ANALYSIS OF ION TRAJECTORIES WITHIN A PINCH COLUMN OF A PF-TYPE DISCHARGE

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Abstract

The paper reports on numerical modeling of motion of ions (protons and deuterons) generated within Plasma-Focus (PF) devices. Trajectories of the ions inside and near by a plasma column are computed for homogeneous and filamentary pinches. Pinch current and ion energy values are varied within a range of 0.6 - 1.8 MA and 5-500 keV, respectively. Also computed is an angular distribution of the investigated ions. The results remain in a good agreement with other theoretical approaches but they do not agree with experimental angular distributions satisfactorily.

1. Introduction

The emission of ions, particularly accelerated primary ions, from PF facilities has been investigated in various plasma laboratories for many years. Numerous experimental data and various ion emission characteristics have been collected and published [1-7], but motion and acceleration mechanisms have not been so far fully explained. Some experimental data [3-7] showed that the fast ions are emitted in a form of pulsed beams of different energy and divergence. Therefore, it was assumed that the primary ions can be accelerated within or near tiny hot-plasma regions (so-called “hot spots”), formed within a pinch column and observed as micro-regions of increased X-ray emission

A discovery of the filamentary structure within pinches, as observed for high-current PF discharges [8], has however changed previous notions about motion of the ions within and nearby a pinch column. Some computations of ion kinetics were carried out for a cylindrical homogenous pinch column [6], but modeling of a filamentary case was performed in the first approximation only [9]. The main aim of this work has been to extend previous computations of ion trajectories for different values of discharge currents and particle energies. Particular attention has been paid to a comparison of a homogenous and filamentary cases.

2. Description of the model

A homogenous pinch column has been treated as a plasma cylinder in which the discharge current distribution is uniform. A filamentary pinch has been considered as a superposition of several (e.g. six) identical current filaments of a very small diameter, parallel to the z-axis and distributed symmetrically upon a surface of the pinch column. In some cases a central (axial) current filament has been added, as shown in Fig.1.

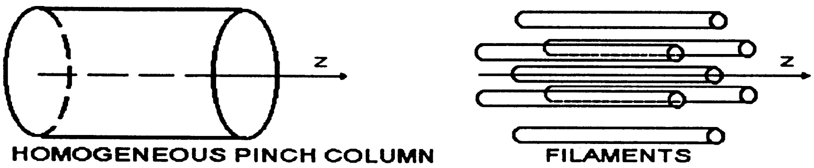

Fig. 1. Discharge current distributions considered for the 3D modeling

For a homogenous pinch the magnetic field has been taken as for a usual linear current, i.e.

$$B_r = 0; \; B_z = 0;$$

$$B_\varphi = {2I}/{cr} \text{ if r } > \text{ R}, \quad B_\varphi = {2Ir}/{c} \text{ if r } < \text{ R}$$

where I denotes discharge current intensity, c - light velocity, and R – a pinch column radius. For a filamentary column, appropriately, it has been assumed

$$B_r \neq 0; \; B_z = 0;$$

$$B_\varphi = \sum_{i=1}^{n} B_\varphi^i$$

To analyze ion kinetics we have solved a system of differential equations of ion motion

$$\frac{dv}{dt} = \frac{e}{mc}(v \times B) - \nu_{coll} v$$

where $v(v_r, v_\varphi, v_z)$ denotes particle velocity, e – its electric charge, m - mass of the particle, and ν_{coll} - collision frequency. During computations we have considered three different values of the collisional term: outside the pinch column, inside the pinch column but outside filaments, and inside the filaments.

Calculations have been performed for three chosen current values: 600 kA, 1.2 MA, and 1.8 MA. Trajectories and angular distributions have been computed for two kinds of charged particles - protons and deuterons, within three separate energy ranges: 5-20 keV, 125-200 keV and 500 keV. In order to reduce computing for z > 0.1 m magnetic field was taken to be zero. Initial positions of particles were chosen in a following way: z = 0, while r and φ were generated by a random number generator. The number of filaments was assumed to be 6 plus the central one.

