INPUT AND OUTPUT BEAM MATCHING FOR A RFQ WHERE A COUPLE OF ELECTRODES ARE AT GROUND POTENTIAL

M. Comunian*, A. Pisent
INFN-Laboratori Nazionali di Legnaro, via Romea 4, I-35020 Legnaro (Padova), Italy

Abstract

The CERN Lead Ion RFQ, of the "four rods" kind, with symmetric supports and vane like electrodes, has been constructed by LNL. The main resonant mode is such that two electrodes, held by the first and the last support, are kept at the ground potential, while the other two have an oscillating voltage of amplitude V respect to the tank, and the voltage amplitude on the beam axis for zero modulation is $V/2$.

The field configuration inside the RFQ is determined, in quasi-static approximation, by the electrodes modulation via the usual potential expansion, but there are additional fields in the input and output regions. Namely there are a longitudinal and a transverse field component determined by the shape of the beam input port and of the electrodes in the radial matching section region. In this paper will be shown the results of three-dimensional electrostatic simulations of the input region; the impact of those field on longitudinal and transverse dynamics is analyzed and proven negligible for our geometry. Moreover we shall consider how to minimize the effect of the longitudinal field at the output region.

Introduction

The RFQ for the CERN Lead injector, operating at 101.3 MHz, accelerates Pb^{+25}_{208} ions from 2.5 keV/u to 250 keV/u. A complete list of parameters and commissioning results are in the companion papers [1] [2]. We shall consider in this paper the solution of a specific problem, the unwanted longitudinal field at the input and output region [3].

Since the beginning of the RF studies for this RFQ, both in aluminum low RF level models and in three dimensional simulations (MAFIA), it has been found that the operation mode was asymmetric, since two electrodes were at ground potential and the other two had an oscillating potential V. We shall refer to this phenomenon as PA (Potential Asymmetry). PA has no consequences inside the RFQ, but in the input and output regions determines an accelerating gap. In particular the problem is relevant at the input since $V = 70$ kV gives a potential on beam axis of 35 kV, while the ions enter the RFQ after an electrostatic pre acceleration (ECR source voltage) of just 20.8 kV.

Later RF studies have proven that it is possible to correct PA by correcting the impedance of the first and last RF cell [4]. This allowed a good understanding of the problem, but the solutions proposed (and verified on cold models) looked of difficult engineering, in the presence of intense fields.

In parallel we have studied the beam dynamics of the problem, and proven that by increasing the radius of the input beam port was possible to increase enough the extension of the longitudinal field and make the effect harmless. Based on this analysis it was decided to modify the geometry of the Radial Matching Section (RMS) and keep PA without any RF correction. The performances shown by the RFQ proved that this was a reasonable choice.

In addition the modulated vanes were mounted so to make the longitudinal field effect in the end region lower than for symmetric potential distributions.

*Present address: CERN, PS Division, CH-1211, Geneva 23, Switzerland.

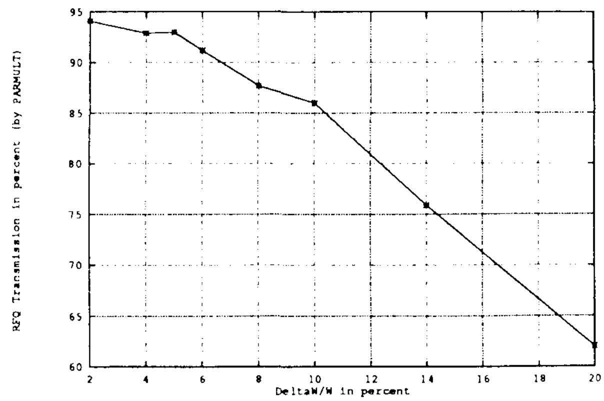

Fig. 1: RFQ transmission as function of energy spread $\Delta W/W$.

Transit Time Factor Description

After the RMS, the RFQ is subdivided in five sections (gentle buncher, prebuncher, buncher, booster and accelerator) [5] the first three of which adiabatically capture a continuous monoenergetic beam in the RF buckets with and efficiency higher than 90%. In Fig. 1 is plotted the RFQ transmission as function of the input energy spread; the acceptance can be estimated around 5% (total).

