ACCELERATION OF DEUTERONS AND PROTONS IN SINGLE RFQ STRUCTURE

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Abstract

Some aspects of acceleration of protons and deuterons in single RFQ are considered. If effects of space charge are significantly hath nominal voltage for acceleration of deuterons can be too small to reach high efficiency of bunching and focusing of protons. It is shown that a raising of voltage up to nominal value for deuterons leads to increasing of capture and transmission for protons. Another problem is concerned with a choice of radial matching section parameters, which are optimal for both beams (proton and deuterons) simultaneously. Methods of optimization are discussed. Analysis of particles dynamics is illustrated by calculations results.

INTRODUCTION

Acceleration of ions with a different ratio of charge to mass e/m in a single channel is possible if two conditions are fulfilled:

1. longitudinal velocities at input of channel are equal for all beams,

2. for every type of ions voltage U is chosen to keep the relation eU/m is constant,

3. in case acceleration more then two types of ion with different A/Z in single RFQ one must have possibility to change intervene voltage in required diapason

$$\frac{eU}{m} = \frac{e_{nom}U_{nom}}{m_{nom}},$$

index "nom"means nominal parameters of ion, which were used in calculation of cell lengths.

So if a ratio e/m of some ion is more, than a nominal one we can use reduced voltage to copy beam dynamic when a space charge force is negligible. In our case we need to reduce voltage by one half.

However in opposite case when space charge influence is not negligible decreasing of voltage leads to weakening of external phasing and focusing forces which can compare with coulomb ones and decrease beam transmission and capture as result. On the other hand we have a reserve for doubling of voltage. So we need to estimate how we can use this reserve.

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CURRENT DEPENDENCE

Let consider transverse motion. Increasing voltage we move a working point on stability diagram up to its middle. Usually focusing factor is chosen as about half of value corresponding to a middle of stability interval.

In a longitudinal motion we have two opposing tendencies which counteract each other. On the one hand increasing of voltage leads to extension of separatrix for every accelerating period. On other hand a synchronization of acceleration is destroyed because we lose synchronous particle which gains given energy and phase passing the cell and which is a single center of longitudinal oscillations inside of beam. Now for every accelerating period there is its own particle, so we have additional coherent oscillation of beam inside separatrix.

As an example we used RFQ channel from the paper [1]. The main parameters of accelerator are shown in the table 1. The results are sufficient to allow conclusion: extension of separatrix is more significantly than additional coherent oscillation, transmission and capture are increased and particles does not leave separatrix. Nominal synchronous phase is changing as a smooth curve from -90 to -30 degrees. So, double voltage gives increasing of synchronous phase from -90 to -64 degrees only. As a result, current of accelerated beam depending of voltage and input current is illustrated on picture 1.

Results of these researches proves possibility of simultaneous acceleration of different types of ion with a wide spectrum of ratio e/m and with given input velocity.

Table 1: Example of RFQ Parameters

Parameters	Value
RFQ frequency (MHz)	432
Vane length (m)	6.5
Average channel radius(mm)	1.8
Vane voltage (kV)	50, 25
Injection energy of H-ions beam (KeV)	25
Injection energy of D-ions beam (KeV)	50
Initial dP/P	0
Final energy of H-ions beam (MeV)	2.5
Final energy of D-ions beam (MeV)	5
RMS emittance (cm · rad)	0.05

OPTIMIZATION PROBLEM

In general case when phase volumes of H and D beams have different orientation in phase planes xx'and yy'one

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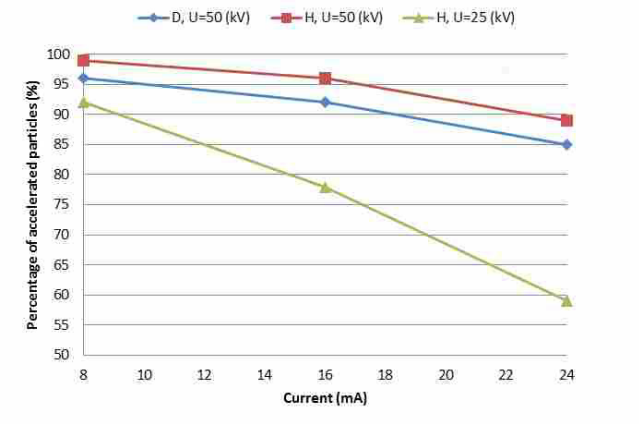

