SIMULATING MULTIGUN SYSTEM WITH LANGMUIR LAW EMISSION CURRENT

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The results of numerical calculations of charged particle trajectories in a three-electrode structure are presented. A complex behavior is considered in the numerical calculations by the method of flow tubes of beams with a current limited by space charge. A method is given for choosing the relaxation parameter of the injector emission current at which after the completion of the transition process a stationary state is reached in the calculation.

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INTRODUCTION

This paper is devoted to the study of the possibilities of calculating the self-consistent state of the electron and heavy-ion beam for the system used in the collective accelerator model [1, 2]. There are injectors of a primary electron beam and a secondary heavy-ion beam with thermionic cathodes (Fig. 1). The system sizes are selected to equal the experimental sizes. The final goal is to obtain the heavy-ion beam passage into the anode of a high perveance electron gun with a cathode and anode apertures.

EL and ION program was created for this axial electrode electro-optical system simulation. There is a problem in calculating the trajectories of ions and electrons, which begin to move from the emission surface of the electron and ion guns with zero velocities. In this case, the emission current is determined by the "3/2 power" Langmuir law and the initial conditions for the trajectories correspond to the regime of current limitation by space charge (see the formulas in the attachment). The program implements the flow tube method for calculation and does not require such multiple particles and such multiple potential distribution calculation as in PIC methods. The final goal of the program is to calculate the self-consistent state of some beams.

First of all it is necessary to obtain an answer to the question whether the electron beam self-consistent state to obtaine in the presence of heavy-ion beam will be stationary. Since for one electron beam simulation the perveance value depends on the transition process for the different relaxation parameter values (Fig. 2). This result is called complex behavior [3] and will be discussed further (see COMPLEX BEHAVIOUR). It is suggested that for electron beam current over ion beam current the electron beam self-consistent state remain constant. Because of this only heavy-ion beam injection whithout ion charge effects will be discussed further (see HEAVY-ION BEAM SIMULATION).

The second question is about the use of thermionic cathode. In the model of the collective ion accelerator by a modulated electron beam in the goffered conducting screen was used ion gun with heavy ions like K+ with a special charge state 1+. However, in the advanced acceleration techniques different multiply charged ions like nitrogen, carbon and others from plasma gun need to be transport [4].

COMPLEX BEHAVIOUR

The first of all, the method of successive step by step approximations for the electromagnetic field and the charge flow trajectory calculation was used as it can been seen in Fig. 1. This is only one electron beam simulation.

The algorithm that simulates the transition process the system uses to establish a self-consistent state of the flow method relaxation of emission current injected into the system. Given a emission current determined by the conditions at the cathode, determined the trajectory of the particles and the distribution of the charge density in the space corresponding to the found particle trajectories. Given the distribution of the charge density determined the potential distribution. Repeating this sequence at each step examined the transition process in the system [5]. Fig. 2 contains the 19 consecutive microperveance values for different values of the emission current relaxation parameter for high microperveance electron gun (see Fig. 1). What is noticed for different values of relaxation parameter: 1) it is seen that for values of the relaxation parameter less than 0.7 microperveance values converge to a value of near 3 2) if values of the relaxation parameter over than 0.7 microperveance diverge. It may be as a stationary and periodic or chaotic state of dynamic system in the given external stationary electric field for different values of the parameter [3]. It is easy to explain this behavior.

The determination of the emission current at the first step for the vacuum distribution of the potential in the diode leads to an excessively high value of the emitted current. The value of the space charge at the first step will be greater with this definition than in the stationary state. Therefore, the potential distribution determined at the second step differs from the stationary one. Because of this, the field near the surface of the cathode can change the sign for some tubes of current. And further, if the field on the cathode prohibits the emission current, then the emitted current will decrease and the distribution of the space charge will change. Therefore, the potential distribution determined at the next step differs from the previous one. Next, the dynamics will be repeated, which leads to a step-by-step oscillation of the current (microperveance) and space charge values. But as follows from the theory, the equality of the field at the cathode to zero is an equilibrium condition (see attachment) for the existence of a certain diode current and potential distribution, at which the equilibrium distribution of the space charge is ensured.

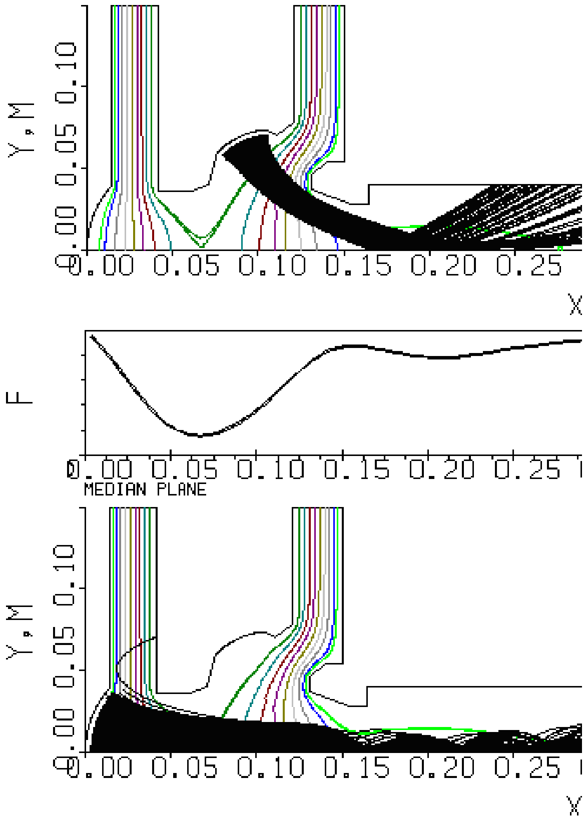

Fig. 1. (up) – High perveance electron gun; (middle) – Axes potential distribution; (down) – Ion gun

A method for choosing a the emission current relaxation parameter has been developed, in which, in the first step, the current relaxation parameter of each tube is several times smaller than for the subsequent steps. The value of the initial relaxation parameter determines the initial value of the current density for each tube at which this value is close to the value in the stationary state. The value of the current relaxation parameter at subsequent steps determines the dynamics of the system step by step. For a parameter value that is less than the critical value during the transient process, the microperveance oscillation range decreases, and at the parameter values greater than the critical value increases, as explained above.