This value has to be compared with the energy spread due to PA. This can be calculated in first approximation as:

$$\frac{\Delta W}{W} \simeq \frac{TV}{V_{ECR}} \tag{1}$$

where V_{ECR} is the preacceleration voltage, and:

$$T = \frac{\int E_z(z)\cos(2\pi\frac{z}{\beta\lambda})dz}{\int E_z(z)dz} \tag{2}$$

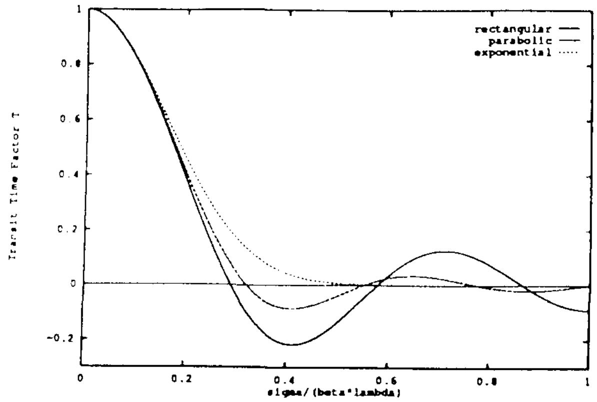

Fig. 2: Transit Time Factor as function of $\sigma/\beta\lambda$ for different field distributions.

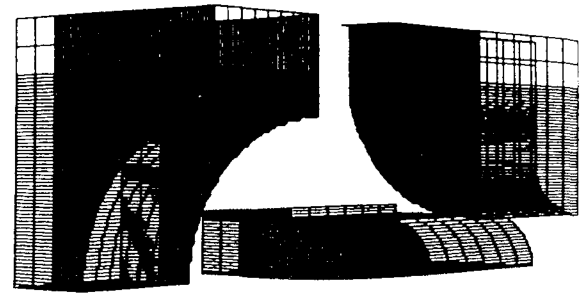

Fig. 3: RFQ input geometry: one quarter, with cavity wall and two half-electrodes.

is the transit time factor; λ is the RF wave-length and β (relativistic factor) is supposed constant during the gap transit.

If T is less than 1% we are within the RFQ acceptance.

The transit time factor depends upon the r.m.s. extension of the longitudinal field:

$$\sigma = \sqrt{\frac{\int z^2 E_z(z)dz}{\int E_z(z)dz}} \tag{3}$$

and on the details of the field distribution, expecially when σ is comparable with $\beta\lambda$. In Fig. 2 are plotted the transit time factor as function of $\sigma/\beta\lambda$ for rectangular, parabolic and gaussian distribution. In particular limited distributions are characterized by zeros that disappears in the case of a gaussian.

Therefore for small T it is fundamental to calculate accurately the field distribution at RFQ input.

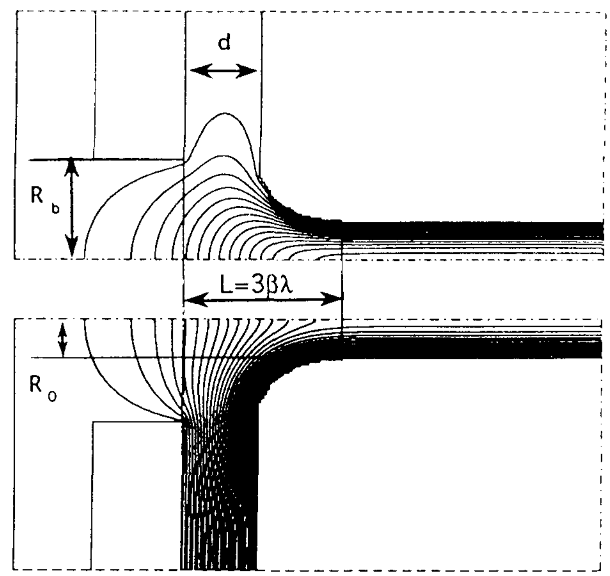

Fig. 4: Isopotentials (Hor. and Ver. planes, R_b = 12mm).

Simulations

Since we are interested to an accurate description of $\vec{E}$ in a region small respect to λ where $\vec{B}$ is virtually zero, it is convenient to do an electrostatic 3D-simulation.

In Fig. 3 is plotted the geometry as input in MAFIA. The parameters R_0 (RFQ average aperture), R_b (radius of beam port), d (internal wall-electrode distance) and L (RMS length) are indicated in Fig. 4, together with the isopotential lines on horizontal and vertical plane. In the plot the horizontal electrodes are grounded.

The longitudinal tapering of the electrode is the one proposed by Crandall [6], that gives for $R_b = 0$ and symmetric potential:

$$\frac{\partial E_{x(y)}}{\partial x(y)} = +(-)\frac{V}{R_0^2}(\sin kz - \frac{1}{3}\sin 3kz)\cos\omega t \tag{4}$$

with $k = \frac{2\pi}{L}$ and $E_z = 0$; this dependence allows a good beam matching.

