

NUMERICAL SIMULATION AND OPTIMIZATION OF COMPRESSION PLASMA FLOWS INTERACTION WITH SOLIDS

S.I. Ananin, V.M. Astashynski

B.I. Stepanov Institute of Physics of the NAS of Belarus, Nezalezhnastsi ave. 68,
220072 Minsk, Belarus, ananin@imaph.bas-net.by

Surfaces modification by compression plasma flows is one of the most promising applications of quasi-stationary high current plasma accelerators because it provides methods of creating conditions which are not realized in other ways.

We have developed a series of models which describe compression plasma flows generation and their interaction with solids. These models are based on coarse-particle method, introducing a magnetic field and taking energy transfer by radiation into account within the framework of the two-flow multi-group approximation [1-4]. This approach makes it possible to describe the structure and dynamics of partially ionized compression plasma flows in high-current plasma accelerators and to carry out the optimization of plasma acceleration in such installations. This paper presents the review of latest results for numerical simulation and optimization of interaction of air and hydrogen compression plasma flows, generated by magnetoplasma compressors of various types, with solids.

The system of non-stationary equations of magnetic radiation gas dynamics, describing the processes under discussion, looks as follows (the temperatures of ions, electrons, and atoms as well as their velocities, are assumed to be identical, $T_i = T_e = T_a = T$, $w_i = w_e = w_a = w$):

$$\frac{\partial \rho}{\partial t} + \text{div}(\rho \bar{w}) = 0$$

$$\frac{\partial \rho v}{\partial t} + \text{div}(\rho v \bar{w}) + \frac{\partial p}{\partial r} + \frac{H}{4\pi r} \frac{\partial}{\partial r}(rH) = 0$$

$$\frac{\partial \rho u}{\partial t} + \text{div}(\rho u \bar{w}) + \frac{\partial p}{\partial z} + \frac{H}{4\pi r} \frac{\partial H}{\partial z} = 0$$

$$\frac{\partial H}{\partial t} = \frac{\partial}{\partial r} \left[\frac{\lambda}{r} \frac{\partial}{\partial r}(rH) \right] + \frac{\partial}{\partial z} \left(\lambda \frac{\partial H}{\partial z} \right) - \frac{\partial}{\partial r}(vH) - \frac{\partial}{\partial z}(uH)$$

$$\frac{\partial \rho E}{\partial t} + \text{div}((p + \rho E)\bar{\mathbf{w}} + \bar{\mathbf{S}}) +$$

$$+ \frac{H}{4\pi} \left(\frac{v}{r} \frac{\partial H}{\partial r} + u \frac{\partial H}{\partial z} \right) - \frac{\lambda}{4\pi} \left[\frac{1}{r^2} \left(\frac{\partial}{\partial r} r H \right)^2 + \left(\frac{\partial H}{\partial z} \right)^2 \right] = 0$$

$$E = \bar{w}^2 / 2 + \varepsilon$$

Here ρ is the plasma density; p is the pressure; \mathbf{w} is the velocity ($u = w_z$, $v = w_r$); ε is the specific internal energy, E is the specific full energy, \mathbf{S} is the energy flux due to radiation; $\lambda = c^2 / 4\pi\sigma_e$, σ_e is the conductivity. This system of equations is completed with equations of state:

$$p = p(\varepsilon, \rho), \quad T = T(\varepsilon, \rho).$$

The radiation flux is considered in the multi-group two-flow approximation in the coordinates r and z . In the given case the spectral composition of the radiation was taken into account in the approximation of three spectral groups. Inside each group the absorption coefficients were assumed to be independent of the frequency and equal to that averaged over Planck distribution within the given group. The boundaries of the intervals for calculations for air flows were as follows: 0.01–6.52; 6.52–9.96; 9.96–247 eV, and for hydrogen flows 0.01–10.2; 10.2–13.6; 13.6–250 eV. More detailed description of the energy transfer calculations is presented in [2].

The method used here to set the boundary conditions does not differ from described in [5]. Initially, the calculated region (its geometry is taken from the corresponding experiments) is assumed to be filled with hydrogen plasma of density ρ_0 and temperature T_0 and the magnetic field is zero.

The simulation was carried out for two different modes of the accelerator work: for the residual gas mode, in which the discharge was taking place in discharge chamber prefilled with the working gas, and for the mode, in which the working gas is injected in MPC during the discharge. In such calculations, the total current time dependencies recorded in experiments were used for border conditions settings.

As a result of numerical simulation, the spatial distributions of plasma parameters (pressure, electron concentration, temperature and velocity of the plasma flow) and current distributions for various conditions of gas supply and for the various dependencies of the total current versus time were received (see for example Fig.1). As calculation have shown, the shock-compressed layer is

formed near the solid surface under action, and this layer exists during all discharge time. It was demonstrated that under certain conditions (for example, in regimes with high total discharge current I_{max} and low distance between the cathode tip and the target surface) the current vortex is formed near the surface. This can have a significant impact on the processes governing the surface modification.

