RFQ design for High-Intensity Proton Beams

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Abstract

A CW RFQ, designed to accelerate 100mA proton beams from 100keV to 4MeV, is being studied by the GECA in Saclay. A preliminary design leading to a beam transmission larger than 97% is presented. A logical approach, based on both the choice of transverse and longitudinal phase advances at the end of the gentle buncher and an adiabatic variation of the RFQ parameters in this region is described.

I. INTRODUCTION

For the new generation of high-power accelerators, high-intensity continuous proton beams are required. In this paper, the study of a Radio Frequency Quadrupole linac (RFQ) able to accelerate a 100 mA proton beam with a high transmission is presented. The input and output energy are respectively 100 keV and 4 MeV and the operating frequency is set at 352 MHz.

In the following sections, the choice of the RFQ parameters is explained and the beam dynamics described. Error studies for our « reference design » are also presented.

II. BEAM DYNAMICS

The input beam energy is settled to 100 keV by the pre-injector of the ECR source SILHI beeing build at the "Laboratoire National Saturne" (LNS). The choice of 4MeV for the RFQ output energy results from both considerations :

- extend the output energy to a high level in order to obtain first DTL cells long enough to allow a FODO focalisation law,
- limit the total RF power below 1.3 MW in order to use only one power klystron to feed the RFQ.

For the beam dynamics study, the input transverse emittance (total, normalized) is 1.5 π.mm.mrad (0.25 π.mm.mrad for the RMS normalized emittance). This value is actually pessimistic, the total emittance expected at the pre-injector output is about 1.0 π.mm.mrad or less. In addition, as usual for CW RFQ, the maximum peak surface field is keept below 1.8 E_κ.

The dynamics has been calculated using these parameters in order to reach the higher transmission. Calculations were done using both the well known PARMTEQ familly codes from the Los Alamos Nationnal Laboratory [1] and codes from the LNS [2]. All calculations began at the end of the Gentle Buncher (GB). Indeed, at this point the particules are bunched but weakly accelerated, so it is the area where the space-charge effect is the most important. Using CURLI and RFQUICK, the first design step gives a good starting point. Nevertheless, the PARMTEQ code results show that most of the losses are located at the end of the GB section. Such a local loss of particles in a CW accelerator involves a local heating of the structure, sparking and pulverization of matter; they must then be avoided. This has been done by tuning the adiabaticity of the acceleration parameter in this region (figure 1). The LNS codes have permitted to choose the phase advances (then the r_0, a and m parameters) at the end of the GB and to smooth the acceleration parameter as shown in figure 1.

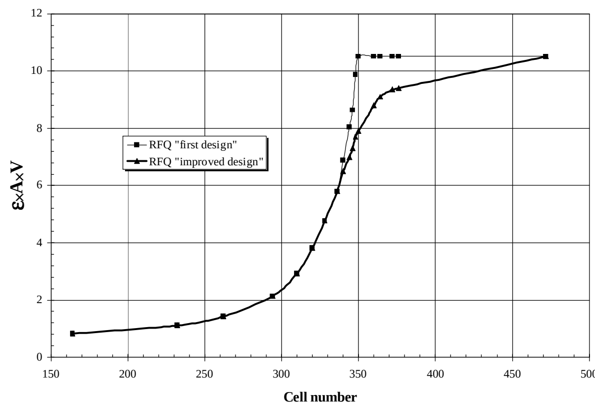

Figure 1 **:** Modification of the acceleration parameter to avoid localized losses.

The results of this operation are :

- the losses are no longer localized,
- the transmission increases from 94% to 97.4% without the multipole effect (PARMTEQ) and to 97.1% with multipoles (PARMULT),
- for the expected total emittance of 1.0 π.mm.mrad the transmission increases up to 98.3%.

Particle	H^+
Operating Frequency	352 MHz
Duty factor	100%
Input/Output Energy	0.1 / 4.0 MeV
Input/Output Current	100.0 / 97.1 mA
Transmission	97.1%
Trans. Emitt. (RMS, Norm.)	0.25 π.mm.mrad
Peak Surface Field	1.8 E_κ
Intervane Voltage	90.2 kV
Total Length	6.45 m

Table 1 : Beam and accelerator specification.

