ACCELERATION OF DIFFERENT ION TYPES IN SINGLE RFQ STRUCTURE

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The possibility of different acceleration of hydrogen and deuterium ions in a single accelerating RFQ channel is considered. Effective capture of particles into acceleration in general case may be proved by optimization of the physical characteristics of injector and RFQ. Analysis of particles dynamics is illustrated by calculation’s results.

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INTRODUCTION

It is known different acceleration of protons and deuterons in single cyclotron. In this case to obtain both of ion types from single plasma source one can simply to substitute working gas in source camera. Acceleration of deuterons is realized on higher harmonic of the RF field than hydrogen ions. Energy of injection into cyclotron, dee voltage, and final energy in case of deuteron acceleration are twice less than the same parameters for proton acceleration. Separate acceleration of protons and deuterons in single LINAC is possible too, but then some reverse of parameters mentioned above must be made. So injection energy of H ions into RFQ, RFQ wane voltage, their final energy must be twice less in comparison with the same parameters for D ions. But specific energy (energy per nucleon) will be equal in both cases.

1. INJECTION AND ACCELERATION PROBLEM

Preparation of ion beams for injection into accelerating resonators is realized by injection system (injector). Injector consists of ions source and LEBT. LEBT pre accelerate and form beam before injection into RFQ. Preacceleration and formation system includes electrostatic and (or) electromagnetic lenses focusing the beam and electromagnetic correctors too. Parameters of these elements (for example amplitudes and field distribution) one can consider as control function relative to the ion beam [1]. Correct choice of parameters of injection system elements and matching section of RFQ help to achieve optimal matching between beam emittance on the RFQ entrance and RFQ acceptance.

But it is serious problem if one need accelerate two of different beams in single channel because different nonlinear Coulomb interactions H and D ions. The values of the currents, energy spectra, phase volumes etc. may be different too. When currents of H and D ions are small it is possible to form approximate equal phase volumes of H and D beams in transverse phase planes xx’ and yy’ on the RFQ matching section entrance. In such case one may wait 90…100% capture into acceleration both of ion types. In general case when RFQ matching section is optimal according with D ion beam but beam current, phase volume orientation of H ion beam significantly distinguish from the same parameters of D-beam, capture and beam transmission of H ion beam will decrease as far as difference of currents will increase. On Figs. 1-6 characteristics of D and H ion beams on RFQ exit depending on beam current and vane voltage are shown. Initial data for calculations are presented in the table. Initial beams were accorded with focusing channel.

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

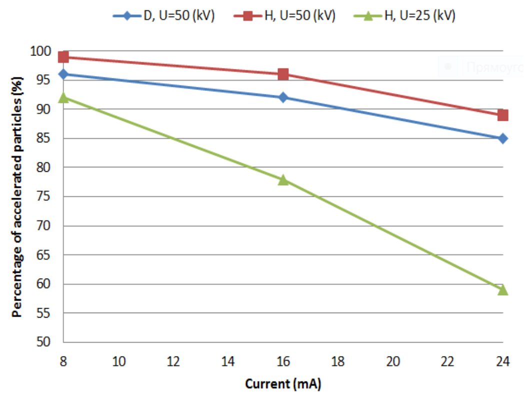

Fig. 1. Dependence of ion capture effectiveness on vane voltage and beam current

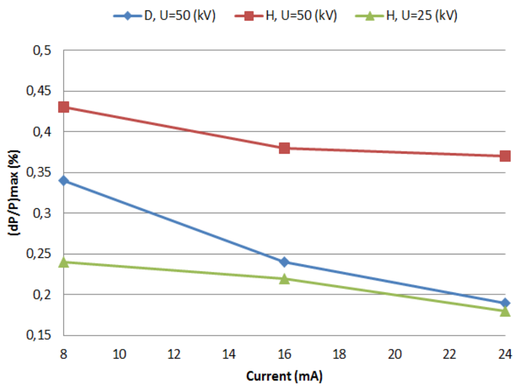

Fig. 2. Dependence of pulsed spectrum width of H and D ion beams on vane voltage and beam current

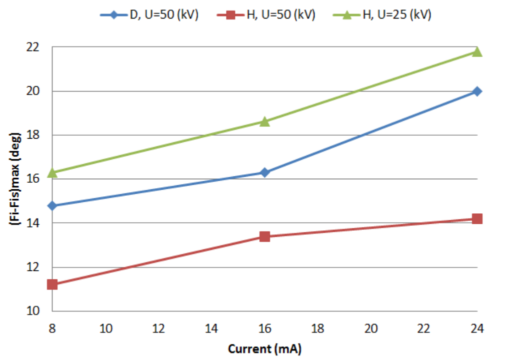

Fig. 3. Dependence of phase spectrum width of H and D ion beams on vane voltage and beam current

As interesting result of calculations one can note that increasing of vane voltage in comparison with similarity principle for lighter ions in this case is useful.

