NUMERICAL SIMULATION OF MULTICOMPONENT ION BEAM DYNAMICS IN TRANSPORTATION LINES

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Abstract

A new version of a program library for numerical simulation of ion beam transportation is presented. The library is aimed for simulation of high current and low energy multicomponent beams extracted from ion sources and based on the macroparticle method. Fields of optic elements can be represented in any analytical form, with tables of experimental fields or calculated with the POISSON program. The problem of beam self electrostatic field is solved by numerical integration of Poisson equation using the fast Fourier transformation. The partial neutralization of a beam space charge by secondary electron emission due to ion losses is taken into account. The program library was used for numerical simulation beam dynamics in transportation lines of several institutes. Some new results are presented.

1 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.

The library is installed on the modern PC hardware and software to extend a number of used finite particles and sells of field mesh in simulation as well as available transport line elements. An advanced Windows graphical interface makes it comfortable and friendly for the User in the interactive mode operation.

The macroparticle method used in the code allows to take into account the nonlinear transverse space charge effects. The program may be used for numerical simulation of dynamics of multicomponent beams with a realistic charged state distribution. This peculiarity is very important, in particular, for the low energy stage transport of a high current ion beam from ion source to accelerator or beam analyzing system.

The program library was used for numerical simulation beam dynamics in transportation lines of JINR, CERN, RIKEN, FINP and IKTP. Some new results are presented.

2 PREVIOS VERSION OF THE PROGRAM

Present version of the program is based on the previos one described in [1]. The last one includes:

- the solution of Poisson equation in 2D Cartesian Coordinates using the fast Fourier transformation method;
- the analytical formulas for calculation of electrical and magnetic fields of the "standard" elements: a solenoid with axial magnetic field, quadrupole and multipole lenses, horizontal and vertical bending magnets, accelerating cavity, drift spaces;
- on-line using POISSON/SUPERFISH Group of Codes for calculations of electrical and magnetic fields from user defined sources: solenoids with iron, einzel lenses, electrodes with complicate configuration etc.;
- using an experimental field-table from a file;
- all magnetic and electrical field values can be changed multiplied by the scaling factor defined in the start-up form;
- possibility to use an real charge distribution of all ion beam species (see Fig. 1);
- different types of density distributions in the four-dimensional phase space: Kapchinsky-Vladimirsky, water bag, parabolic, Gaussian;
- achieving the coincidence of the initial conditions in the averaged sense for the various random generation by means the linear transformation of the phase space variables (x , x', y , y').

3 PRESENT VERSION

3.1. In a bending magnet the motion of centres of masses of ions with different charges is taken into account. For a deviation x of radius of an ion from equilibrium radius of an ion charged states Z_0 we have the equation:

$$x'' + \frac{1}{\rho_0^2} x = \frac{1}{\rho_0} - \frac{1}{\rho} + \frac{Ze}{cp_z \beta_z} E_{xs}$$

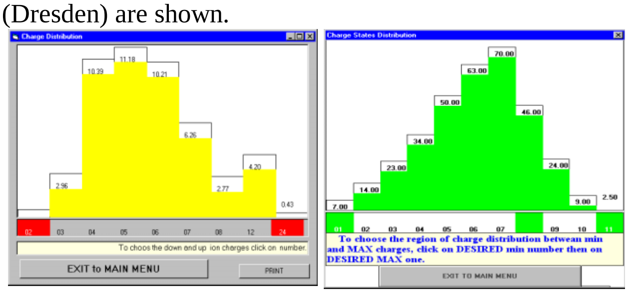
$$\frac{1}{\rho_0} = -\frac{Z_0 eB}{cp_{z0}}, \quad \frac{1}{\rho} = -\frac{ZeB}{cp_z},$$

where p_{z0} - longitudinal momentum of a synchronous particle, B - induction of a magnetic field in a bending magnet. It should be mentioned, that at the exit from a magnet, at nonzero beam current, deviation and angle of center of masses of particles with Z_0 are not equal to zero due to action on it by other charges during a separation of beam species. In calculations these deviations were eliminated. In practice they can be eliminated by small change of an induction of a magnetic field B or with the help of adjusting dipole magnets. The definiton the ion charged state of equilibrium particle Z_0 particle may be done in an initial beam data file (case of Fig.1a) or from the user interface of the initial charge state distribution (Fig.1b).

