RFQ LINACS WITH CONSTANT INNER APERTURE AND MODULATION

P. Junior, H. Deitinghoff, A. Harth
Institut für Angewandte Physik der Universität Frankfurt am Main,
Robert-Mayer-Str. 2 - 4, D-6000 Frankfurt am Main, West Germany

Abstract

RFQ's are considered, where each of the four electrodes consists of an inner continuous pipe covered with a sequence of appropriate pieces of outer pipes. The acceleration rate then varies with the length of these outer sections. As a consequence of such a simple construction pattern the buncher design principle, usually based on constant phase advances, has to be abandoned. The paper presents prototypes and discusses acceptances and beam currents.

Design Principles

In our aim of investigation RFQ setups with a construction as easy as possible, we studied four rod linacs[1], where each of the four rods consists of an inner continuous pipe, on which appropriate slices of outer pipes are brought. Fig. 1 show the principle. When the acceleration parameter A_{10} of the corresponding potential expansion[2,3] can only be varied with the length of the slice as a consequence of chosing uniform parameters D_1, D_2 at a given distance R of optical and rod axis, the buncher cannot be developed in the usual manner[4,5]. The convention is that the three quantities, namely the transverse phase advance per cell, in smooth approximation given by

$$\frac{\sigma_t^2}{\pi^2} = -\frac{eVA_{10}\sin\phi_s}{2mv^2} + \frac{1}{2}\left[\frac{eVA_{01}}{m\omega^2a^2}\right]^2 \qquad (1)$$

(the A_{21}-term being neglected), the longitudinal phase advance per cell

$$\frac{\sigma_l^2}{\pi^2} = \frac{eVA_{10}\sin\phi_s}{mv^2} \qquad (2)$$

as well as the longitudinal aperture (bunch length) are kept constant. This last condition relates the synchronous phase to the velocity

$$v^2(1 - \phi_s \operatorname{ctg}\phi_s) = \text{const.} \qquad (3)$$

Such a design guarantees almost perfect matching of subsequent cell acceptances both for transverse synchronous and longitudinal particles moving on the axis. The constant in (3) is given by the input velocity v as well as the starting synchronous phase ϕ_s chosen. When bunching is finished, further acceleration is accomplished with constant synchronous phase ϕ_s, usually 30°, and maintenance of (1) with σ_t = const. is then possible. f = $\omega/2\pi$ stands for the radiofrequency, e/m for the specific charge of particles, protons in this study, a means the inner aperture (s. figs. 1) and v the voltage between rod neighbours. Table 1 comprehends data of this study object, which we regard as exemplary.

Performances

Comparing figs. 1a and 1b it seems evident that with identical diameters D_1, D_2 and distance R resp. the transverse phase advance cannot be kept constant. The consequence of this inconvenience is that to some degree

Table 1

T_{input}	7.5 keV	T_{output}	60 keV
f	54 MHz	ϕ_s range	60° - 30°
V	10.5 kV	a	4.5 mm
R	12.4 mm		

transverse acceptances of subsequent 3λ cells do not match, although σ_t increases. This is shown in figs. 2, drawn acceptances being derived at observance of conditions (2) and (3). Therefore only the common area of all acceptances can be utilized for the beam and a certain loss in acceptance and beam current must be taken in account. As the longitudinal emittance of the DC beam is still small at the beginning, A_{10} becomes as small as possible, i.e. the first slice should be as thin as possible. However, a finite limit of A_{10} exists and this cannot be brought down to arbitrary small values, as is the case, when the modulation is variable. In a conventionally designed linac[6] e.g. where data are the same as in table 1, A_{10} ranges from 0.07 - 0.5 along the buncher. Our design possibilities are shown in fig. 3, where modulation m = 2R - D_1/2R - D_2 is taken as the parameter. A constant modulation throughout the linac seems unfavourable. Small modulation at the beginning corresponds to small acceleration rates later in the linac, large modulation gives too large A_{10} resulting in small transverse phase advances and acceptances. Thus our study implies two modulations namely 1.6 and 1.75, cells 1 - 6 are equipped with 1.6 (part I), 7 - 12 with 1.75 (part II). Regarding the transition from part I to II our calculations of matching the acceptance of cell 7 to the emittance as given by the common areas of figs. 2 showed that again matching turned out optimal, when the transverse phase advances of cells 6 and 7 agreed.

