational work. Use is being made of the smooth behaviour of all relevant field harmonics with the linear dimensions of all considered cells occurring. The method is demonstrated by two linac schemes, one consisting of barrel-like the other of trapezoidally shaped rods.

Analytical Foundations

RFQ designs are usually based on the linearized equations of motion

transverse

$$\frac{d^2x}{dt^2} + \frac{eV}{m}\left[-\frac{1}{8}k^2 A\sin\phi_s + \frac{\chi}{a^2}\sin(\omega t - \phi_s) - \frac{1}{4}k^2 A_{21}\sin(\omega t + \phi_s)\right]x = 0 \quad (1)$$

longitudinal

$$\frac{d^2u}{dt^2} + \frac{eV}{m}\frac{1}{4}k^2 A\sin\phi_s u = 0, \quad (2)$$

where the energy gain per cell from input T_o to output $T_o + \delta T$

$$\delta T = eAV\cos\phi_s$$

happens along a distance

$$\beta\lambda = \frac{mV_o^3}{\text{[illegible]}\,\delta T}\left[\left(1+2\pi\frac{\delta T}{T_o}\right)^{3/2} - 1\right],\ k = \frac{2\pi}{\beta\lambda}.$$

At given ion species $\frac{e}{m}$, applied voltage between electrodes V, frequency f, input synchronous phase and initial energy for each cell in the buncher part 3 degrees of freedom namely synchronous phase ϕs, aperture a and modulation b/a are successively chosen such that the transverse phase advance σ_o, the longitudinal phase advance and the bunchlength remain constant. In the subsequent linac part with fixed aperture and synchronous phase the only degree of freedom left the modulation is chosen that way that still the transverse phase advance remains constant.

Only in case of ideal electrodes the geometric parameters a, b and $\beta\lambda$ (fig. 1) are analytically related to coefficients A, χ and A_{21} in equs. (1) and (2)[1,2]

$$A = \frac{b^2 - a^2}{b^2 I_o(ka) + a^2 I_o(kb)},$$

$$A_{21} = 0,\ \chi = 1 - AI_o(ka),$$

thus generating the correct phase advances.

Numerical Approach

Minor pretensions in the design process only arise, because the transverse phase advance of Mathieu's equ. (1) is iteratively determined. This methode is reported in [3]. Simpler electrodes imply rather complex relationships and require considerably more computational effort. For such profiles[4] we have composed a computer code, which numerically correlates geometry a, b, $\beta\lambda$ to field harmonics A_{10}, A_{01}, A_{21}. When we chose a representation with corrective factors

$$f = \frac{A_{10}}{A},\ g = \frac{A_{01}}{\chi},\ h = A_{21}$$

we found rather smooth behaviour of these, fig. 2 demonstrates an almost linear dependence. As a consequence a net of f(ka, kb), g(ka, kb), h(ka, kb) values was supplied to the design code[3] within that range, which covers the linac layout. This can easily be outlined by referring to the ideal profile using [3]. Fig. 3 gives an example of a mesh typical for such a net.

In this way linear interpolation of values between meshpoints suffices, frequently repeated calculations of field harmonics necessarily occurring with iterative procedures are avoided. Of course, sufficient data must be provided to the net, before a linac is generated, such demands remain moderate, in our examples nets were composed of 12 coordinates ka with 5 modulations respectively. Fig. 4 illustrates slopes of geometric parameters in 3 different linacs, all serving the same purpose namely 10 - 150 keV protons, 108 MHz, a = 2.5 mm, V = 21 kV, ϕ_s from 75° to 30°, σ_o = 60°, R_o = 9 mm. Construction drawings are plotted in fig. 6, and fig. 7 shows a rod manufactured on a lathe.