Examples of simulation in that approach is shown in the Fig. 2, 3. These figures show the visualization of the beam dynamics. This color image is a superposition of traces of all particles. Each charge state is presented with different color. Rectangular boxes in the top of this picture represent the elements of the transport line. The input beam parameters are presented in the left column of figures. The right side column shows the output beam parameters.

Figure 2 represents the example of particle trajectories of Ca_{48} and He_4 beam in the injection line of U-400 cyclotron at JINR (Dubna).

In Figure 3 the results of Ar_{40} beam dynamics simulation in ECR Ion Source transport line at IKTP (Dresden) are shown.



a) b)

Figure 1. Initial charge state distributions:
a) - JINR (Dubna), b) - IKTP (Dresden).

3.2. To estimate a magnitude of neutralization factor of an ion beam space charge in a transportation channel, the following model surveyed. One of the possible reasons is the emission of secondary electrons during losses of ions on devices of a construction of a beam line. The typical value [2,3] of the secondary electron yield for Ar with energy in range 1–50 keV per ion charge *Z* hitting a metallic surface is approximately equal to *Z*. Most of the emitted electrons are relatively slow with the energy distribution peaked at 5-10 eV and this energy does not strongly depends on a sort of ions.

In the program each lost ion was exchanged by a particle with energy 10*Z* eV, charge *Ze* and mass Zm_e, where m_e is the electron rest mass. Obviously, that the maximum effect from action of electrons will be achieved if their longitudinal velocities coincide with mean velocity of ions. The estimation gives, that corresponding longitudinal kinetic energy of electrons is 1-2 eV at the energy of ion 10-20 keV/*Z*. The rest of energy was assigned to a transverse motion.

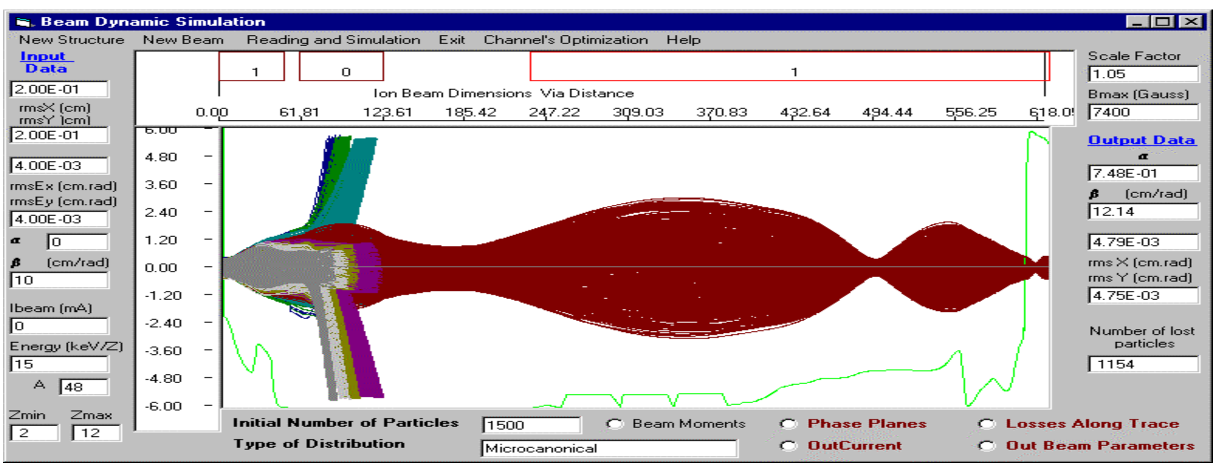


Figure 2. Visualization of the of Ca_{48} and He_4 beam dynamics simulation.

