MULTIBEAM SYSTEM SIMULATION

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In this paper the possibility of calculating the dynamics of particles of an ion beam and an electron beam in a formation system was investigated. The results of the calculation are compared with the experimental data.

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INTRODUCTION

In modern industrial technologies high-current beams of charged particles are widely used and the creation of multi-beam systems has been discussed for a long time. The use of such systems can solve a number of difficulties that arise when the space charge forces of the ion beam requires compensation in the formation system. For example, the application of space-charge forces of an electron beam for focusing, proposed when creating a collective linear accelerator of heavy ion beams [1, 2], as well as a linear induction accelerator. For the calculation of such systems, a good result is obtained by solving of the synthesis problem and then analyzing the results obtained by the synthesis. The possibility of calculating the electron and ion beam formation system of the high-current heavy-ion collective accelerator model is shown.

1. SOLUTION OF THE ELECTRODES GEOMETRY SYNTHESIS PROBLEM

Using the synthesis program, it is possible to determine the distribution of the potential outside the beam, which provides a given beam configuration (Fig. 1, left). The problem of synthesizing a tubular electron beam with a high degree of compression and a microperveance of the order of 3 μA/V$^{3/2}$. The obtained electrode shapes are valid only for infinite electrodes. When designing, it is necessary to compensate for the effects of the finite dimensions of the electrodes, taking into account the practical implementation of such a system and the resulting heterogeneity of the current density at the cathode.

Using the synthesis program, the geometry of the given equipotential was calculated. As you know this task is incorrect.

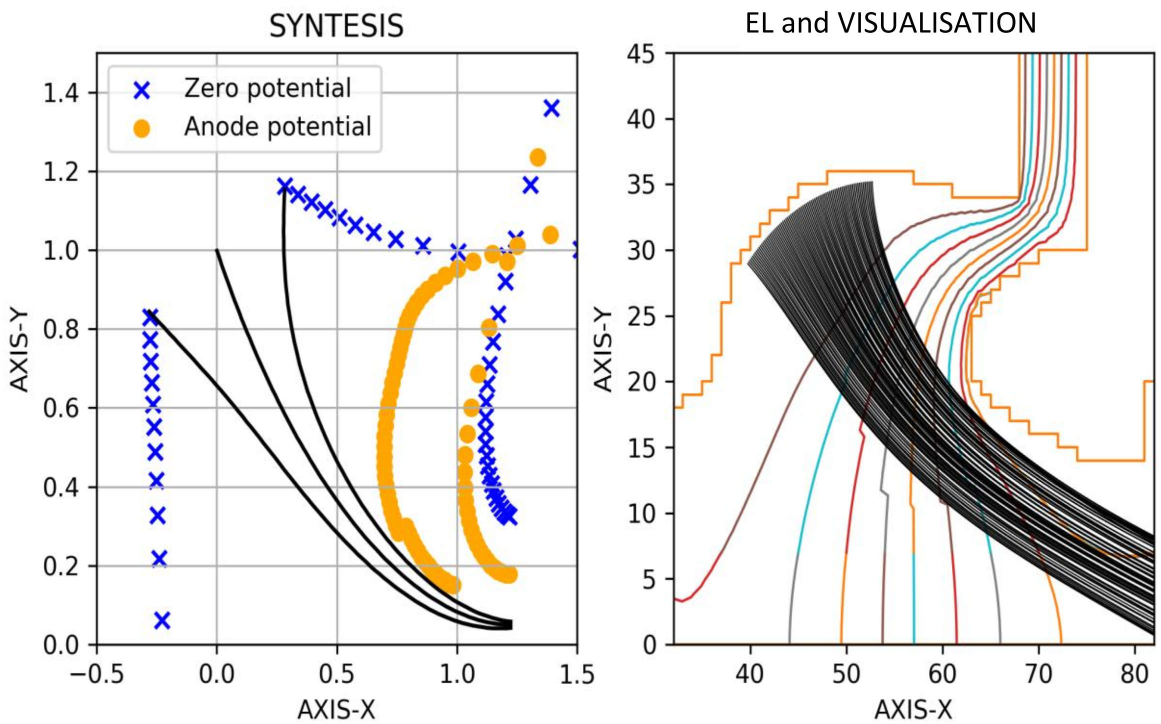

Fig. 1. The results of calculation by synthesis (left) and trajectory analysis (right)

And this can serve as an explanation for such a complex potential structure for given parameters of the central beam trajectory. From the point of view of providing electric strength, further trajectory analysis is required for a given electrode geometry and operating voltage. The shape of the electrodes of the forming systems is carefully modeled and when assembling a high accuracy of repetition of the calculated geometry is required.

