CHARACTERIZATION OF BEAM PARAMETER AND HALO FOR A HIGH INTENSITY RFQ OUTPUT UNDER DIFFERENT CURRENT REGIMES

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Abstract

The characterization of the beam distribution at the exit of a high intensity RFQ is a crucial point in view of a correct simulation of beam behaviour in the following linac structure. At this scope we need to know the beam halo quantification as a function of the input beam and RFQ parameters. In this paper, the description of beam halo based upon moments of the particle distribution at the exit of the TRASCO-RFQ [1] is given.

INTRODUCTION

The first time step of SPES [2] realization is the creation of a two-way facility able, on one hand, to accelerate a 10 mA protons beam up to 20 MeV for nuclear studies and, on the other hand, to accelerate a 30 mA protons beam up to 5 MeV for cancer therapy and preliminary ADS studies. This two-way facility, forces the TRASCO RFQ (Fig. 1), which is used to accelerate beam up to 5 MeV in both cases, to work with two very different current regimes. Considering that RFQ design has been optimized for a 50 mA protons beam, it is evident that a very deep RFQ parameters optimization is needed.

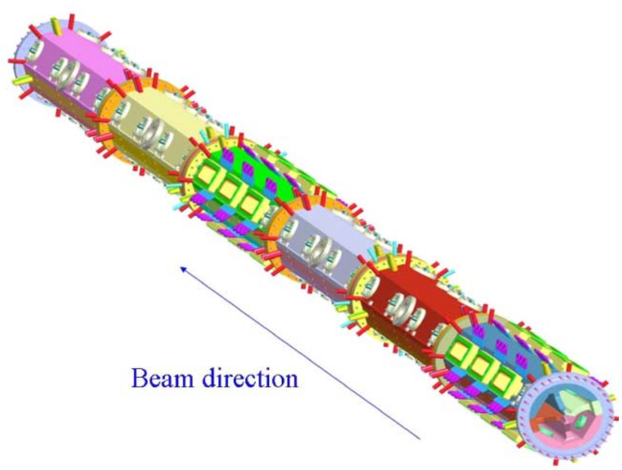

Figure 1: TRASCO-SPES RFQ design.

RFQ BEAM DYNAMICS

Beam dynamics has been simulated with PARMTEQM [3] code. All the simulations are executed starting with a 4-D Waterbag distribution of 100000 macroparticles at RFQ in. All results are obtained analyzing the full distribution output file. Therefore, it has been possible to evaluate parameters that simulation program normally do not calculate. In Tab. 1 and Tab. 2 summarize the main RFQ nominal parameters [4] and Twiss parameters at RFQ in/out for the two current regimes.

Table 1: RFQ characteristics (1)

Particle	Proton
Energy	0.08 – 5 MeV
Frequency	352.2 MHz
Duty Factor	100 %
Length	713 cm
Maximum surface field	<33 MV/m (1.8 Kilpatrick)
RF Power consumption	<800 kW

Table 2: RFQ characteristics (2)

Current (mA)		**10 mA**		**30 mA**	
Transmission		99.6 %		98.0 %	
		in	*out*	*in*	*out*
E.n.rms. *(mm-mrad)* *(deg-MeV)*	*x*	0.2	0.205	0.2	0.216
	y	0.2	0.2	0.2	0.212
	z	-	0.253	-	0.191
Alpha	*x*	1.37	-1.13	1.57	-1.27
	y	1.37	0.15	1.57	0.29
	z	-	0.288	-	0.05
Beta *(mm/mrad)* *(deg/MeV)*	*x*	0.049	0.27	0.054	0.32
	y	0.049	0.10	0.054	0.11
	z	-	439.9	-	435.4
H (halo parameter)	*x*	0.25	0.39	0.25	0.68
	y	0.25	0.35	0.25	0.60
	z	0	1.06	0	2.09

Fig. 2 shows simulation results for the two current values. Each plot is divided into four sub-plots showing beam projections in phase space. In particular, x-x', y-y', x-y and $\Delta\varphi$-ΔW plane are plotted from top left to bottom right. As regard the low current case, it can be noticed that phase-energy distribution presents a two picks structure. This has two main reasons: non linear effects due to space charge are too small to remix distribution, separatrix width results larger than necessary allowing beam to expand in longitudinal phase space. Associated with current increase there is a halo formation. In other words, a small fraction of particles acquires enough transverse energy from the repulsive space-charge forces within the beam to form halo. A measure of halo is important because halo particles can be lost on the walls of the beam line structures, where they will induce unwanted radioactivity. A halo parameterization is important in order to compare real beam halo with that calculated for different known distributions. Uniform distribution must be the starting point for comparisons. Transport matrix codes use in general this distribution to make dynamics simulations and space charge routines implemented in multiparticle codes such as PARMTEQM, are based on an elliptical uniform symmetry of the beam. Other significant distributions for comparison are Parabolic, Gaussian and Hollow. Therefore, it is necessary to evaluate beam halo parameter and compare it with that obtained for the mentioned distributions.