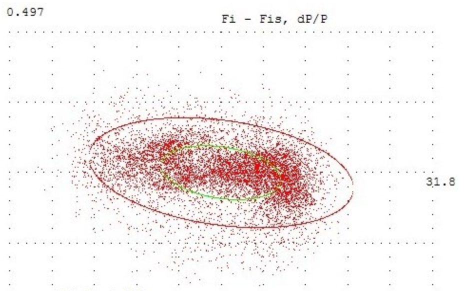

Fig. 4. Phase volume of D ion beam of 24 mA current and vane voltage 50 kV in energy-phase plane

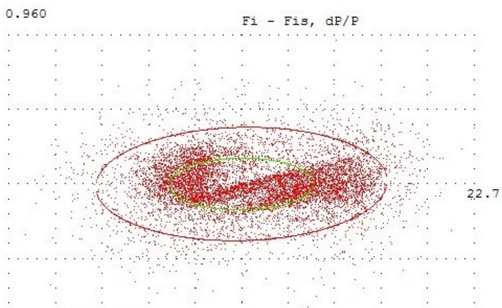

Fig. 5. Phase volume of H ion beam of 24 mA current and vane voltage 50 kV in energy-phase plane

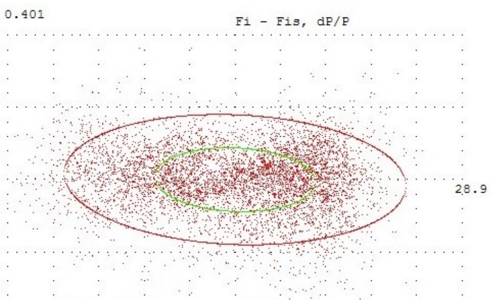

Fig. 6. Phase volume of H ion beam of 24 mA current and vane voltage 25 kV in energy-phase plane

2. OPTIMIZATION PROBLEM

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

$$\frac{d^2x}{dt^2}+K_x(t,I,U,r_x,r_y,\varphi_0)x=0\,, \qquad (1)$$

$$\frac{d^2y}{dt^2}+K_y(t,I,U,r_x,r_y,\varphi_0)y=0\,, \qquad (2)$$

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:

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

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

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

$$\frac{d}{dt}G_{yD}=-A'_{yD}G_{yD}-G_{yD}A_{yD}\,. \qquad (6)$$

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:

$$G_{xH}(T,\varphi_0)=G_{xHT}(\varphi_0), \qquad (7)$$

$$G_{yH}(T,\varphi_0)=G_{yHT}(\varphi_0), \qquad (8)$$

$$G_{xD}(T,\varphi_0)=G_{xDT}(\varphi_0), \qquad (9)$$

$$G_{yD}(T,\varphi_0)=G_{yDT}(\varphi_0)\,. \qquad (10)$$

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

$$I(u) = c_1 \int_{\varphi_1}^{\varphi_2} \Phi_{xH}(\varphi_0) d\varphi_0 + c_2 \int_{\varphi_1}^{\varphi_2} \Phi_{yH}(\varphi_0) d\varphi_0 + c_3 \int_{\varphi_1}^{\varphi_2} \Phi_{xD}(\varphi_0) d\varphi_0 + c_4 \int_{\varphi_1}^{\varphi_2} \Phi_{yD}(\varphi_0) d\varphi_0, \quad (11)$$

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

$$\Phi_{xH}(\varphi_0) = \mathrm{Sp}(G_{xH}(0,\varphi_0) - B_x)^2,$$
$$\Phi_{yH}(\varphi_0) = \mathrm{Sp}(G_{yH}(0,\varphi_0) - B_y)^2,$$
$$\Phi_{xD}(\varphi_0) = \mathrm{Sp}(G_{xD}(0,\varphi_0) - B_x)^2,$$
$$\Phi_{yD}(\varphi_0) = \mathrm{Sp}(G_{yD}(0,\varphi_0) - B_y)^2.$$

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 - 10].

CONCLUSIONS

Acceleration of two types of ions with near relation in single accelerating channel may be used in big projects to obtain a lot of multicharged ions of different types and for some applied purposes. For example in big system for carbon therapy [11]: acceleration of multicharged ions before injection into big ring.

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УСКОРЕНИЕ РАЗЛИЧНЫХ ТИПОВ ИОНОВ В ОДНОМ УСКОРИТЕЛЕ С ПОКФ

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Рассматривается возможность раздельного ускорения ионов водорода и дейтерия в одном ускоряющем тракте линейного ускорителя с ПОКФ. Эффективный захват частиц в ускоряющий режим в общем случае может быть обеспечен оптимизацией параметров инжектора и ускорителя. Анализ динамики частиц проиллюстрирован результатами вычислений.

ПРИСКОРЕННЯ РІЗНИХ ТИПІВ ІОНІВ В ОДНОМУ ПРИСКОРЮВАЧІ З ПОКФ

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Розглядається можливість роздільного прискорення іонів водню і дейтерію в одному прискорювальному тракті лінійного прискорювача з ПОКФ. Ефективне захоплення частинок у прискорювальний режим у загальному випадку може бути забезпечено оптимізацією параметрів інжектора та прискорювача. Аналіз динаміки частинок проілюстровано результатами обчислень.