Yet determination of fig. 2 and meshpoints are restricted to a construction scheme with constant distance R_o between rod- and optical axes. Indeed a condition (s. fig. 1) $a + R_1 = b + R_2 = R_o$ can hardly be maintained throughout the linac. Fig. 4 explains that the ratio $s = R_o/(a + R_1) = R_o/(b + R_2)$, when chosen equal to 1 in the first shaper cell increases to more than 1.2 in the last linac cell in our examples. When we start with a smaller ratio s in the shaper, we usually end up with too small an inner rod diameter $2R_2$, which then may cause problems with cooling (s. fig. 1). Fig. 5 illustrates effects, indicating how at given ka and modulation further corrective factors

$$c_{10} = \frac{A_{10}}{fA},\ c_{01} = \frac{A_{01}}{g},\ c_{21} = \frac{A_{21}}{h}$$

again show smooth behaviour with the ratio s. Fig. 2 shows, how the total corrections fc_{10}, gc_{01}, hc_{21} are effected with s = 1.2. However, the influence on rod geometry proves small and not till the end of the linac (0.01 mm for the trapezoidal resp. 0.07 mm for the barrel case) as is seen in fig. 4.

Generally this ought to be considered, thus our design method as proposed here, seems suitable in a very general sense.

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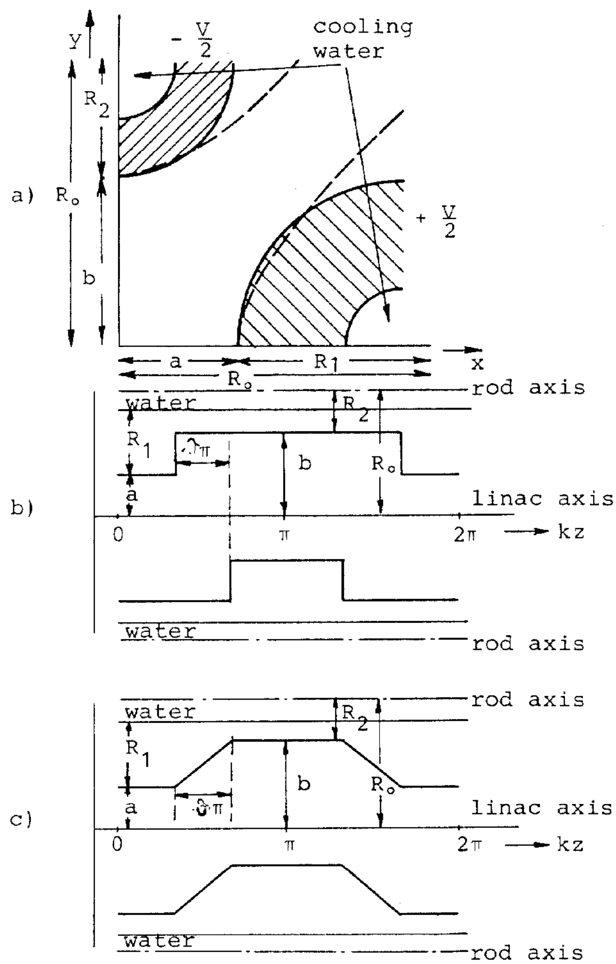

Fig. 1 Cross sections of RFQ rods
a) transverse, dashed hyperbolas correspond to ideal case
b) longitudinal, rectangular barrel type
c) longitudinal, trapezoidal type