Figs. 4 demonstrate this transverse matching of II to I and furthermore the figures indicate, how the acceptance of any following cell in II covers all corresponding forthcoming ones. The longitudinal behaviour is shown in fig. 5, and figs 6a,b and 7 show the performances of acceptances, when the beam carries 2 mA corresponding to a tune depression of about 0.4 in cell no. 1. Fig. 8 comprehends relevant data of such a linac and in fig. 9 a photo of a rod is shown.

For all determinations of relations between field harmonics A_{10}, A_{01}, A_{21} and geometric conditions D_1, D_2, R, $\beta\lambda$ together with iterations necessary for the design we used the procedure described in [7], however, here we adapted a new 3D potential code[8] to RFQ proportions and installed it into our mesh net routine of [7]. Finally table 2 shows how this study compares to the analogue[6]. As a second example we used this method for the design of a 108 MHz analogue to our RFQ linac as described in [9]. Table 3 informs on the comparison of both.

We can conclude saying that for not too high demands in acceptance and beam current our simple setup of an RFQ linac seems suitable.

Computations were carried out at the HRZ of the university of Frankfurt.

Table 2

	total length [cm]	mean acc. rate [keV/cm]	$\frac{\sigma}{\sigma_0}$	I_{beam} [mA]	zero current transverse acceptance [π mm mrad]
this study	49.77	1.32	0.4	2	0.2
facility[6]	46.28	1.22	0.4	5.5	0.9

Table 3 RFQ II

	linac	study
ϕ_s	75° - 30°	75° - 30°
A_{10}	0.05 - 0.68	0.11 - 056
σ_0	60°	35° - 45°
l	-	1.2 - 12.5 mm
total length	82 cm	80 cm
energies	10 - 300 keV	10 - 300 keV
f	108 MHz	108 MHz
a	3 mm	3 mm
R	9 mm	8.7 mm
V	28 kV	28 kV
total section number	26	20
number of buncher sections	16	8
I(0.4)	16 mA	7.5 mA

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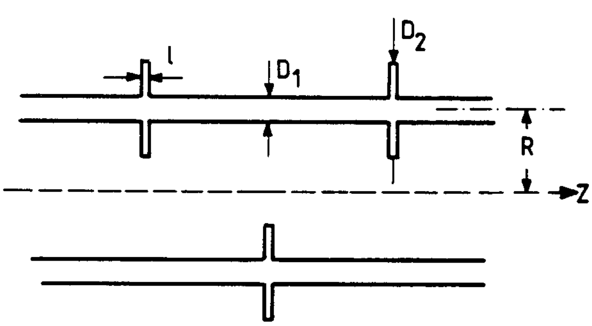