The RFQ parameters are listed in table 1. It can be added that r_0 = 3.75mm is kept constant all along the structure and that ρ/r_0 = 1.0. This is not the best choice to reduce the peak surface field but in this case, the multipolar effects are weak. Some of the most important parameters are shown in figure 2 as a function of the cell number.

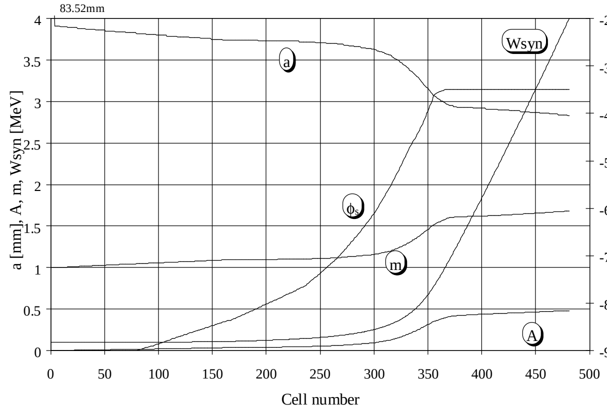

Figure 2 **:** RFQ parameters versus cell number.

The next figure gives PARMULT simulation results for the two cases previously described. Black points are lost particules. Figure 3-A clearly shows that most of them are located around cell 352 at an energy of about 808 keV (the end of the GB).

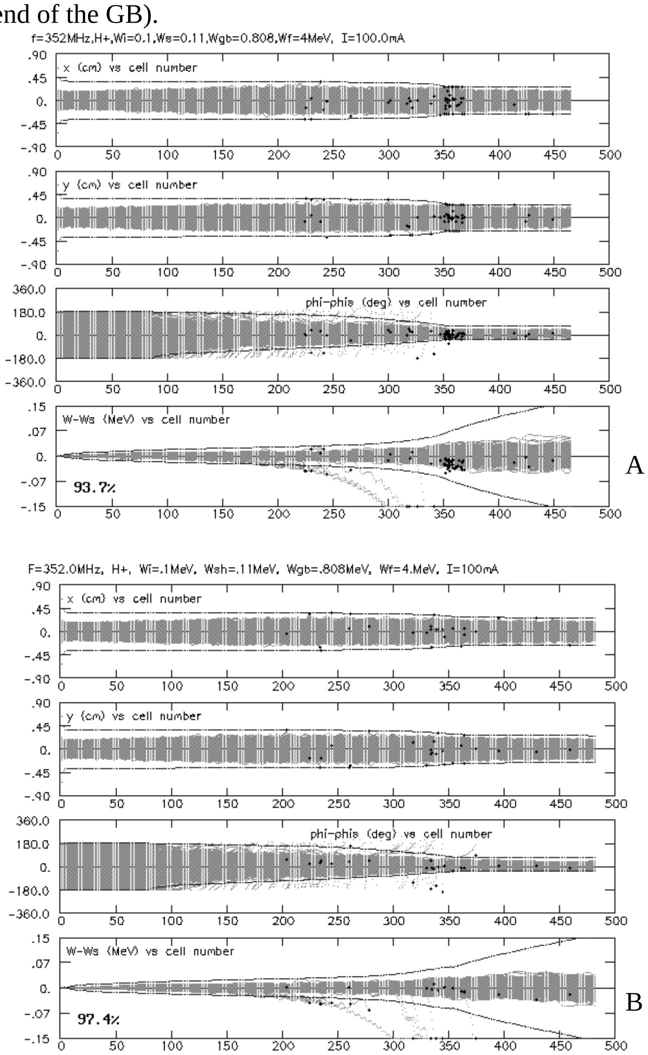

Figure 3 : PARMULT simulation with (A) and without (B) modification of the acceleration parameter.

Next figure shows the improvement obtained on the energy deposited by the beam on the vanes.