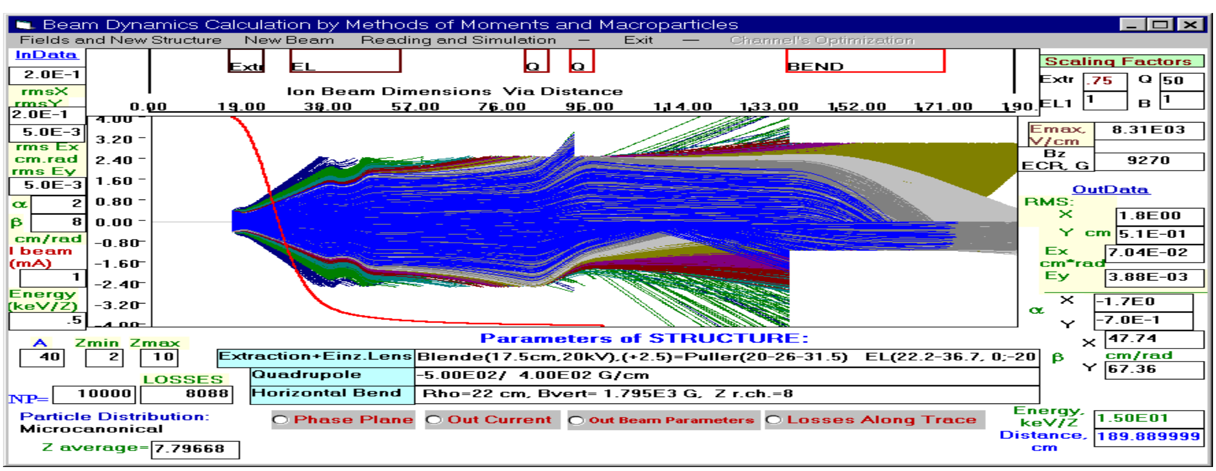


Figure 3. Visualization of the Ar_{40} beam dynamics simulation.

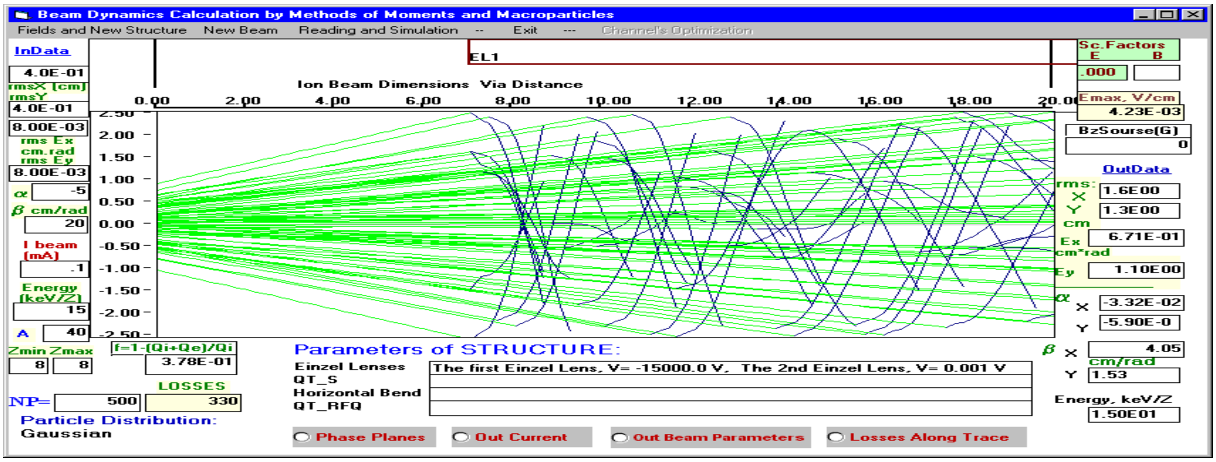


Figure 4. Visualization of the ions and beam dynamics simulation.

The trajectories of ions and secondary electrons are presented in Figure 4. It is necessary to mark that for amplification of a compesation of a space charge effect, in the given example the transverse velocities of electrons were set equal to zero. In this case as it is visible from a figure, during life time of an electron (half of period of oscillations of an electron in a field of ions) the ions pass on distance in some centimeters. Thus the of neutralization factor is about 40 %, that may noticeably change the dynamics of an ion beam.

It should be mentioned that in the presence of magnetic field this effect is absent.

4 CONCLUSION

The program library for calculation of transport lines of intense charged multicomponent beams is developed. It may be used to calculate the electron and ion beams, the distribution of ion charge states including space charge of the beam. The partial neutralization of a beam space charge by secondary electron emission due to ion losses is taken into account. This effect may noticeably change the dynamics of an ion beam.

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