Figure 1: Dependence of ion capture effectiveness on vane voltage and beam current

can seek compromise solution using for example method presented [2,3]. In these papers matching section geometry is formed to accelerate beam, which have transversal phase volume at random oriented relatively acceptance of RFQ regular structure. It is known [4] that under some condition such as linear approximation of accelerating and focusing fields, micro canonical charge distribution and representation of bunches uniformly charged ellipsoids, equations of particle dynamics in RFQ channel may be presented in following form:

$$\frac{d^2x}{dt^2} + K_x(t, I, U, r_x, r_y, \phi_0)x = 0 \quad (1)$$

$$\frac{d^2y}{dt^2} + K_y(t, I, U, r_x, r_y, \phi_0)y = 0 \quad (2)$$

where t – time, U – vane voltage, I – average beam current, r_x, r_y – envelopes of beam in xx'and yy'planes, ϕ_0 – initial phase. Such equations may be used to describe dynamics in radial matching section too. In case of separate acceleration of two beams one need consider two of systems look like (1-2) attaching all dependent variables index H or D. To determine functions r_x, r_y in [2] used matrix algebra method. Let consider matrices A_x, A_y depending on K_x, K_y and matrices G_x, G_y which determine ellipses by filled points presented real particles in phase space, while take place conditions

$$\xi' G_x \xi \le 1, \eta' G_y \eta \le 1,$$
$$\xi = (\xi_1, \xi_2), \xi_1 = x, \xi_2 = dx/dt,$$
$$\eta = (\eta_1, \eta_2), \eta_1 = y, \eta_2 = dy/dt.$$

In case of two separate beams matrix elements G_{xH}, G_{yH}, G_{xD}, G_{yD} determine envelopes and orientation of phase ellipses in phase space. Let consider system of equations:

$$\frac{d}{dt}G_{xH} = -A'_{xH}G_{xH} - G_{xH}AxH, \quad (3)$$

$$\frac{d}{dt}G_{yH} = -A'_{yH}G_{yH} - G_{yH}AyH, \quad (4)$$

$$\frac{d}{dt}G_{xD} = -A'_{xD}G_{xD} - G_{xD}AxD, \quad (5)$$

$$\frac{d}{dt}G_{yD} = -A'_{yD}G_{yD} - G_{yD}AyD. \quad (6)$$

Optimization process includes solution of system of equations (3-6) together with auxiliary conjugate on the interval from the entrance of regular part of RFQ to the entrance of radial matching section, i.e. from $t = T$ to $t = 0$. Initial conditions for the system (3-6) are the matrices of ellipses defining acceptances of regular part of accelerator, depend on initial phase ϕ_0:

$$G_{xH}(T, \phi_0) = G_{xHT}(\phi_0), \quad (7)$$
$$G_{yH}(T, \phi_0) = G_{yHT}(\phi_0), \quad (8)$$
$$G_{xD}(T, \phi_0) = G_{xDT}(\phi_0), \quad (9)$$
$$G_{yD}(T, \phi_0) = G_{yDT}(\phi_0). \quad (10)$$

The optimization problem for the radial matching section is to find a function of radius change along the matching section, providing under condition (7 - 10) the maximum possible overlapping of family of ellipses at the entrance of the radial matching section. Optimization procedure is lead to minimization of functional

$$I(u) = c_1 \int_{\phi_1}^{\phi_2} \Phi_{xH}(\phi_0)d\phi_0 + c_2 \int_{\phi_1}^{\phi_2} \Phi_{yH}(\phi_0)d\phi_0 \quad (11)$$
$$+c_3 \int_{\phi_1}^{\phi_2} \Phi_{xD}(\phi_0)d\phi_0 + c_4 \int_{\phi_1}^{\phi_2} \Phi_{yD}(\phi_0)d\phi_0$$

where constants c_i are choose taking into account currents difference $(I_H - I_D)$. Functions $\Phi_{\chi\lambda}$ in expression (11) are determined as

$$\Phi_{xH}(\phi_0) = Sp(G_{xH}(0, \phi_0) - B_x)^2,$$
$$\Phi_{yH}(\phi_0) = Sp(G_{yH}(0, \phi_0) - B_y)^2,$$
$$\Phi_{xD}(\phi_0) = Sp(G_{xD}(0, \phi_0) - B_x)^2,$$
$$\Phi_{yD}(\phi_0) = Sp(G_{yD}(0, \phi_0) - B_y)^2.$$

Here B_x and B_y are given matrices and according to ellipses which intermediate oriented between G_{xH} and G_{xD} and G_{yH} and G_{yD}.

Functional (11) estimate the degree of mutual overlapping of ellipses corresponding to various initial phases at the entrance of matching section. ϕ_1 and ϕ_2 are limits of variation of initial phase ϕ_0; $\lambda = H, D$. Examples of choice of functionals and procedure of its minimization for similar tasks are given in [5–17].

CONCLUSION

1. Separate acceleration of two or more types of ions with different relation A/Z in single RFQ channel

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may be used for example for preacceleratoin multicharged ions obtained from ECR sources before their injection into booster sinchrotron. Accelerated up to big enough energies ions are used for different applied purposes.

2. Proposed scheme optimization may be used too for RFQ output matching section optimization when one need to prepare ions of different type for further acceleration in DTL structure.

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