2. TRAJECTORY ANALYSIS

Using the trajectory analysis program, it is possible to obtain trajectories of beams in a given geometry for given electrode potentials, taking into account the eigen fields of the beams determined by the space charge distribution. A significant number of calculation programs use "large particle" models as in PIC methods. In this paper we show the possibility of using the current tube method for calculations. A numerical program EL and ION is designed, which simulates the dynamics of charged particles in the electron-optical system [3, 4]. For the particle current density, the flow continuity equation is satisfied. To calculate the electric potential and the electric field strength, used the solution of the Poisson equation for given boundary conditions on a uniform rectangular grid. The density of space charge is determined along the trajectories at the grid nodes at a given value of the current of each tube. The trajectories are determined by integrating the equations of motion in given fields for given initial conditions. The emission current is limited by the space charge and is determined for each current tube according to the "3/2 power" law.

The solution is determined by the "step-by-step" method. The first approximation is the distribution of the vacuum potential, and then the emission current density is determined, the trajectories of the current tubes are located and the distribution of the charge density at the grid nodes. After that, the calculation steps are performed again taking into account the distribution of the emission current density and the space charge density of the previous step. The relaxation of the emission current of the n‘s step is determined by formula

$$j_n = j_{n\text{-}1} + \gamma * [\, f(j_{n\text{-}1}) - j_{n\text{-}1} \,].$$

With the help of the compiled program, the geometry of the electrodes of a low-voltage (up to 1 kV) electron gun with beam compression and an axial hole was determined (see Fig. 1, right). A search for the geometry of the electrodes was carried out and an electron gun was constructed (Fig. 2) for a voltage of up to 150 kV.

