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2.5D NUMERICAL METHOD FOR MHD EQUATION WITH MAGNETIC DIFFUSION IN ARBITRARY MOVING COORDINATE SYSTEM FOR Z-PINCH PLASMA SIMULATION

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Introduction

There is a great variety of approaches in code constructing, which are used now for plasma flows in Megagauss magnetic fields simulation. Among them one can find Lagrangian, Eulerian, Lagrange-Eulerian codes.

In this paper the code MAG [1, 2] for plasma modeling in arbitrary moving coordinate system and its present stage of development are presented. Using of arbitrary moving coordinate system allows to simulate flows with large deformations inside the flow region, conserving the correct description of conditions on its weakly deformated boundaries.

Model

The system of equations used in MAG code is Braginskii [3] model for one-temperature case (only electron temperature is taken into account)

$$\begin{aligned}
\tfrac{\partial\rho}{\partial t} + div(\rho\cdot\mathbf{u}) &= 0\\
\rho\cdot\left(\tfrac{\partial\mathbf{u}}{\partial t} + (\mathbf{u}\cdot\mathbf{grad})\mathbf{u}\right) + \mathbf{grad}p &= -\tfrac{1}{4\pi}\cdot[\mathbf{B}\times\mathbf{rotB}]\\
\rho\cdot\left(\tfrac{\partial\mathcal{E}}{\partial t} + (\mathbf{u}\cdot\mathbf{grad})\mathcal{E}\right) + p\cdot div\mathbf{u} + div\mathbf{q} &= \rho\cdot Q_{ext} + \mathbf{j}\cdot\mathbf{E}\\
\tfrac{\partial\mathbf{B}}{\partial t} &= -c\cdot\mathbf{rotE}\\
\mathbf{E} &= \tfrac{\mathbf{j}}{\sigma} - \tfrac{1}{c}\cdot[\mathbf{u}\times\mathbf{B}]\\
div\mathbf{B} &= 0\\
\mathbf{j} &= \tfrac{c}{4\pi}\cdot\mathbf{rotB} - \tfrac{c\,m_p}{e}\cdot\tfrac{A_i}{Z\,\rho}\cdot\nabla p\\
\mathbf{q} &= -\text{æ}\cdot\mathbf{grad}T
\end{aligned}\tag{1}$$

All variables are generally accepted.

The heat conductivity, electrical conductivity coefficients and average ion charge were calculated using the tables, which had been proposed in the paper [4].

Brief description of the numeric method

The initial MHD system has been written in Cartesian and cylindrical coordinate systems, then the dependence on the third variable has been eliminated. After this it was written in moving coordinate system. The received in such manner system describes 2D plasma flows with three components of dependent vector variables: mass velocity and magnetic field. This system has been splitted into two systems: hyperbolic and parabolic. The explicit TVD-type difference scheme has been used for hyperbolic system and implicit Kershaw-type scheme has been used for parabolic one. The linear solver has been constructed on the basis of ICCG method.

The received hyperbolic system is solving in a moving coordinate system. There are five algorithms for coordinate system moving:

- the Lagrange one;
- the Euler one;
- a local algorithm (new coordinates of a site are determined by the coordinates of four neighbour sites);
- an algebraic algorithm (coordinates of inner mesh sites are determined by the coordinates of the boundary sites);
- an algorithm of mesh constructing, using the solution of Poisson equation.

These algorithms allow to perform modeling of wide range of MHD flows:

- Plate expansion under laser radiation
- Plasma – wall interaction in tokamak
- Z-pinch instability developing

Some examples of numerical modeling

In this paper we would like to give three examples of modeling, which could be performed using the presented method.

The *first one* is the modelling of laser beam interaction with thin aluminium plate. The modeling was performed in plane and axial symmetry. Initially plate of 50 micrometers thickness with density of $2.7 \mathrm{g/cm^3}$ was heated by laser beam. The energy was absorbed in the density range from $3 \cdot 10^{-4} \mathrm{g/cm^3}$ to $3 \cdot 10^{-3} \mathrm{g/cm^3}$. The plate was expanding, and in the middle of the expanded area the hot area of plasma has been produced.

The problem was modelled, taking into account spontaneous magnetic field (the term $\frac{cm_p}{e} \cdot \frac{A_i}{Z\rho} \cdot \nabla p$ in the equation (1) is responsible for this field). The magnetized electrical conductivity and heat conductivity coefficients were taken into account.

Results are presented in Fig.1. One can easily see, that while taking into account spontaneous magnetic field, maximum temperature in plasma fakel is 1.5 times larger than without its accounting.

Second one is a problem of modeling of plasma – wall interaction in tokamak. This modeling was performed taking into account external magnetic field, and without magnetic field. In Fig.2. one can see the results of this modeling. In Fig.3 the graph of evaporated wall mass with respect to the angle for two cases is presented.

The *third one* is the compressing of initially perturbed gas puff Z-pinch by the φ component of magnetic field. The initial conditions are: 1.4 cm gas puff with density of $8 \cdot 10^{-6} \mathrm{g/cm^3}$ and temperature of 10^{-2}eV was compressed by magnetic field, produced by linearly growing to 1.6 MA for the time of 100 ns current. In the second calculation pinch was initially rotated (initial value of mass velocity was: $u_\varphi = 10^5$ cm/sec).

One can see stabilizing of plasma with respect to rotation.