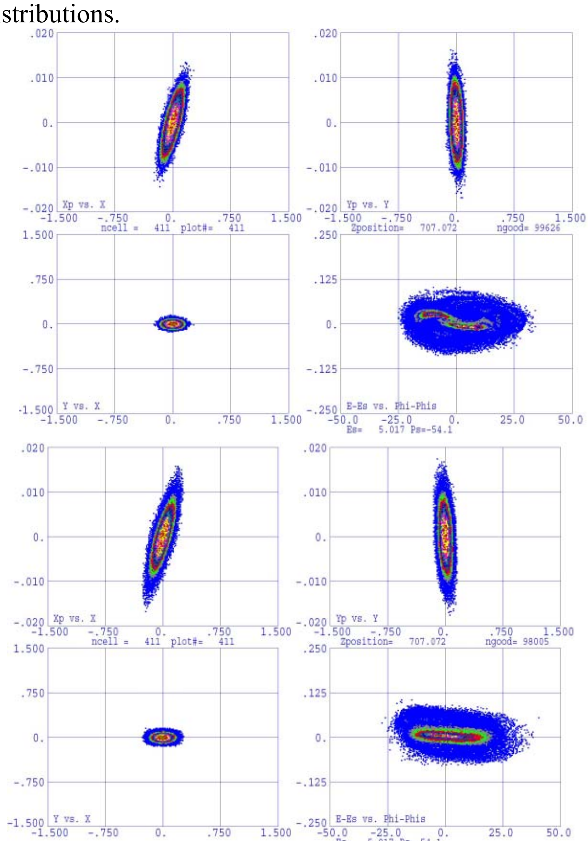

Figure 2: RFQ out for 10 mA (up) and 30 mA (down).

Wangler and Crandall [5] introduced the beam *halo parameter (H)* that gives a very good halo description:

$$H=\frac{\sqrt{3I_4}}{2I_2}-2$$

$$I_2=\langle q^2\rangle\langle p^2\rangle-\langle qp\rangle^2$$

$$I_4=\langle q^4\rangle\langle p^4\rangle+3\langle q^2p^2\rangle^2-4\langle qp^3\rangle\langle q^3p\rangle$$

In situation of elliptical symmetry in phase space, H has a value *0* for KV distribution, a value *0.25* for 4-D Waterbag distribution and unitary value for Gaussian distribution. Multiparticle simulations show that significant halo in the 2D phase-space projection corresponds to H > 1.

RFQ PARAMETRIZATION

With the help of *halo parameter*, RFQ dynamics is presented in the next pictures. The effect of current increase on transmission and on rms emittance is shown in Fig. 3. Transmission as a function of input emittance is not shown because it remains almost constant. In Fig. 4, the parameter halo (H) is plotted for different input currents. While halo formation is controlled on transversal plane, it can be seen a halo increase in longitudinal plane even for low current values (> 5 mA).

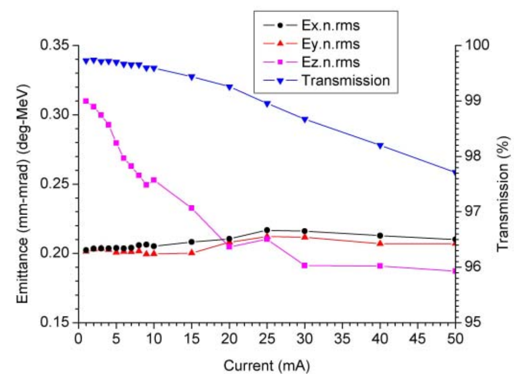

Figure 3: Transmission and rms emittance as a function of input current.

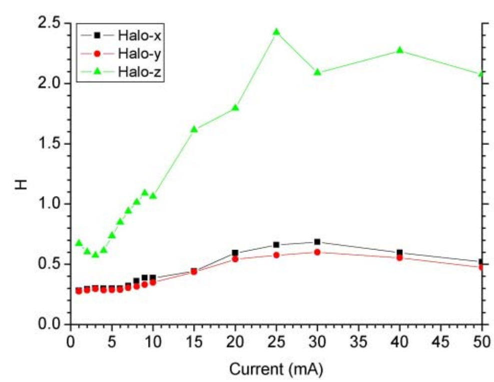

Figure 4: Parameter halo as a function of input current.