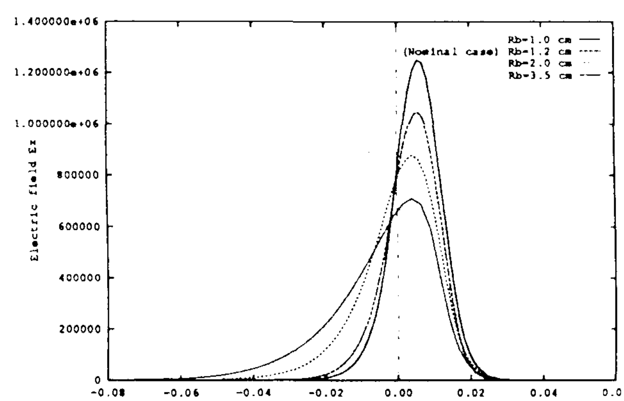

Fig. 5: E_z (arbitrary units) for different R_b (z=0 on internal tank wall).

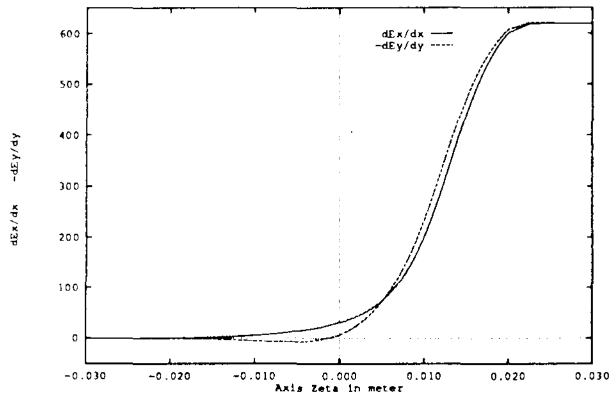

Fig. 6: $\frac{\partial E_x}{\partial x}$ and $-\frac{\partial E_y}{\partial y}$ (arbitrary units) as function of z (R_b = 12 mm).

We have simulated the case with PA for different R_b; it is now present a field component $E_z(z)$ whose shape and σ depend on the aperture R_b (Fig.5).

The transverse field maintains the dependence (4) with the addition of a small component:

$$\frac{\partial E_x}{\partial x} = \frac{\partial E_y}{\partial y} = -\frac{1}{2}\frac{\partial E_z}{\partial z}$$

that has a maximum in the flex points of $E_z(z)$. The cylindrical symmetry of this component is determined by the beam port.

When $\sigma \simeq \beta\lambda$ (Table 1) the longitudinal effect is negligible. For this reason we have chosen R_b = 12 mm for our RFQ.

To check effects of beam bunching in the gap, possibly hidden by the transit time factor description, we have written a code that integrates the longitudinal equation of motion in the gap (with the actual $E_z(z)$). Also from this analysis the longitudinal effect result negligible for our geometry. Energy spread resulting from both calculation methods are listed in Table 1; part of the discrepancy is due to the small lack of symmetry in z of $E_z(z)$. The transit time integral in sin should be considered together with integral (2).

Moreover by numerical integration of the transverse envelope equation with the actual z-dependence of field gradients (Fig. 6) we have verified that the matching is not worst than with field gradient (4) and that the usual PARMULT routine can be used for the calculation of the RMS.

Table 1: RMS geometry

$\beta\lambda$	6.9 mm	R_0	4.5 mm
$L = 3\beta\lambda$	20.7 mm	R_b	12 mm
d	9 mm	σ	6.3 mm
$\Delta W/W$ formula (1)			0.32%
$\Delta W/W$ simulations			0.45%

RFQ Output

At the RFQ output one has again a longitudinal component with three differences: $\beta\lambda$ is ten times bigger ($T \simeq .93$) the electrodes are modulated and the beam is bunched ($\Delta\phi = \pm 12°$). The field in the last cell can be derived from:

$$U(x,y.z) = \frac{V}{2}\left[\frac{x^2-y^2}{R_0^2} + AI_0(kr)\cos\frac{2\pi z}{\beta\lambda} \pm 1\right]\cos\omega t$$

where A is the accelerating factor ($A \simeq 0.6$ at RFQ end). The sign of the PA term (± 1) depends on which electrode is connected to the last support (at ground potential). In particular the potential on the axis can be made:

$$U\left(0,0,n_c\frac{\beta\lambda}{2}\right) = \frac{V}{2}(A-1)\cos\omega t$$

by connecting at ground potential the electrodes that end with the smaller aperture.

In this way the energy spread generated by the exit gap is reduced to 67% of the case without PA and in our RFQ can be neglected.

Conclusions

By increasing the input beam-port bore diameter and conveniently choosing the electrodes connected to the last support it was possible to obtain optimal performances for our RFQ without correcting Potential Asymmetry.

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