Numerical simulation program of multicomponent ion beam transport from ECR ion source

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Abstract In order to research multi-component ion beam transport process and improve transport efficiency, a special simulating program for ECR beam is becoming more and more necessary. We have developed a program written by Visual Basic to be dedicated to numerical simulation of the highly charged ion beam and to optimization of beam dynamics in transport line. In the program the exchange of electrons between highly charged ions and low charged ions or neutral atoms (residual gas in transport line) is taken into account, adopting classical molecular over-barrier model and Monte Carlo method, so the code can easily give the change of charge state distribution along the transmission line. The main advantage of the code is the ability to simultaneously simulate a large quantity of ions with different masses and charge states, and particularly, to simulate the loss of highly charged ions and the increase of low charged ions due to electron exchange in the whole transport process. Some simulations have been done to study the transmission line of LECR3[1] which is an ECR ion source for highly charged ion beam at IMP. Compared with experimental results, the simulations are considered to be successful.

Keywords Multi-component ion beam, Molecular over-barrier model, Monte Carlo method, Charge exchange, Highly charged state

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1 Introduction

In order to simulate the transport process of multi-component ion beam extracted from ECR ion source we have developed a program named MCIBS 1.0 (see Fig.1) and obtained a series of ponderable results.

The simulation process of MCIBS is divided into several steps: i) create test ions from one of representative distributions; ii) calculate the orbit of each ion in transport elements using transport matrix; iii) revise the trace of ions in space charge field using space charge subprogram and determine the final charged state in this step using electron exchange (capture) subprogram; iv) judge the final positions of ions. If a particle encounters the wall of vacuum chamber, it will not be traced in next transport step. The above process will be repeated again and again until ions reaching the end of transport line.

The program was written by Visual Basic for numerical simulation of charged particle beam transport, and all subprograms were fabricated using Fortran 95 as dynamic library. The present program is mainly used for the numerical calculation and optimization of multi-component beam dynamics in the transport lines including various magnetic elements, such as dipole magnet, solenoid lens and so on. It can simultaneously simulate behaviors of 200,000 particles, 340 m long transport line at most. As a result of simulation, orbits of particles and beam cross section graphics, phase space distribution at any position in the transport line can be shown on the PC. Using it

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one can see clearly the change of charged state distribution, particle's trace and beam current at each moment during the whole transport process.

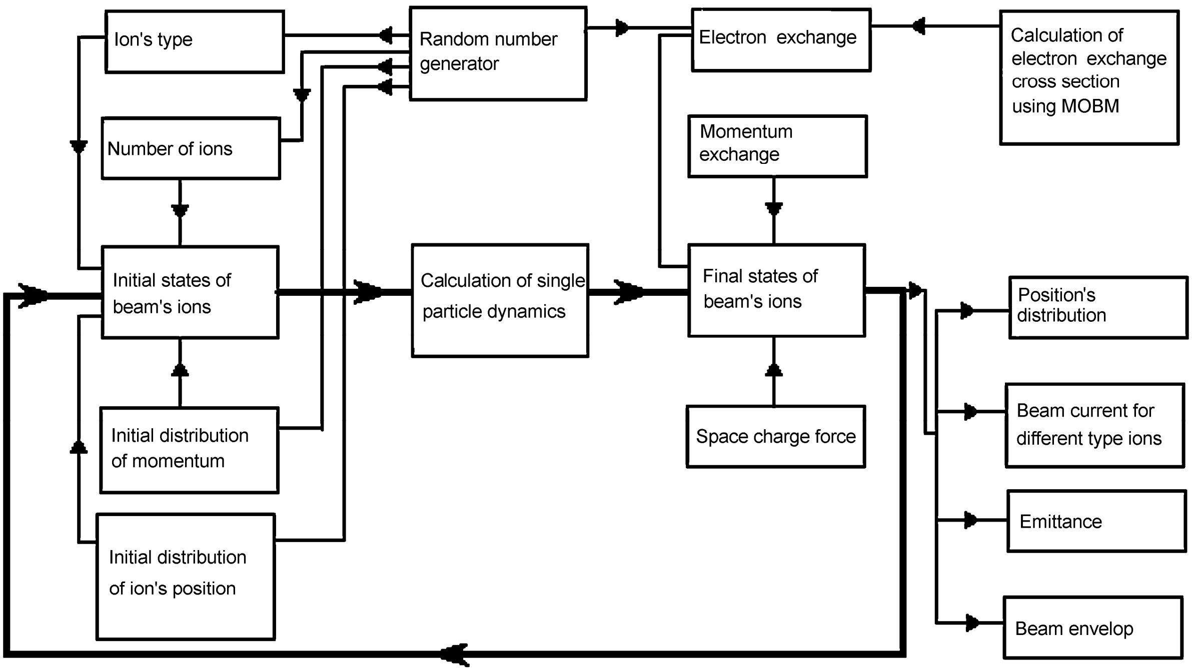

Fig.1 The principle block diagram of MCIBS1.0.