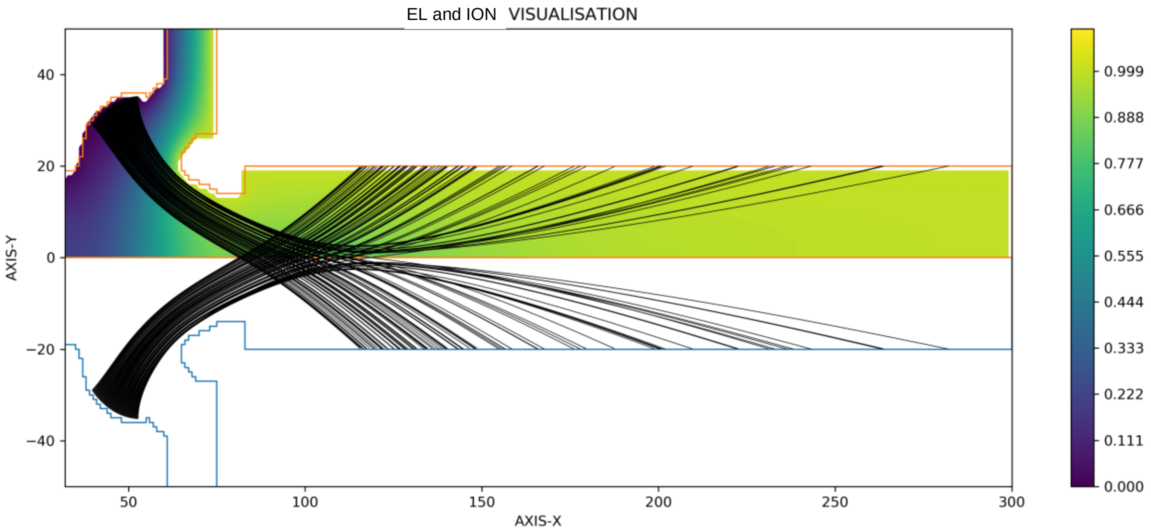

Fig. 2. The result of calculating electron trajectories

3. CONTROL OF THE SYSTEM BEHAVIOR

The sequence of perveance values at each step is called the orbit. The initial segment of the sequence of values of the perveance is called the transition mode. To suppress step-by-step oscillations of the numerical solution, the method of relaxation of the emission current is used. It is interesting to trace orbits for different values of the relaxation parameter of the emission current density. Fig. 3 shows the dependence of the sequence of values of the microperveance on the step number in the calculations of the self-consistent state of the converging electron beam.

A study of the dependence of the properties of a dynamical system on the values of a parameter makes it possible to calculate the dynamics of highly perverted beams of charged particles in complex behavior. A method has been developed for choosing the relaxation parameter, in which, in the first step, the relaxation parameter of the current of each tube is several times smaller than for the subsequent steps. The relaxation coefficient at each subsequent step remains constant.

For the value of this value is less than the critical value, as shown in the figure, the transient in the system leads to a steady self-consistent flow state. The choice of the relaxation coefficient is important, since the stability of the flow state depends on it. In Fig. 3, green color shows the case when, after the transition was completed, the relaxation of the emission current was stopped. In this case, the steady-state value of the beam current at the subsequent calculation steps remains in the system. The state of the flow is stable, as in calculations for values of the relaxation parameter less than the critical value. For the stability of the state found by numerical calculation, an algorithm for calculating the emission current density at each step of the calculation is important, as can be seen in (Fig. 3).

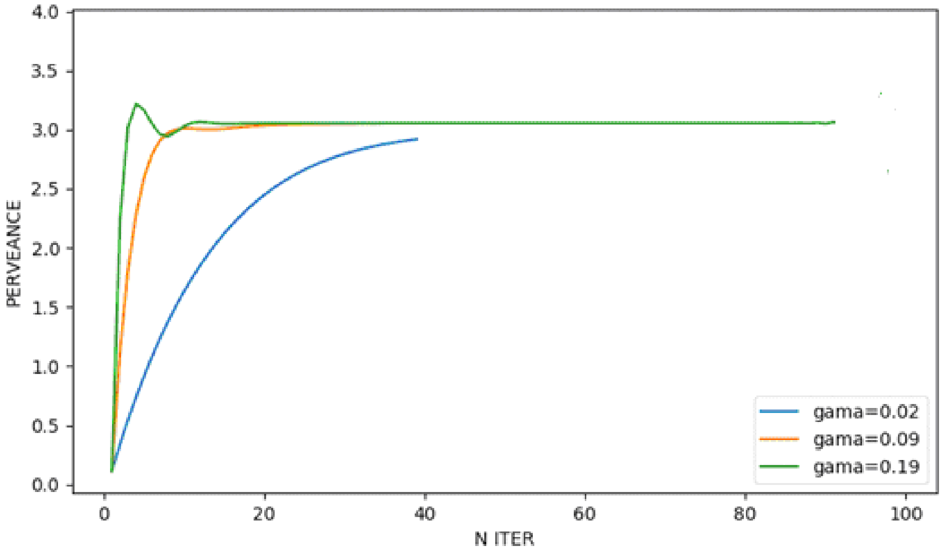

Fig. 3. Dependence of the microperveance on the step number of the calculation

4. RESULTS OF THE TWO-BEAM SYSTEM CALCULATION

The program made it possible to simulate the ion flow generation system in the presence of a converging electron beam. The self-consistent field of the electron and ion beam was calculated by successive approximations. When at each approximation the self-consistent state of one beam is calculated for a given space-charge distribution of the second beam. The calculation finishes at constant states of both beams. The possibility of improving the quality of the ion beam by selecting the appropriate curvature of the emitting surface was shown [5]. The two-beam system ensures the formation of a wide-aperture ion beam in the drift space (Fig. 4) in external electric fields and the fields of charged-particle beams. The results of the calculation of a high-current electron injector were compared with experimental data. The presence of a high-current electron beam diverging behind the anode leads to the fact that the axisymmetric ion beam hits the walls of the drift tube. As in the experiment, when the ions were recorded without an electron beam on the collector, and in the presence of an electron beam, the current signal ceased to be registered.