Fig. 1a Scheme of Buncher Cell

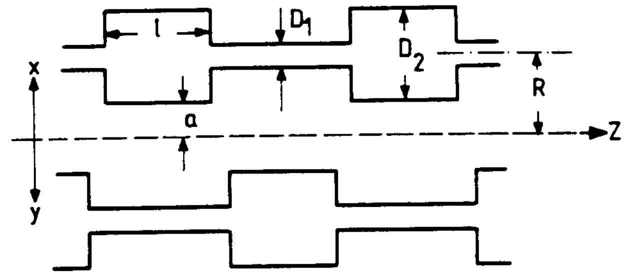

Fig. 1b Scheme of Accelerator Cell

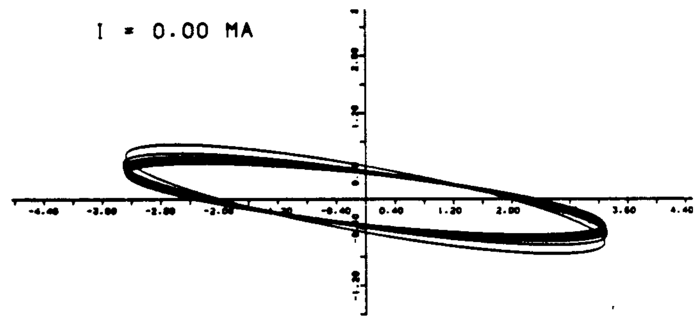

Fig. 2a X - X' - Acceptances of Buncher Cells 1 - 6

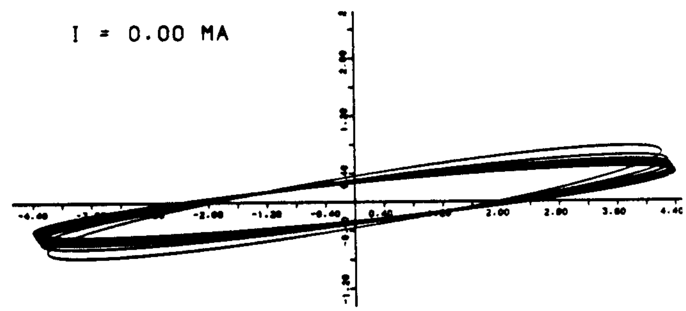

Fig. 2b Y - Y' - Acceptances of Buncher Cells 1 - 6

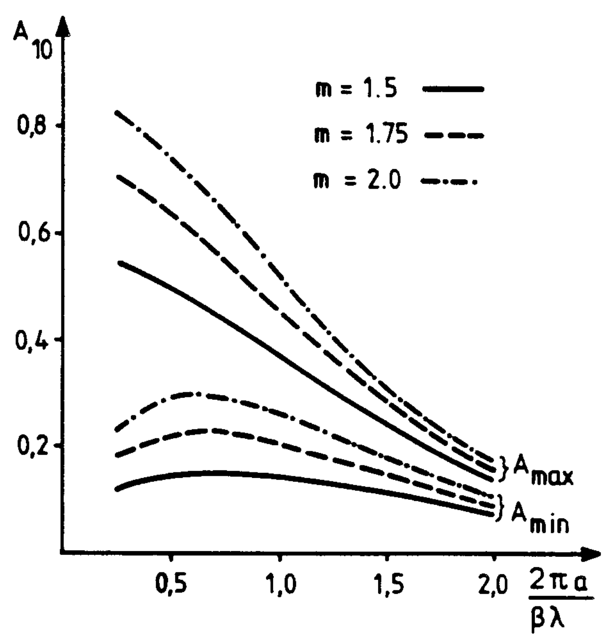

Fig. 3 Range of Acceleration Rate A_{10} versus normalized Aperture at different Modulation

