MULTI-COMPONENT ION BEAM CODE – MCIB04

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Abstract

Multi-Component Ion Beam code (MCIB04) is program library for numerical simulation of the charged particle beam transport lines realized on the PC with Windows user interface of Visual Basic. Applications of the program library on examples of numeric simulations of the beam dynamics in the axial injection channels from ECR ion sources into cyclotrons are illustrated.

INTRODUCTION

The present program library is used for the numerical calculation and optimization of beam dynamics in the transport lines including various magnetic and electrostatic elements. Transverse space charge fields are taken into account. The main advantage of the code is simultaneous simulation of a number of particle components with different masses and charge states. This peculiarity is very important, in particular, for the Low Energy Beam Transport (LEBT) of a high intensity ion beam from ion source to accelerator or beam analysing system.

The library is based on two methods of simulation: the particle-in-cell (PiC) method using the fast Fourier transformation method for the solution of Poisson equation in 2D Cartesian coordinates and the momentum method for particle distribution function.

The PiC method is successfully used for detailed investigation of beam distribution function. This method is also helpful to consider the non-linearity of ion space charge fields [1]. The program may be used for numerical simulation of dynamics of multi-component beams with a realistic charged state distribution. The external electromagnetic fields may be considered both in the analytic form and with the help of the field map.

Fast analysis and study of the averaged beam characteristics, such as root-mean-square (RMS) dimensions, is attained by the momentum method. The main advantage of the momentum method in comparison with PiC method is fast calculation and therefore applicability for beam transport line optimization. The external electromagnetic fields are assumed to be linear. The approach of effective linearization of transversal fields for a special kind of distribution function was introduced to solve the problem of the beam self field in the frames of second order moments. The optimization is based on minimization of a quadratic functional at any point of the beam line by using either gradient or simplex-methods.

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NONLINEAR DISTORTION OF THE BEAM EMITTANCE

In the FLNR JINR the beam of $^{48}Ca^{5+}$ ions is obtained in 14.5 GHz ECR - ion source with helium as a plasma supporting gas. The current of the helium component of the beam extracted from ECR-ion source may achieve 1 mA and is often greater than the calcium one (current of $^{48}Ca^{5+}$component of the extracted beam is less than 100 μA).

In the presence of focusing solenoid placed between ECR-ion source and analyzing magnet and for the big magnitude of the helium space charge the strong nonlinearity of the helium beam self field leads to the formation of a hollow beam of $^{48}Ca^{5+}$ ions just after the analyzing magnet and increases the emittance of calcium ions beam. In Fig.1 $^{48}Ca^{5+}$ particle distributions in (*x*,*y*) and (*x*,*x*') planes just after analyzing magnet are shown. Helium beam current is equal to 1000 mA. Calculations have been done by PiC method.

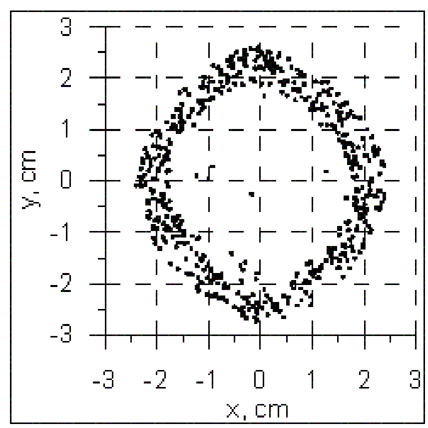

Figure 1a: $^{48}Ca^{5+}$ ions distribution in (x,y)-plane

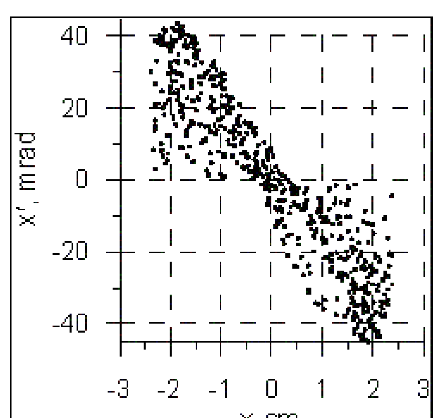

Figure 1b: $^{48}Ca^{5+}$ ions distribution in (x,x′)-plane

COMPARISON OF TWO SIMULATION METHODS

The comparison of two simulation methods on example of DC-72 cyclotron [2,3] axial injection of $^{2}H^{1+}$ ions has been made. The trajectories of ions during transportation in the beam lines calculated by PiC methods are shown in Fig.2a. Beam current is equal to 500 μA, kinetic energy – 16.83 keV. The envelopes of the $^{2}H^{1+}$ beam (that is doubled RMS dimensions of the beam) calculated by momentum methods are shown in Fig.2b. The comparison of the beam envelopes obtained by two methods is shown in Fig2.c. As may be seen from Fig. 2c the difference in the results of simulation by two methods is very small.