The possibility of using a plasma source of nitrogen ions was investigated [6]. Such ion source has many advantages before another type of ion sources. There are possibility to use the different sort of gases and others.

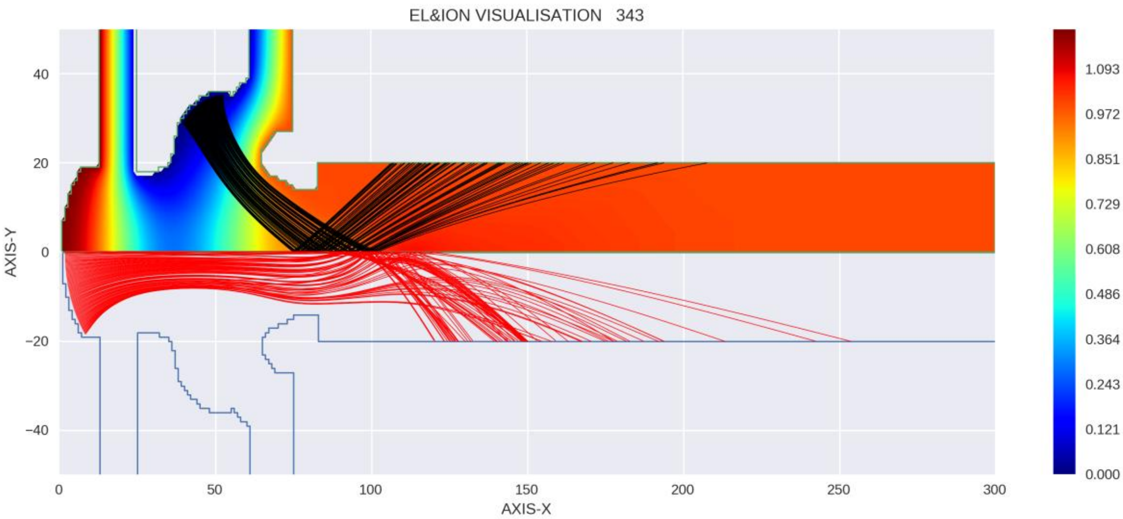

Fig. 4. The results of calculating the trajectories of electron (up) and ion (down) beams

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ МНОГОПУЧКОВЫХ СИСТЕМ

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Изучены возможности расчета самосогласованного состояния электронного и ионного пучков для системы, используемой в модели коллективного ускорителя. Приведены результаты численных расчетов траекторий заряженных частиц в трехэлектродной структуре. Обсуждается сложное поведение при численных расчетах пучков с током, ограниченным пространственным зарядом, методом трубок тока. Приводится способ выбора параметра релаксации эмиссионного тока инжектора, при котором после завершения переходного процесса в расчете достигается стационарное состояние. Проведено сравнение результатов расчета с экспериментальными данными как для сильноточного инжектора электронов, так и для эмиттера ионов азота. Обсуждается возможность расчета системы формирования пучка ионов азота в присутствии электронного пучка.

ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ БАГАТОПУЧКОВИХ СИСТЕМ

П.О. Мартиненко

Досліджено можливості розрахунку самоузгодженої системи з електронного та іонного пучків для моделі колективного прискорювача. Наведено результати чисельних розрахунків траєкторій заряджених частинок у триелектродній структурі. Обговорюється складна поведінка при чисельних розрахунках пучків зі струмом, обмеженим просторовим зарядом, методом трубок струму. Наводиться спосіб вибору параметра релаксації емісійного струму інжектора, при якому після завершення перехідного процесу в розрахунку досягається стаціонарний стан. Проведено порівняння результатів розрахунку з експериментальними даними як для сильнострумового інжектора електронів, так і для емітера іонів азоту. Обговорюється можливість розрахунку системи формування пучка іонів азоту при наявності електронного пучка.