Transversal phase-space may be considered halo free in low current region (1-10 mA) where parameter halo is similar to that of the parabolic distribution *(H=0.25)*. For high currents there is an acceptable halo increase causing short tails formation. This effect is not phase-plane dependent (it's almost the same for x-x' and y-y'). Longitudinal phase-space presents a halo structure that increase with current as for transversal plane, but in this case halo is more evident. Halo structure assumes

Gaussian* behaviour up to 10 mA, while it overcomes Gaussian limit for higher currents.

RESULTS AND IMPROVEMENTS

In order to improve RFQ performances at low current, electrode voltage and input emittance may be varied. A wide emittance region (0.06-0.25 mm-mrad) has been investigated and for each emittance value electrode voltage has been varied to +-5 percent. Results show that the effect of voltage variation on beam halo is very small (Fig. 5).

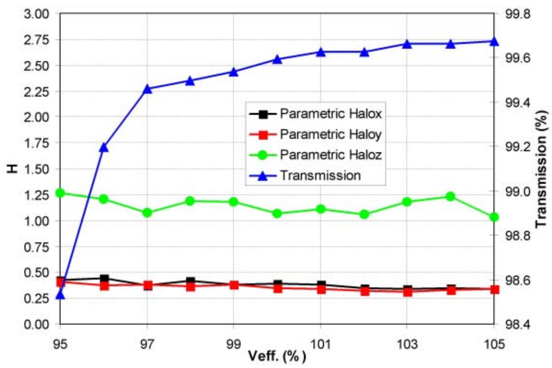

Figure 5: Beam halo and transmission as a function of electrodes voltage.

As regard emittance, decreasing beam current from 30 mA to 10 mA means to decrease beam perveance of the same amount. Considering envelope equation, it is simple to see that to restore previous balance between space charge term and emittance term, it is sufficient to decrease rms emittance by a factor $\sqrt{3}$ that is at 0.12 mm-mrad. This partially solves the problems of limited space charge and has some effects in longitudinal plane allowing the two picks approach themselves but it is not a painless operation. Low current separatrix is larger than high current one. This means that beam has much more space to evolve in longitudinal dimension. This effect combined with the apparent space charge created by low input emittance allows beam halo to increase. Results presented in Fig. 6 show that parameter halo increases with emittance decrease. Fig. 7 shows simulation results for low current and low input emittance.

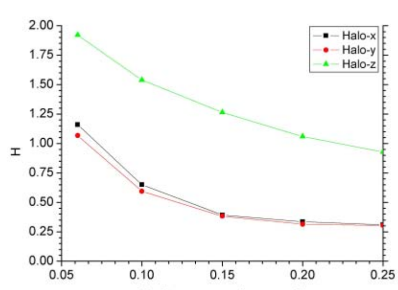

Figure 6: Beam halo as a function of rms emittance.

With very low emittance values, the multi-picks problem is completely solved, but apparent space charge effects cause degradation of transversal beam quality. On the other hand, high input emittance values guarantee low transverse and longitudinal halo, but sharp multi-picks structure.

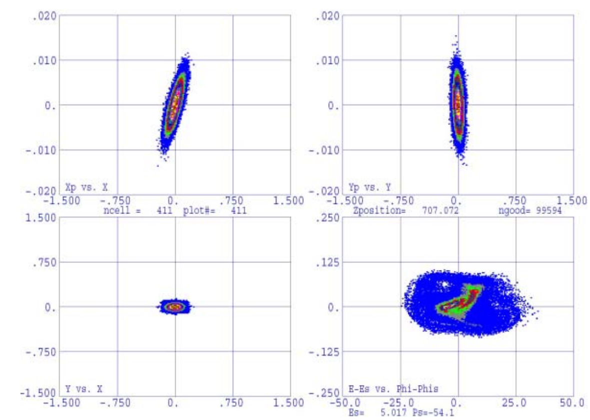

Figure 7: RFQ out for 10 mA and low emittance.

CONCLUSIONS

RFQ analysis shows that good quality beam transmission requires some care. Other studies are in progress to upgrade simulations, substituting 4-D Waterbag distribution at RFQ input, with distribution simulated by source extraction and LEBT transport [6]. An important result in understanding RFQ future behaviour will be the possibility to implement the measured LEBT distribution as input distribution. All the results will be valued taking into account the effects on halo development in the following Linac.

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*It is referred only to tails distribution and not to the beam core that might be very different from a Gaussian. This is implicit in the halo parameter definition that is very little sensitive to beam core.