2 Main methods and physics processes considered in the simulation

It is well known that for a multi-component ion beam simulation program, the determination of particle's initial states including position, charge state and energy etc., is very important. In this program the initial states of particles are mainly obtained from some specific distributions or real experiment results. The distributions may be chosen from the uniform, Gaussian, water bag and parabolic by users.

The program is mainly based on four different methods of mathematical simulation: (i) Monte Carlo method[2,3] to create test particles according to the distribution mentioned above and determine the final charge state of particles in each two-body collision; (ii) matrix transport method[4,5] to determine the orbits of particles in each transport element. (a simulation step); (iii) molecular over barrier model (MOBM[6,7]) to determine the cross section of multiple electron capture when collision occurs between different charge state ions or ions and residual gas molecules in transport line; and (iv) long ellipse-cylinder model to approach the space charge force of ions during the transport process.

An advanced Windows graphical interface makes it comfortable and friendly for users to operate in an interactive mode. The program may be used for numerical simulation of multi-component beam transport .The main advantage of the code is simultaneous simulation of a number of particles with different masses and charge states. Another function is to simulate the change of any ion's quantity and proportion in total current. This function is very important, particularly for a low- energy high current beam extracted from an ion source.

3 Input of beam initial parameters

Beam initial data include beam type, extraction voltage, extraction radius of ion source, available radius of transport elements. All those parameters can be directly written down in a chart (Fig.2) at the beginning of simulation. The beam type, as an optional term, includes 107 elements, such as oxygen, carbon, copper, iron, etc. In the library four types of distribution, i.e. uniform, Gaussian, water bag and parabolic, are provided. User can freely choose anyone of them according to the experiment. The initial data of particles including particle's momentum, charge state and position could be obtained according to any kind of distributions mentioned above.

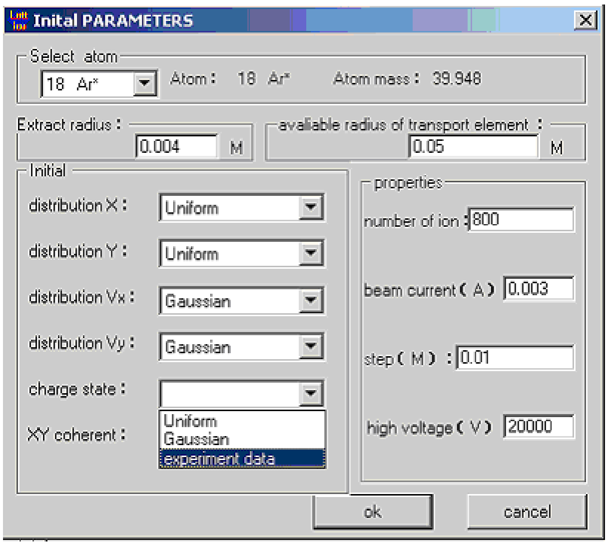

Fig.2 Initial parameter chart.

In order to make the initial charge state distribution more realistic the code offers another option. Some mass-charge spectra from experiments have been stored in the library and new ones can be added by user. These spectra can be used to determine initial charge state of ions extracted from ECR ion source. The user interface is shown as Fig.3.

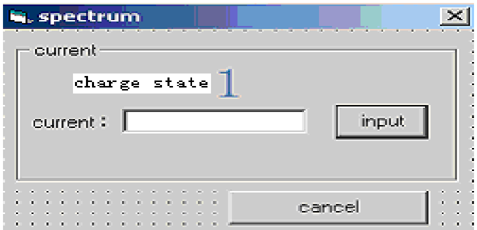

Fig.3 Initial charge state input from experiment data.

4 User interface to set up transport line

Users can easily build a transport line by towing special symbols to working zone in the main menu using a mouse (Fig.4). For example , the symbol ‘A’ represents a drift space.

At present, available transport devices include solenoids, bending magnet, quadrupole and drift space. When an element is towed to the working zone, a parameter dialogue window will pop up for the user to input initial parameters of this device. For example, amplitude of the longitudinal field and effective length are required for a solenoid.

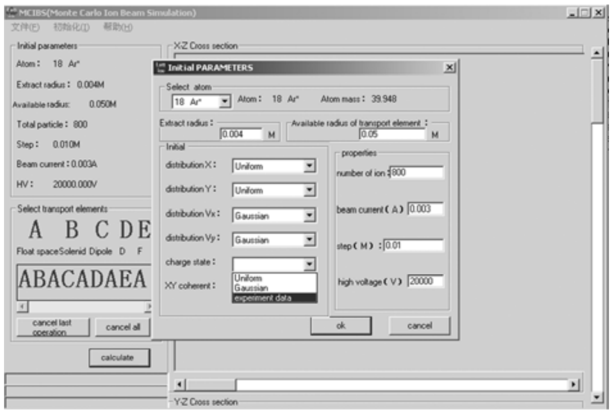

Fig.4 Program main menu.

5 User interface about residual gas in pipe

It is well known that ions probably collide with the residual gas molecules during beam transport. The electron exchange and momentum transfer will occur. Considering this, type and pressure of residual gas are also required to be input in the program by user in a special dialogue window (Fig.5).