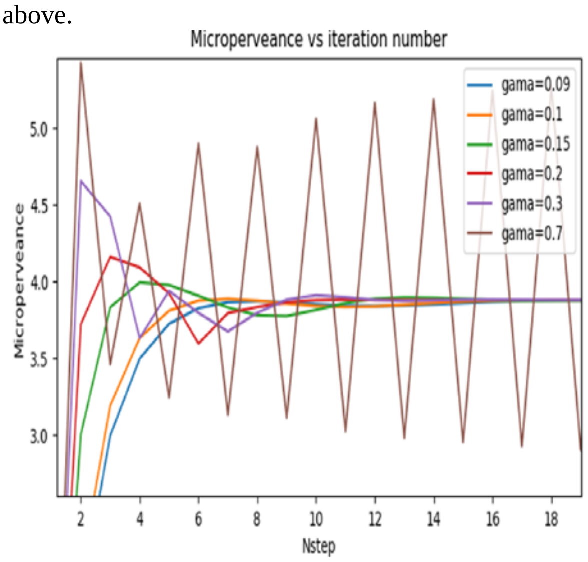

Fig. 2. Microperveance values for some relaxation parameter (gama) values

HEAVY-ION BEAM SIMULATION

An ion source to be used in collective method acceleration experiments has been designed, constructed and tested. Fig. 1 (down) shows the injection of the heavy-ion beam in more detail. In this region, the particle trajectories are calculated with smaller step sizes and primary externally electron beam are accelerated downstream as it can been seen in Fig. 1 (up). These parameters optimised in previous simulations to obtain a particle trajectory accuracy better than 0.5%, important to model the heavy-ion gun It seems that there is a focusing in the trajectories of the heavy-ion beam better then in case simulating an ion beam without an electron beam.

The results of the calculation are compared with the experimental data for both the high-current electron injector and for the thermoemitter of alkali metal ions.

ATTACHMENT

When a voltage is applied to the diode gap, electrons emitted by a heated cathode form a space charge distribution in the diode gap in a time of the order of the time of flight of the diode gap. The presence of a space charge leads to a change in the distribution of the potential in the diode gap and a decrease in the electric field at the cathode down to zero. This field depends on the space charge distribution. But a decrease in the emission current and an increase in diode voltage reduces the effect of space charge and preserves the electric field at the cathode. When the stationary diode voltage is reached, if the diode current is substantially lower than the cathode emission current (at high cathode temperatures), the electric field at the cathode would be zero.

In a one-dimensional flat diode, the value of the diode voltage determines the current density through the diode and the potential distribution in the diode. The steady stationary state of the flow is stable, in the sense that the current density remains unchanged. With small variations in the density of the space charge and velocity as functions of the spatial coordinate in the linear approximation, the variation of the current density is zero. The equilibrium distribution of space charge and velocity is established.

$$\frac{d\varphi}{dx} \approx \frac{4}{3} x^{\frac{1}{3}};$$

$$\rho \approx -\frac{d^2\varphi}{dx^2} = -\frac{4}{9} x^{-\frac{2}{3}}; v \approx \varphi^{\frac{1}{2}} = x^{\frac{2}{3}};$$

$$j = (\rho_0 + \delta\rho)(v_0 + \delta v);$$

$$j = j_0 + \delta j = \rho_0 v_0 + (v_0\, \delta\rho + \rho_0 \delta v);$$

$$\frac{d\rho_0}{dx} v_0 \approx \frac{8}{27} x^{-1}; \frac{dv_0}{dx} \rho_0 \approx -\frac{8}{27} x^{-1};$$

$$\frac{d\rho_0}{dx} v_0 + \frac{dv_0}{dx} \rho_0 \equiv 0;$$

$$\delta j = v_0 \delta\rho + \rho_0 \delta v = (v_0 \frac{d\rho_0}{dx} + \rho_0 \frac{dv_0}{dx}) \delta x = 0.$$

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ МНОГОИНЖЕКТОРНЫХ СИСТЕМ С ТОКОМ ЭМИССИИ, ОПРЕДЕЛЯЕМЫМ ЗАКОНОМ ЛЕНГМЮРА

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Работа посвящена исследованию возможности расчета электронного и ионного инжекторов для системы, использованной 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 тока эмиссии инжектора, при котором после завершения переходного процесса в расчете достигается стационарное состояние пучка. Проведено сравнение результатов расчета с экспериментальными данными как для сильноточного инжектора электронов, так и для термоэмиттера ионов щелочных металлов.

ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ БАГАТОІНЖЕКТОРНИХ СИСТЕМ З ЕМІСІЙНИМ СТРУМОМ, ЗГІДНО ЗАКОНУ ЛЕНГМЮРА

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Робота присвячена дослідженню можливості розрахунку електронного та іонного інжекторів для системи, використаної в 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 пучка. Проведено порівняння результатів розрахунку з експериментальними даними як для сильнострумового інжектора електронів, так і для термоеміттера іонів лужних металів.