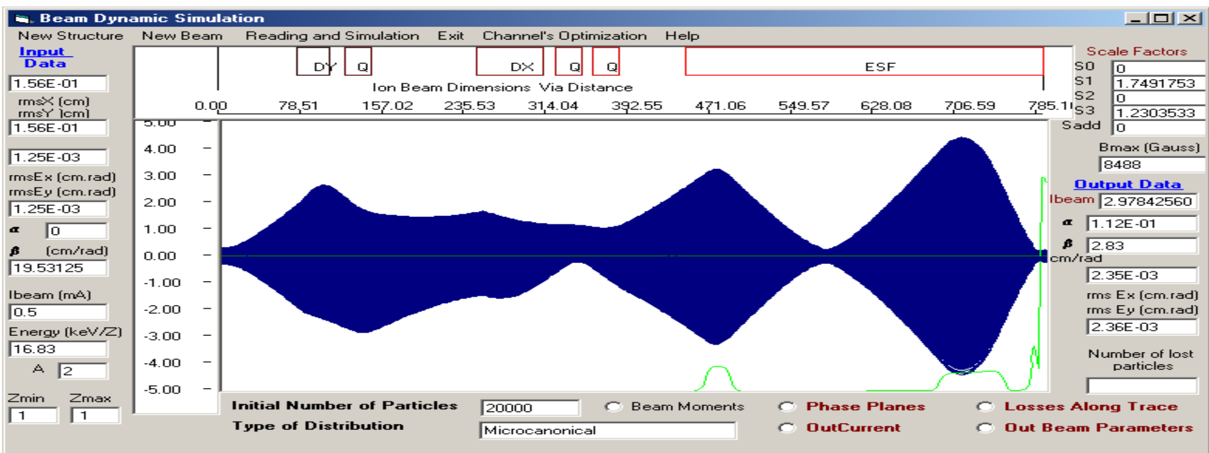

Figure 2a: $^{2}H^{1+}$ ion trajectories in PiC methods. Beam current – 500 μA, kinetic energy – 16.83 keV

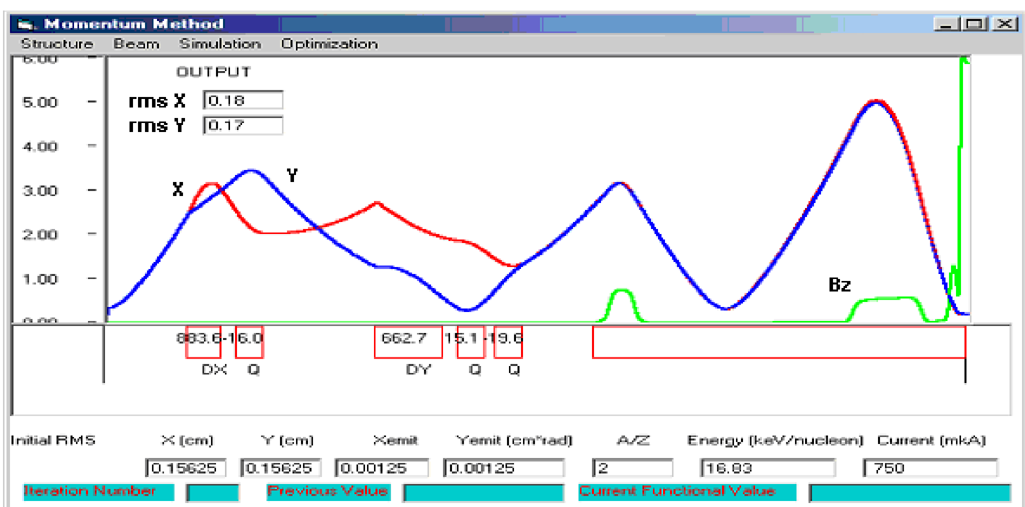

Figure 2b: $^{2}H^{1+}$ beam envelopes (doubled RMS-dimensions) in momentum method

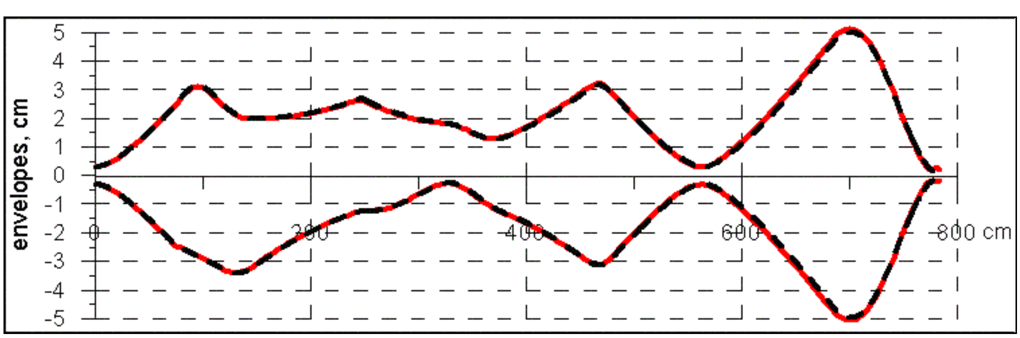

Figure 2c: Beam envelopes: solid lines – PiC method, dashed lines – momentum method

$^{40}Ar^{8+}$ ION BEAM TRANSPORTATION IN DC-72 AXIAL INJECTION CHANNEL

The scheme of heavy ion axial injection channel of the DC-72 cyclotron is shown in Fig.3. The trajectories of the argon ions in the channel calculated by the PiC method are shown in Fig.4. The beam current is equal to 160 μA ($^{40}Ar^{8+}$ beam current – 50 μA), extraction potential of the ECR-ion source is 13.5 kV.