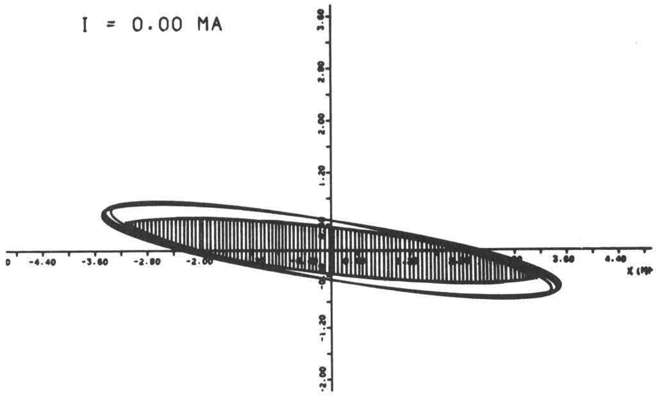

Fig. 4a X - X' - Acceptances of Part II and common Area taken from Fig. 2a

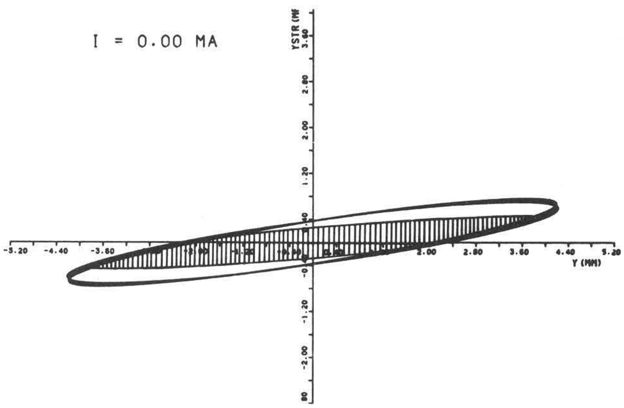

Fig. 4b Y - Y' - Acceptances of Part II and common Area taken from Fig. 2b

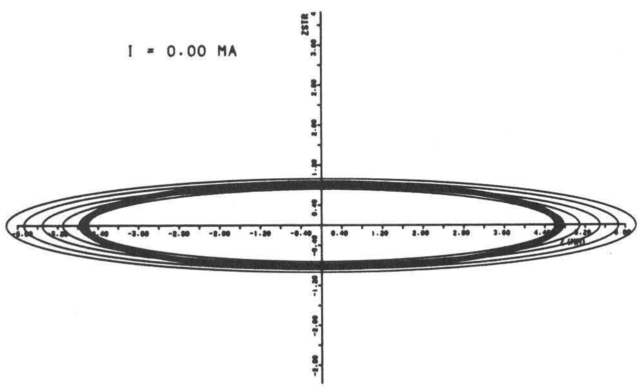

Fig. 5 Longitudinal Acceptances of Parts I and II

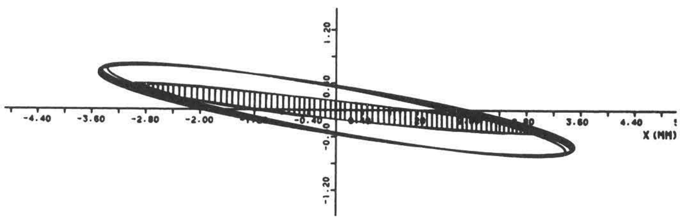

Fig. 6a Common Area of Part I in Acceptances of Part II at 2 mA (X - X' - Plane)

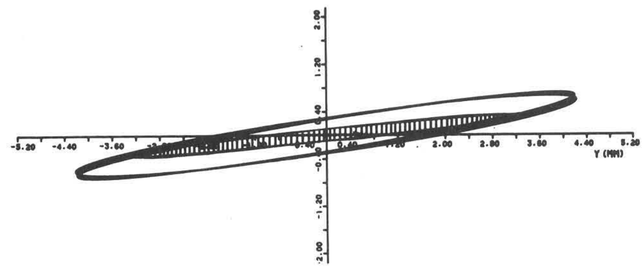

Fig. 6b Common Area of Part I in Acceptances of Part II at 2 mA (Y - Y' - Plane)

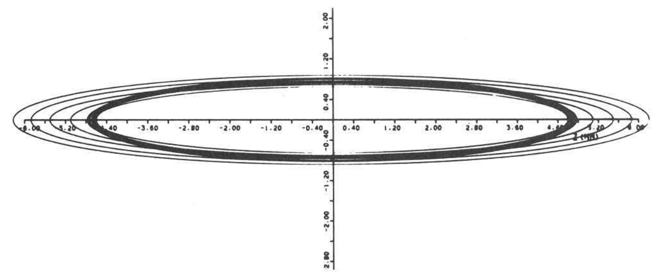

Fig. 7 Longitudinal Acceptances of Parts I and II at 2 mA

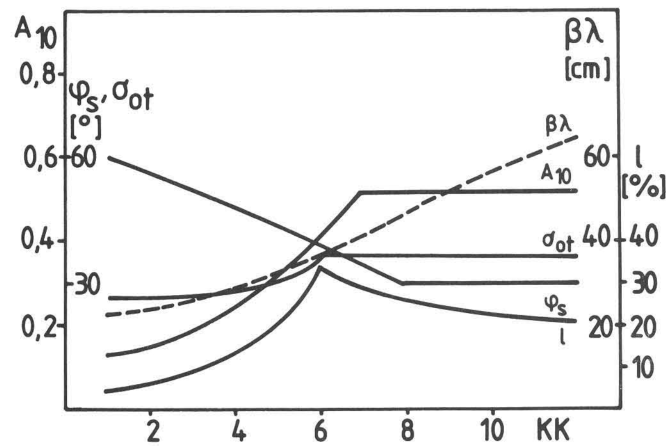

Fig. 8 Relevant Data of LINAC

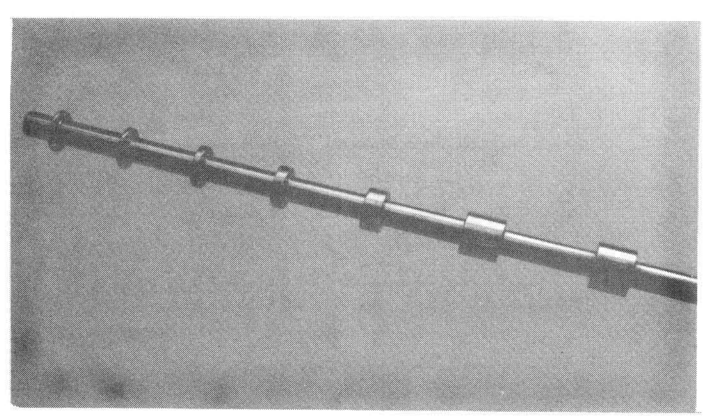

Fig. 9 Photo of ROD