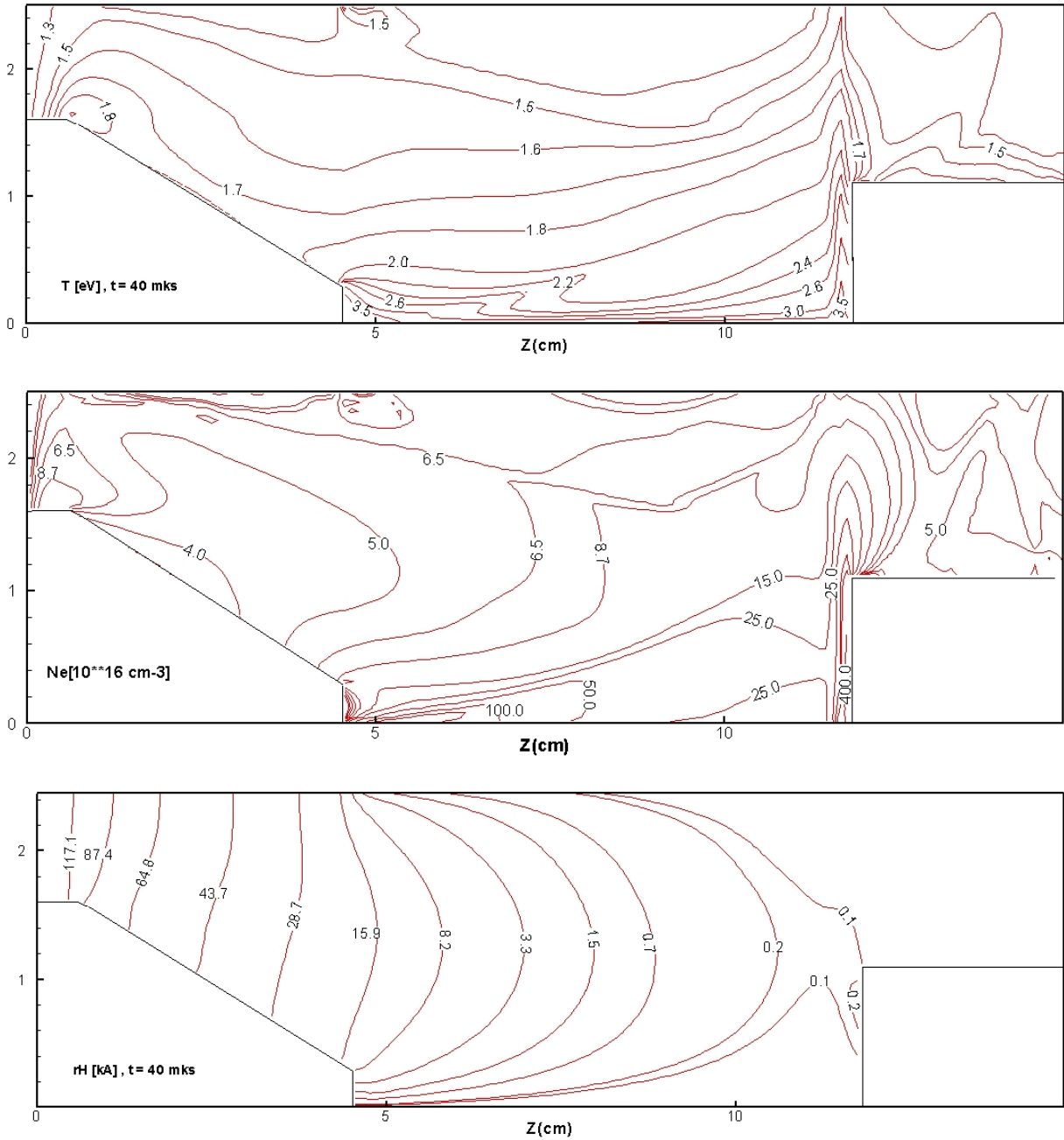


Fig. 1 Main plasma parameters in calculation area

It was shown that in regimes with too high initial current raise the current vortex is formed on the entrance of the plasma accelerator. This current vortex prevents plasma axial acceleration. As a result, most of the energy stored in capacitor banks may be spared in some cases not on the acceleration of the plasma flow along the system axis, but on ohmic heating of plasma which is leaving the system between anode bars.

The calculations have shown that the parameters of compression plasma flows at the exit of magnetoplasma compressor depend primarily on the magnitude of the maximum total discharge current I_{max} and the mass flow of the working gas. As the mass flow rate of the working gas decreases, the plasma parameters at the outlet of the system grow (for fixed I_{max}). But for the implementation of regimes with high total currents, on the contrary, it is necessary to increase the mass flow of working gas, because the shortage of working gas supply in the discharge gap increases the erosion of the electrode system. Thus, to maximize the output parameters of compression plasma flows, generated by magnetoplasma compressor, it is necessary to match the working gas mass flow and total discharge current in the system.

Thus, our model can be used for optimization of plasma flows acceleration in described conditions.

This work was carried out with financial support from the Belarusian Republican Foundation for Basic Research (project F11K-115).

References

1. **Ananin S.I., Astashynski V.M., Bakanovich G.I. at all.** Sov. J. Plasma Physics. **16** (1990) 186–196.
2. **Ananin S.I.** Journal of Applied Mechanics and Technical Physics. **32** (1991) 465–471.
3. **Ananin S.I.** Dynamics of plasma flows interacting with a target. Sov. J. Plasma Physics. **21** (1995) 966–969.
4. **Ananin S.I., Astashynski V.M.** Plasma Physics Reports. **23** (1997) 37–40.
5. **Ananin S.I., Astashynski V.M. and Emel'yanenko A.S.** Proc. of the 6-th Intern. Conference "Interaction of radiation with solids" (Minsk, 2005) 158–160.