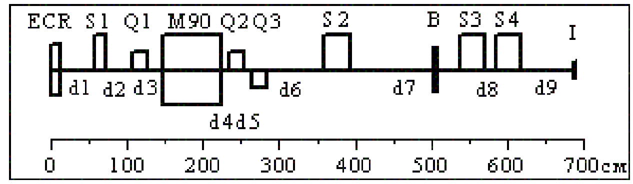

Figure 3: ECR – ECR-ion source, S1-6 – solenoids, Q1-3 – quads, M90 – vertical analyzing magnet, d1-6 – drifts, B – buncher, I – inflector of the cyclotron

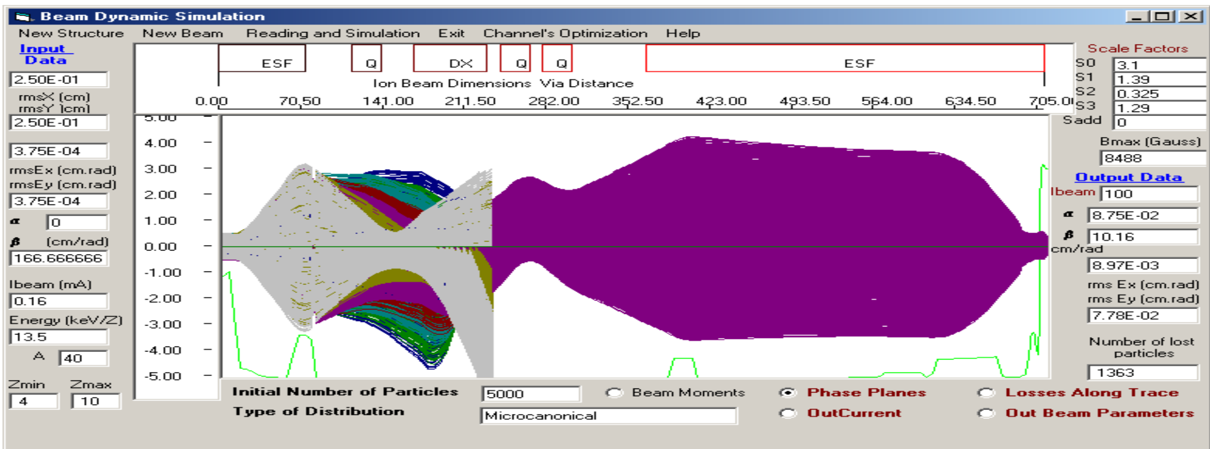

Figure 4: Argon ions trajectories in the channel. PiC method.

H^- IONS IN AXIAL INJECTION CHANNEL OF VINCY CYCLOTRON

The influence of the beam space charge on the H^- ion motion during axial injection into the VINCY cyclotron [3] has been investigated by momentum method. The scheme of the channel is shown in Fig. 5.

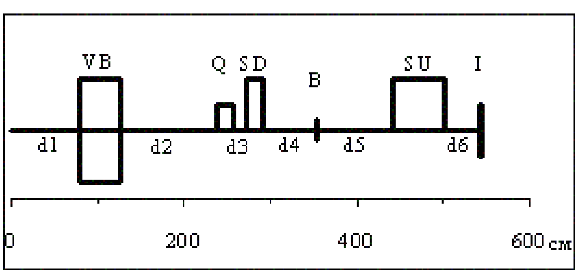

Figure 5: Scheme of the channel: d1-6 – drift spaces, VB – vertical bending magnet, Q – quadroupole; B – buncher; SD, SU – solenoids; I – inflector.

During simulation the H^- beam current have been increased up to 1.5 mA. The values of the acceptance of the channel have been found for various beam current. The H^- beam envelopes for beam current 1.5 mA are shown in Fig.6. The acceptance of the channel in this case is equal to 30 π mm·mrad

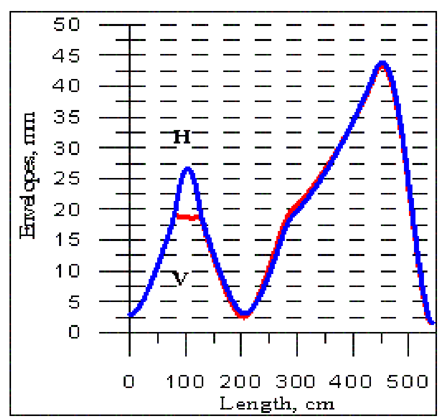

Figure 6: Horizontal (H) and vertical (V) envelopes of the H^- ion beam for beam current 1.5 mA. Momentum method

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