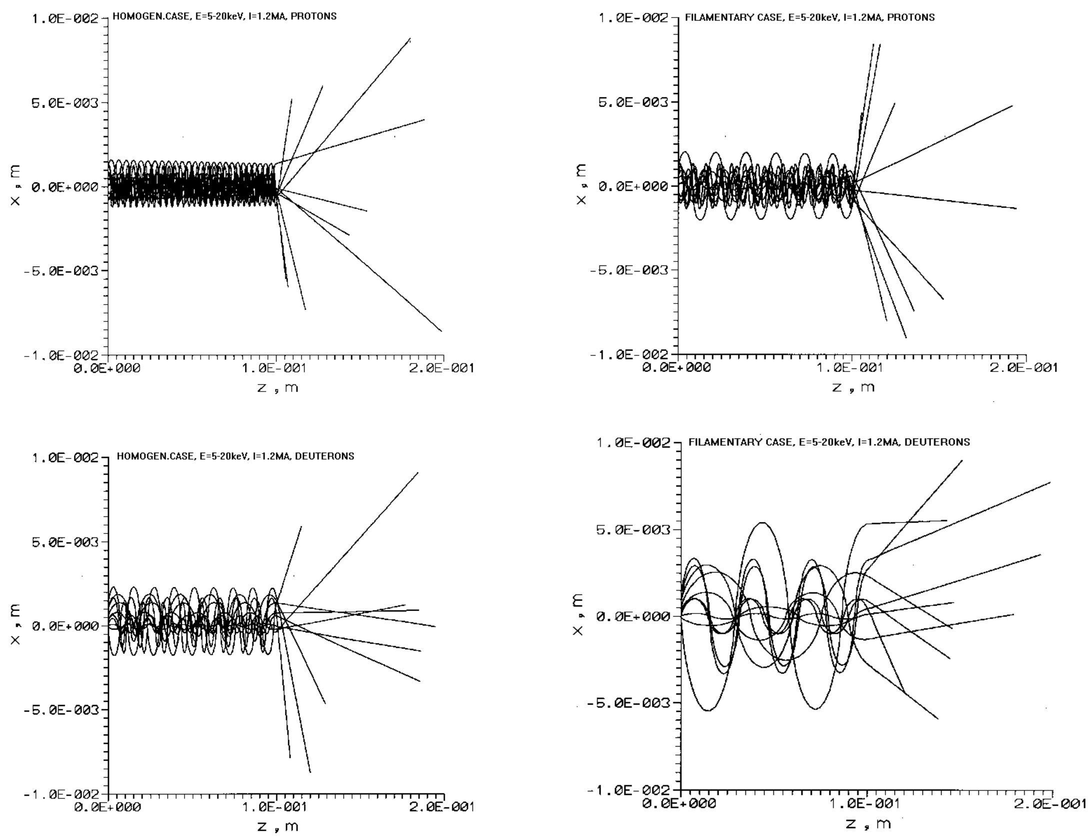

Fig. 2. Trajectories of ten particles (protons – upper diagrams, and deuterons – lower diagrams) emitted within the energy range of 5-20 keV. Particles source were taken at $z = 0$, r - random. Pinch current was $I_p = 1.2$ MA.

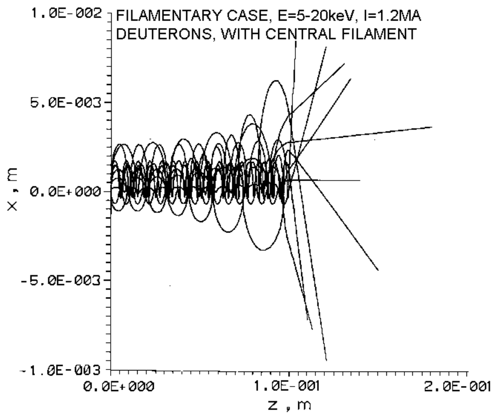

Fig. 3. Conditions the same as in Fig.2, but with an additional central filament.

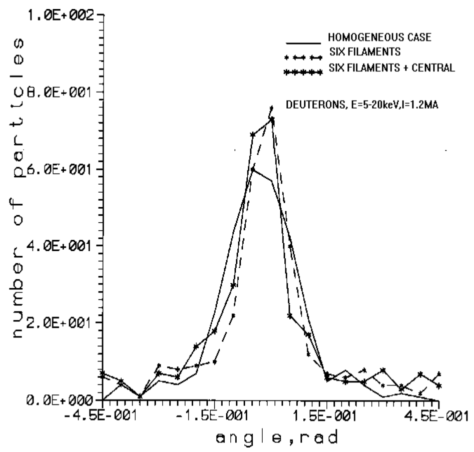

Fig. 4. Angular distribution of deuterons emitted mostly along the symmetry axis.

3. Results of numerical calculations

The main results of numerical modeling have been presented in Fig.2. The most interesting results were obtained for low energy particles, when magnetic field influence was strongest.

High-energy particles need much more stronger magnetic field for its deflection. Therefore, they leave the pinch column volume very quickly, without sufficient interactions with a dense plasma. On the contrary, low-energy particles can stay long enough within the pinch column and interact with a surrounding plasma. We have also considered appearance of the central filament. For such a case the deuteron trajectories are shown in Fig.3. An angular distribution of fast deuterons emitted in the upstream direction has calculated for all the pinch configurations, as shown in Fig.4.

The computed trajectories are very similar to those obtained before for a homogeneous pinch column [6] or for a filamentary case [9]. However, the computed angular distribution does not exhibit a characteristic local minimum near the z-axis, observed experimentally [7]. It has been confirmed that low-energy ions are more important for pinch column dynamics than fast ones, e.g. low-energy deuterons can be confined by local magnetic traps. It was assumed that a time scale of pinch column development is much more longer than that of particle motion, but it is questionable for slow ions. The model applied seems to be too simple to explain all the experimental evidences. Therefore we propose to investigate influence of a conical form of the collapsing current sheath.

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