Space - Charge Ion Optics for Multi - Beamlets

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A self consistent 2D multi-component beam dynamics code TRAKT [1] has been used to develop a design for extracting electrode system of plasma multi-beamlets sources. On the basis of this design, a technique of geometry construction is proposed, not requiring large computing resources. It is presented an example of ion extracting system in ECR ion source.

1 Describing of Simulation Model

Among models, describing ion beam injection can be allocated two main groups, in which in this or that degree of approach a problem of beam forming with required parameters is decided. In the first case start of ions in the accelerating electrod field [2,3] is supposed, and the area of beam extraction is not considered. Thus, as a rule, the insufficiency of experimental data concerning starting emittance results due to indefinitely of initial data take place and the question about reasonableness of a forming beam remains open. The more common approach assumes start of particles directly from plasma [4,5,6]. Density of background particles in this case is determined by using Boltzmann equillibrium distribution [5], or there are considered Maxwellian distribution of velocities in braking field [4] and uniform distribution of plasma density along a start surface. At the approach, described in work [6], the distribution of particle inlet velocity can differs from Maxwellian distribution and plasma density can differs from uniform. Both these parameters can be set by some functions of distribution according to really existing and measured in a source. The consideration of a background components requires generation of a plenty particles (up to several of thousands) and huge computing resource expenses. The realization of such approaches present a real challenge for a today's day. The essence of method is reduction of construction of the beam start surface - border of transitive plasma area, where the background particles already do not penetrate. The left-hand position of a boundary surface is originally looked. Thickness of a sheath region is defined by using of one-dimensional Self's equation [7]. Size of sheath depends on parameters of source's plasma: density, electron temperature, type of ionization, voltage difference across of plasma and extracting electrod. Depending on thickness of sheath region and curvature of equipotential surface, in according to potential on a plasma electrode in zero approximation of a field (without considering space charge of beam), radius of a spherical surface are selected so that the boundary surface of sphere was originally in the plasma region outside a sheath region, and self-consistent Poisson - Newton equations are solved. If there is "lock-out" of beam, so the left-hand position is determined. Physically it means, that the chosen surface is in sheath region, where besides main components there are the background particles and space charge compensating influence of which is not taken into account. The subsequent process is reduced to definition of such position of a boundary surface by change of spherical surface radius and movement of a surface left to right, at which does not occur beam "lock-outs". On each step of process, depending on the initial purposes, is made one or several adjusting actions:

- radius of sphere changes;
- distance between electrodes changes;
- form of plasma and extracting electrodes are corrected.

It is enough 3-5 steps, as a rule, to obtain required surface. The choice of emitter surface as spherical or flat imposes restriction on uniformity of plasma concentration and, accordingly, on types of sources, for which such uniformity is possible. In case, when the plasma is non-uniform (for example, duaplasmotron) border of plasma will have the more complex form.

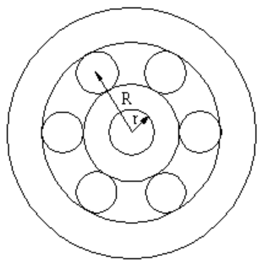


Fig.1. Cross section of a plasma electrode

For numerical modeling of a multi-component beam for a multi-aperture extractor are used 2D code TRAKT . On a plasma electrode are located beamlet layers with one, six beamlet rings by a diameter r. The distance between beamlet layers is R-r (Fig.1). At account set of beamlet rings on second layer are replaced by a cylindrical pipe with external radius R + r and internal radius R-r. The estimation of change for beam quality at 2D approximation doesn't made, but it is clear, that phase volume of a real beam will increase because of azimuthal field inhomogeneity.

2 Peculiarities of Electrode System Construction for a Multi-Aperture Sources

At designing of electrodes for multi-beamlets, as is shown in work [8], each aperture works independently, i.e. perveance and beam divergence for each aperture the same, as for single. Therefore it is necessary to develop system of electrodes for one aperture. The following scheme of geometry construction is offered.

Normalized perveance of an accelerating electrode at a given voltage between electrodes V is defined:

$$P_N = (I / V^{3/2}) / \chi, \chi = \frac{4\varepsilon_0}{9}\sqrt{2e}\sum_{i=1}^{n}\frac{\gamma_i}{\sqrt{M_i}},$$

Where ε_0 - dielectric permittivity of vacuum,

χ - Child constant of a multi-component beam,

γ_i - relative mass concentration of i-component ,

M_i - atomic weight of i- component.