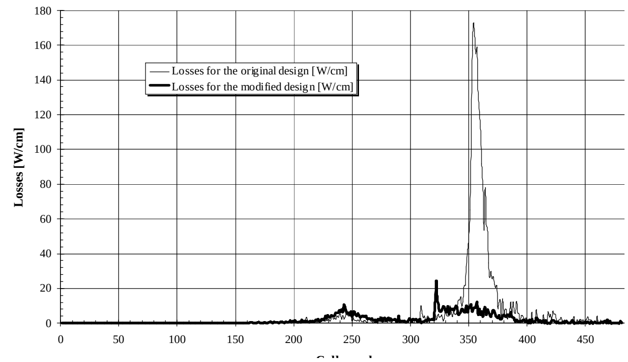

Figure 4 : Losses versus cell number with and without improvement of the dynamics.

III. ERROR STUDIES

All the simulations were carried out using PARMULT with high order multipoles. In order to reach a good accuracy, all the calculations were done with at least 20000 particules. We first studied beam's imperfections at the RFQ entrance : mismatching, displacement in position and angle, energy dispersion and detuning. We have also studied the effects of tilt errors on the vane voltage and some cumulated defaults. Figure 5 shows the evolution of the transmission versus the type of default.

PARMULT permits to modify the Twiss parameter α, β, γ, and ε of the beam. The limit of 95% of transmission appears in figure 5-A and 5-B to be at $\pm$ 15% of x mismatch (β), $\sim\pm$ 20% of x' mismatch (γ). In the case of beam displacement (figure 5-C) the limit appears to be at $\pm$ 11% ($\pm$0.5mm). Some work is done in order to reduce this sensibility to beam misalignments. The limit in beam angle (steering) do not seems to be so critical as it reaches $\pm$ 18mrad (figure 5-D). Some studies on energy dispersion show that the RFQ admit $\Delta W/W$ up to 4.5%! The detuning of energy could reach $\pm$2%. Studies of transmission versus vane voltage show that the limit of transmission is reached when the vane voltage is reduce by 3%. Another important parameter is the tilt witch could appear on the vane voltage (figure 5-E). The transmission is a little better for a tilt of -7%. For that tilt, the vane voltage is higher at the begining of the RFQ, where the beam is at low energy and the space-charge effects high. Nevertheless such a tilt increases the peak field and sparking can occur. Furthermore, a negative tilt (more than -10%) involves an important pick of longitudinal losses at the end of the acceleration.

The last study describes cumulated errors which are given in the legend of figure 6. This figure shows the losses in the longitudinal plane. No localized losses appear, and the level remains low. A major point is that expected transmission is 88.5% if all individual errors are cumulated. Despite, the simulation gives 85.8%. The main concern is the effect of accumulated defaults rather than effects of sole defaults. All the beam parameters have to be carefully adjusted.