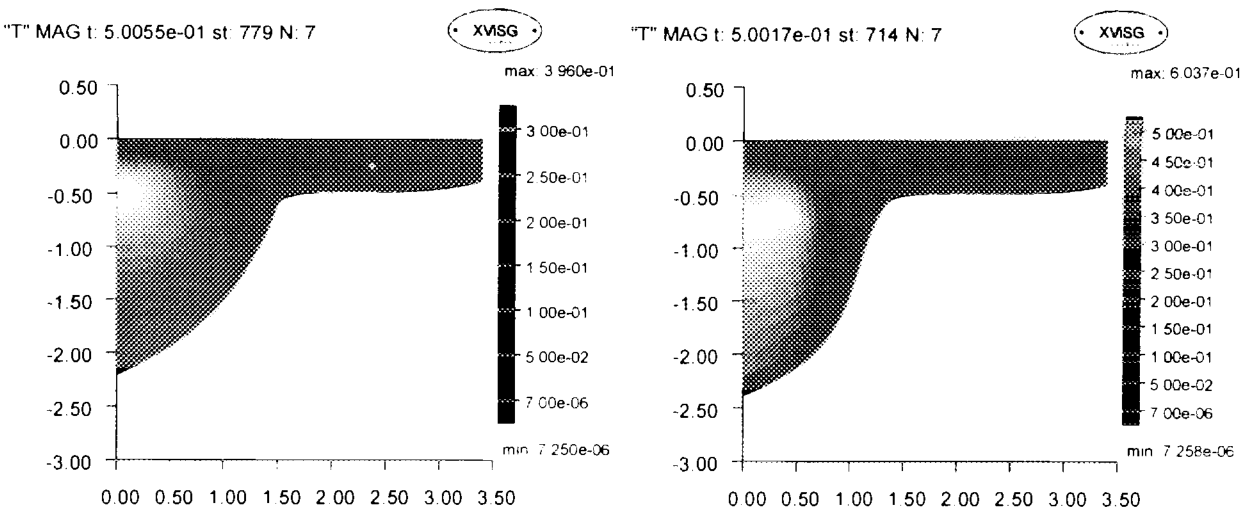

Fig 1. Temperature's map. Left - w /o magnetic field, right - with the field.

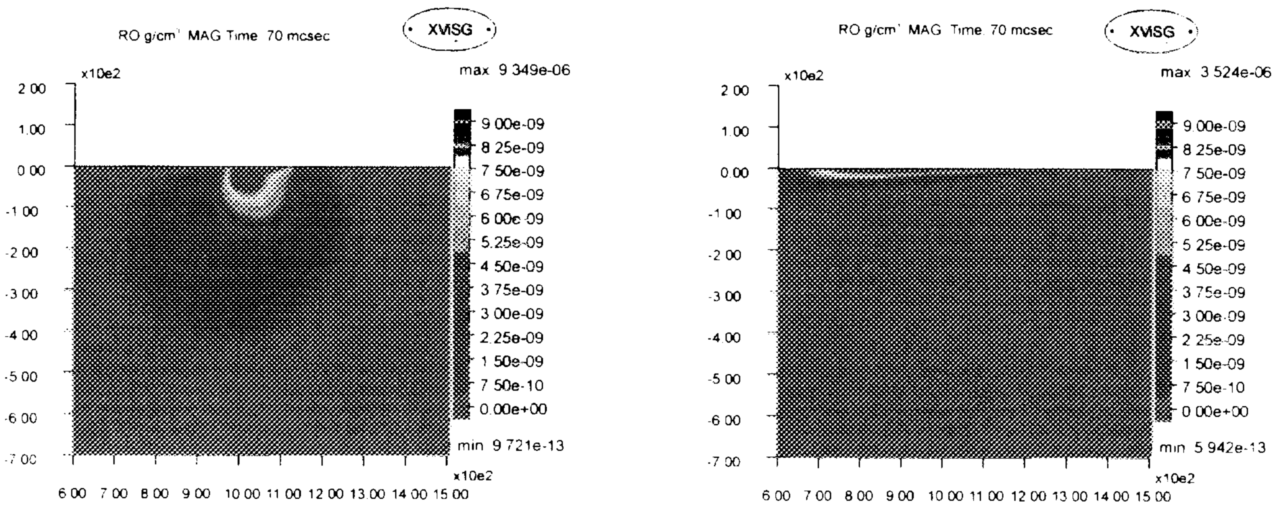

Fig 2. Density's maps, angle of beam 40. Left - w /o magnetic field, right - with the field.

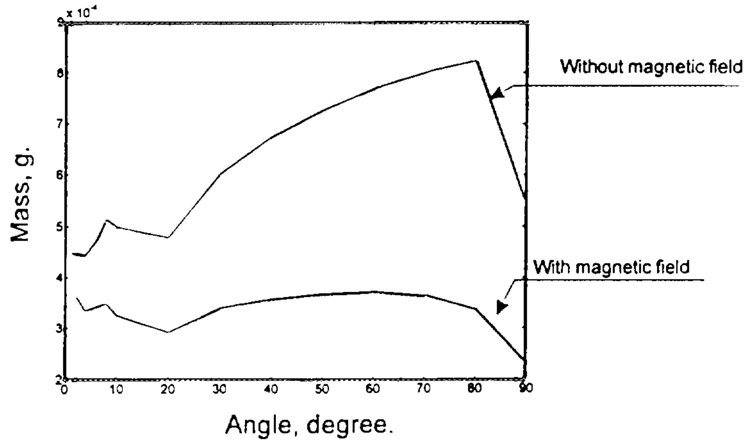

Fig. 3 Evaporated mass vs. angle of beam

Conclusion

Presented in this paper MAG code is now fastly been developing. Now the authors are working on the radiation transport accounting. We plan to implement in the nearest future two-temperature MHD model.

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