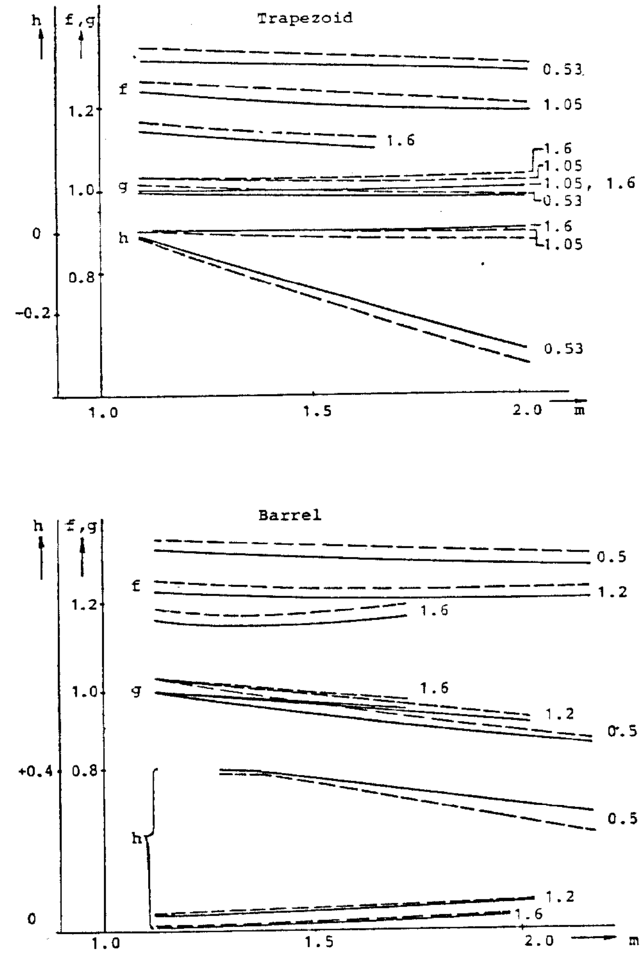

Fig. 2 Correction factors vs. modulation for different parameters ka,
----- s = 1.2, ——— s = 1, ϑ = 0.4

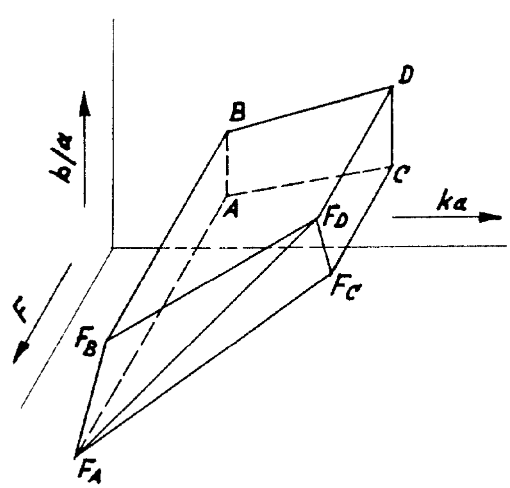

Fig. 3 Example of a mesh

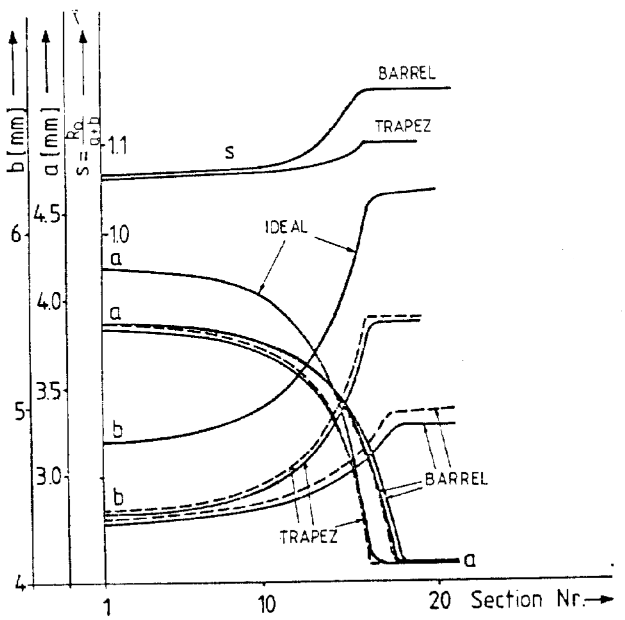

Fig. 4 Slopes of geometric data vs. $\beta\lambda$ cell number with ϑ = 0.4, variable s -----, fixed s ———. Note that both profiles answer the purpose of acceleration from 10 - 300 keV along a distance of about 42 cm with 21 kV electrode voltage, while ideal electrodes need 25 kV.

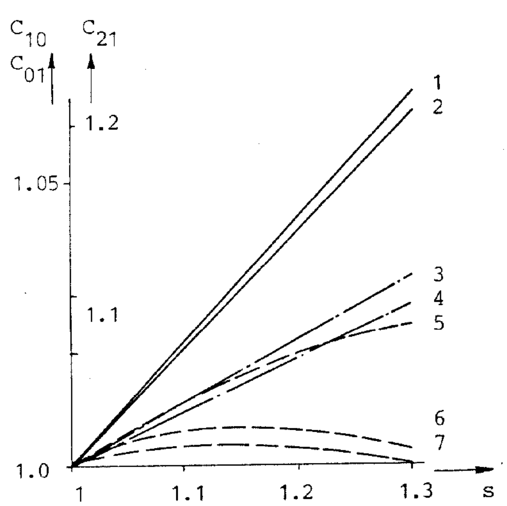

Fig. 5 Corrections vs. s for ka = 0.27 and 0.53, small enough to effect rod geometry hardly, trapezoidal case ϑ = 0.4
——— C_{21}, ----- C_{01}, -.-.- C_{10}