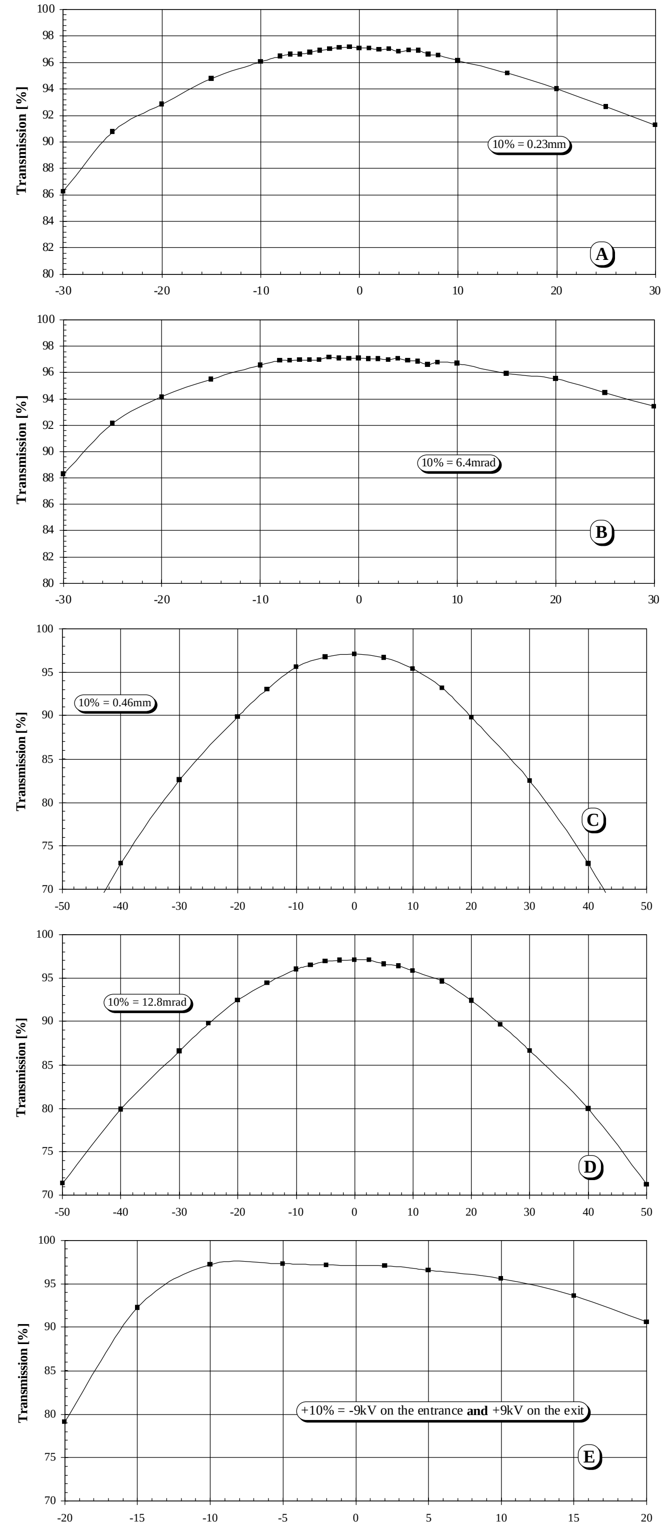

Figure 5 **:** Transmission versus errors (all in per cent of the original parameter).

- A and B for the sensitivity to the twiss parameters (respectively β and γ)
- C versus input beam displacement
- D versus beam steering errors into the RFQ (beam angle)
- E for a tilt of the vane voltage.

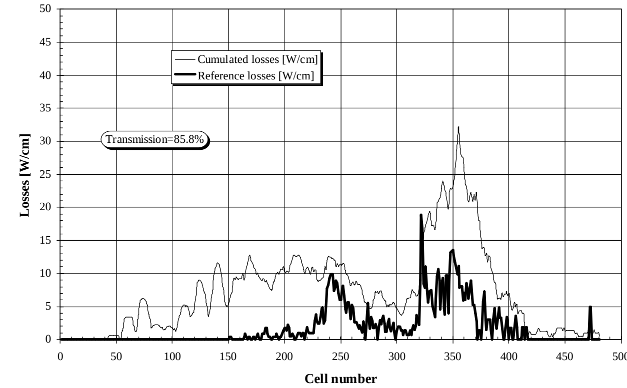

Figure 6 : Losses versus cell number. The reference curve is obtained without any errors. The thin line is obtained with x mismatch = 10%, y' mismatch = 15%, x and y displacements = 10%, x' and y' displacements = 10%, and tilt error = +5%.

IV. CONCLUSION

For the new generation of high-power accelerators, a reliable CW RFQ with a high output energy is required. The life time of such an accelerator will be greatly improved if damages done by beam losses can be avoided. The goals for the beam dynamics are then :

- a transmission as high as possible,
- no pick of losses which could localy damage the vannes,
- an easy adjustement of the beam to the RFQ input.

In the « reference design » presented here, almost all these challenges are completed. The transmission is larger than 97%. Only the sensitivity to beam misalignement must be improved. An optimisation of the adaptation section is expected to fulfill such requirement.

V. ACKNOWLEDGEMENT

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VI. REFERENCE

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See also

K.R. Crandall and T.P. Wangler, Linear Accelerator and Beam Optics Codes, AIP Conf. Proc. 177, 22 (1988).

[2] J-M. Lagniel, « Tools for the design of high-current linacs », LINAC94 Conf. Proc.