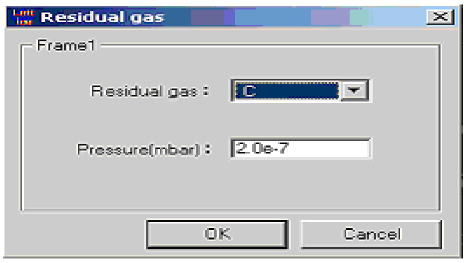

Fig.5 Residual gas parameters input dialogue.

6 Output of simulation result

As already mentioned, beam envelope will be shown on the computer screen when the simulation is completed. Horizontal plane and vertical plane of the ion trace graphic are simultaneously shown in two picture zones. In the picture, different colored curves represent traces of ions with different charged states, so we can easily identify different charged-ion’s trace during the whole transport process (see Fig.6).

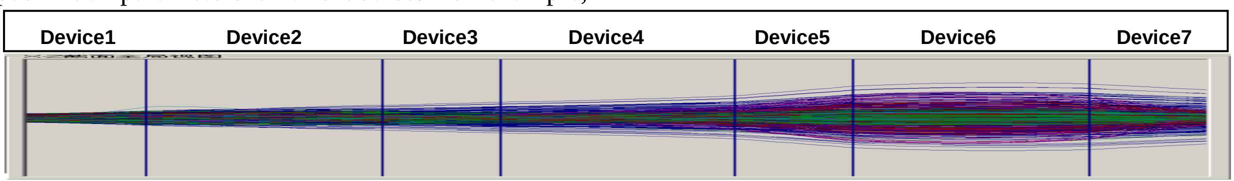

Fig.6 Vertical ion’s trace in the transport line.

In the picture zone, beam cross section graphics at any positions in the transport line can also be easily seen by clicking on the above graphic, i.e, when user clicks at any position in the above picture, the beam cross section graphic at this point will appear on the screen with different ion's number and their current shown (Fig.7). The user can also see the change of cross section and differently charged ion's number along the transport line by tracking the bar at the bottom of Fig.4.

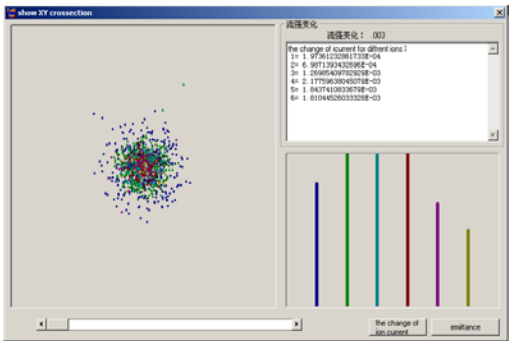

Fig.7 The beam cross section and distribution of ions with different charge states.

When user wishes to know the beam emittance along the transmission line, he can click on the button "emittance" at the bottom of Fig.7 to activiate an emittance graphic (Fig.8). Similarly, user can see the emittance variation along the transport line by draging continuously the bar at the bottom of Fig.8.

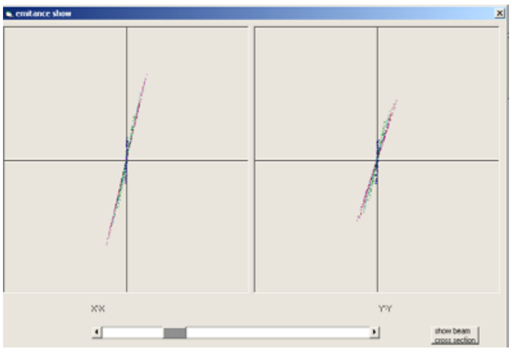

Fig.8 The phase space emittance graphic (non-uniformed).

7 Conclusions and outlooks

Using the program, we have simulated the LECR3's transport line for He^{+} and He^{2+}, and the results agree well with those calculated by Trace-3d. The change of ion's charge state along the transport line can be seen clearly from the change of different ion's number. The highly charged ions decrease and the intermediately charged ions increase. On the other hand, we find that when an intense and low energy beam passes through a solenoid, it will become a hollow beam by simulations. Results from emittance measurement and wein-filter beam detector also verified this phenomenon.[8,9]

We are going to improve this library by optimizing the calculation methods and add the function of ECR plasma simulation. Once completed, this program can be used to simulate the whole process from ion's production to transportation.

References

1 ZHANG Z M *et al*. Rev Sci Instrum, 2002, **73** (2-2): 580

2 Robert C P, Casella G. Monte Carlo statistical method, Berlin: Springer Verlag, 1999

3 Rubinstain R Y. Simulation and the Monte Carlo method, ISBN:0-471-08917-6, 1981

4 Steffen K. Basic course on acelerators optics, CAS CERN 85-19, 1985

5 Humphries S. ,J Charged Particle Beam, John Wiley & Sons, Inc, 1990

6 Grozdanov P. J Phys, 1980, **B13**: 3835

7 Niehaus A. J Phy, 1986, **B19**: 2925

8 Cao Y, Zhao H W, Ma L *et al*. Rev Sci Instrum, 2004, **75** (6):

9 Zhang Z M, Zhao H W *et al*. Rev Sci Instrum, 2004, **75** (46):