For reception of beams with small angle divergence it is necessary to have normalized perveance $P_N \approx 0{,}1$. It should impose the requirements of high uniformity of source plasma concentration. If beam divergence and normalized perveance are known then extracted current and either distance between plasma and accelerating electrodes or voltage are defined according to an equation Child-Lengmuir [9] . In work [10] is marked, that not average distance between plasma border and accelerating electrode, but distance between electrodes is used in Child-Langmuir expression and gives the best conformity with experimental data for three-electrode system.

On the following step geometry construction for one aperture is used numerical modeling by according to some principles of plasma and accelerating electrode's geometry forming [9].

After system of electrodes for one aperture according to a common current of a multiaperture beam is developed accommodation of holes on a plasma electrode so that of lateral space was enough for forming of required electrod geometry. If distance between holes on an electrode is not enough, lateral space for forming of electrodes with Pierce or specially selected geometry for the single aperture is reduced . It can be the reason of constructive or technological difficulties.

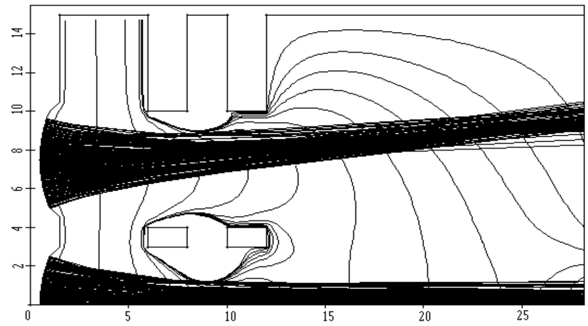
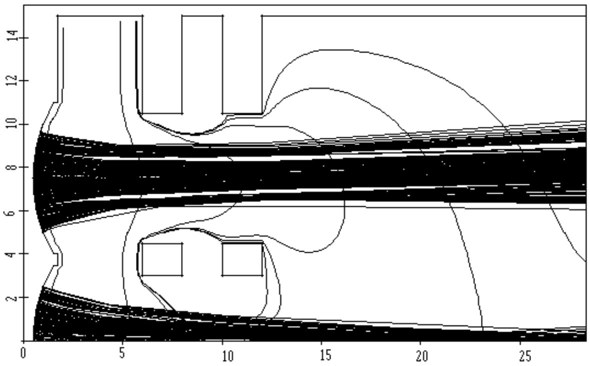


Fig.2. A deflection of the beamlet due to lateral shift (0.5 mm down-shift with respect to axis of symmetry has result to 5° beamlet deflection at normalized perveance 0.78)

Control of emittance's growth also requires that stacking beamlets against each other was with minimal overlap. It will be possible if lateral shifts up or down of apertures on accelerating electrode from axis of symmetry of plasma electrode apertures may be made (Fig.2). It is necessary to take into account, that it is true for beams with low emittance and small diameter. On the following step the geometry is corrected with using of numerical simulation.

3 Example of Extraction System in ECR Source

Now the extraction system ECR source for the high-voltage accelerator is considered. For such sources it is possible to recieve uniform plasma concentration, therefore the submitted technique can be applied. Statement of the problem: it is required to design three-electrode extraction's system for two-component beam O_2^+ (60 %) and O_1^+ (40 %), extracted current is 50 A, output energy is 30keV, with beam divergence is near 2° . On a plasma electrode are located two layers of beamlet rings 5 mm diameters, one and six rings accodingly. The distance between beamlet layers is 7,5mm. For small beam divergence it is necessary $P_N \approx 0{,}1$. Therefore, knowing output energy beam, it should be defined the most acceptable variant, appropriate to voltage 33 kV. Taking into account all above listed peculiarities of extracting system construction it was possible to design system, represented on fig.3.



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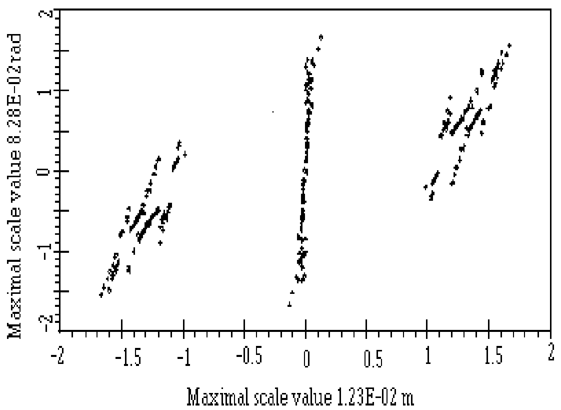

b

Fig.3. The electrod system of ECR source
a. Trajektory,
b. Diagram emittance
of main beam component

4 Conclusion

The submitted technique can successfully be applied to design of electrode system in various types of sources with uniform concentration of plasma. When the plasma is strongly non-uniform, the complex border of plasma can be set by line segments. It will complicate a problem for calculators but will let qualitatively to estimate researched geometry of electrodes and to construct optimum geometry.

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