Curves	1,3,5	1,4,6	1,3,5	2,4,7
ka	0.53	0.53	0.27	0.27
b/a	1.4	2	1.4	2

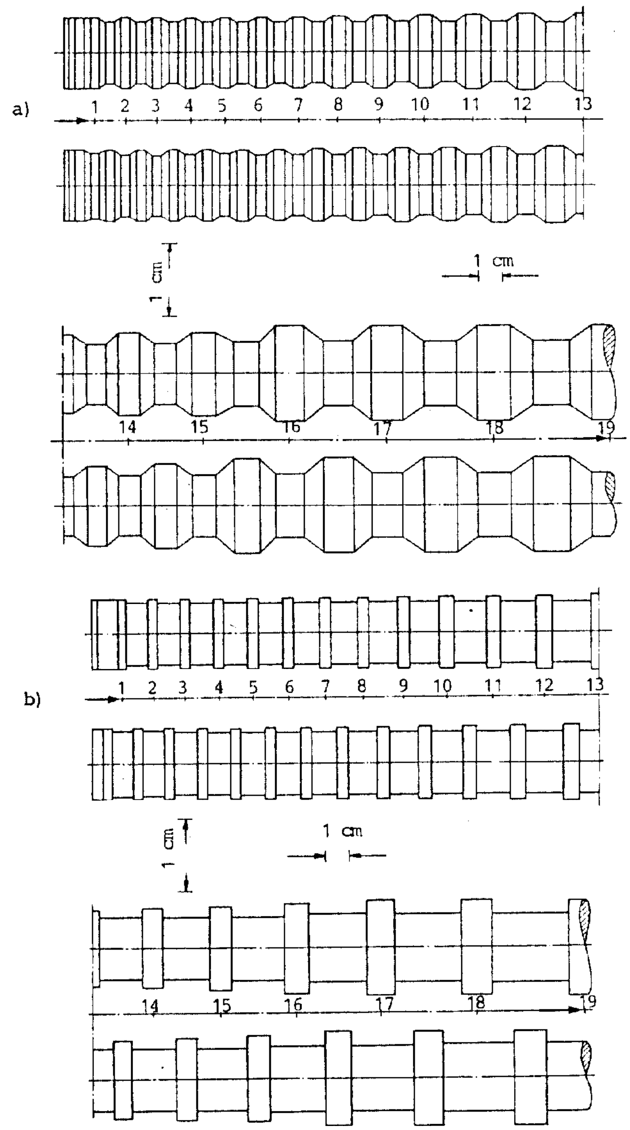

Fig. 6 Construction drawings of
a) trapezoidal rods
b) barrel-like rods

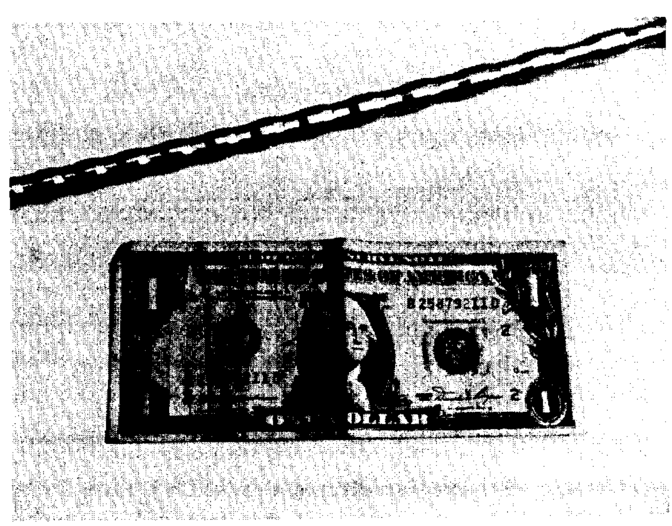

Fig. 7 Photo of trapezoidally shaped rod