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Interaction of laser beams with magnetized substance in a strong magnetic field

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Abstract. Laser-driven magneto-inertial fusion assumed plasma and magnetic flux compression by quasisymmetric laser-driven implosion of magnetized target. We develop a 2D radiation magnetohydrodynamic code and a formulation for the one-fluid two-temperature equations for simulating compressible non-equilibrium magnetized target plasma. Laser system with pulse radiation with 10 ns duration is considered for numerical experiments. A numerical study of a scheme of magnetized laser-driven implosion in the external magnetic field is carried out.

1. Introduction

Development of new powerful sources of implosion with external magnetic field (magnetized target fusion or magneto-inertial fusion [1-10]) makes demands of radiation hydrodynamic simulations. Magneto-inertial fusion (MIF) is an alternative path to the magnetic and inertial fusion, where magnetic field suppresses the thermal conductivity in a magnetized plasma (the target), thereby reducing the heat losses, increasing the lifetime of the configuration, and hence the thermophysical properties and energy parameters of the reactor. The mathematical model is based on the calculation of the transport (diffusion, thermal, radiative) processes of atoms, ions, electrons, molecules, photons in a strong magnetic field.

This work is devoted to the simulation of laser beams interaction with an axisymmetric dense magnetized plasma, e.g. such burning plasma parameters can be produced in magneto-inertial fusion. For this reason the numerical model of the process is based on the multi-component radiation gas dynamics with turbulence model. The radiation transfer is taken into account in multi-group diffusive approach. The main distinguish of this proposed model is the presence of the externally applied magnetic field.

2. Model and System

A model of laser-driven imploding target in an externally applied magnetic field is created in [11-13]. We consider the mathematical model of fusion burn in targets under compressed magnetic fields for magneto-inertial fusion in centrally symmetric coordinate system. This model is based on the one-fluid, two-temperature equations of magnetic radiation gas dynamics. They take into account the equation of state and the absorption coefficients for laser radiation, resonance absorption, the



generation of overthermal electrons and transfer of internal plasma energy, ion heating by laser radiation (direct ion heating), determine conditions of achieving self-sustaining fusion. The electromagnetic processes in the fusion target and a surrounding plasma region described by Maxwell's equations and Ohm's law with finite plasma conductivity. The radiation transport is considered in a multi-group approximation framework "back and forth".

A numerical technique using dynamic adaptive grid and computer code for the nonstationary radiation magneto-gasdynamics models for describing the plasmodynamic processes occurring in different MIF schemes is developed. A computer code MATTINA (MAGnetized inerTial Target In Numerical Analysis) is developed. Modified alternatively triangular three-layered iterative scheme is applied for the solution of radiation transport equations, where the time step was selected via conjugate directions method.

It has been proposed to use laser and plasma beams to implode a magnetized target [14-19]. The device consists of: 1) the system of target irradiation involves the lasers or hohlraum; 2) the "dynamic" system to compress the initial seed magnetic flux directed along the geometric axis of symmetry. The magnetic system is located outside the target area. The target is located in the center of the dynamic magnetic trap and can be irradiated with laser energy in the direct drive configuration or indirect drive system (conventional hohlraum).

The laser system does not participate in the coils compression. They represent a separate system designed to compress the target through radiative effects. I.e. laser system and "shrink coil" are not connected, there two different (decoupled) technical systems. Thus, the target is compressed in two ways: by external radiation (laser energy) and by means of the dynamic magnetic field of the trap, e.g. probkotron.

Hohlraum means the system of lasers that generates hot temperature plasma, that is the source of broadband radiation. One can create hohlraum by applying high current on the surface of the capsule (i.e. not laser-generated plasma) in an experimental stand. The external magnetic field will penetrate inside the hohlraum.

3. Calculation results

Modeling calculations based on the proposed numerical method for solving the system of gas dynamics equations are performed. A comparison of the numerical and modeling solutions was carried out using the values of decision errors in the standards of various kinds.

Laser system with pulse radiation with $5\div 10$ ns duration is considered. Numerical simulation of the magnetized target compression is done for $q_{las} \leq 10^{14}$ W/cm². Initial values of the intensity of a seed magnetic field in the rarefied medium reach a fraction of Tesla. A computational domain and target of magneto-inertial fusion consist of the central part and one coaxial layer. They have a cylindrical shape with the following range of values of initial parameters of target and medium. The central part of the target (inner radius $R = 0.05$ cm) is filled with deuterium-tritium ($D-T$) gas mixture with density $\rho = 5 \cdot 10^{-2}$ g/cm³ and temperature of $T = 297$ K. It was surrounded by the coaxial layer (outer radius $R_c = 0.1$ cm) consisting of metal (Al) with density $\rho = 2.7$ g/cm³ and temperature of $T = 297$ K. The computational domain has outer radius $r = 0.2$ cm. Thermodynamic parameters of external rarefied medium (Ar) are defined: $T = 297$ K, $\rho = 1.29 \cdot 10^{-3}$ g/cm³.

The dynamics of the magnetized plasma expansion into an ambient gas is considered. The spatial distribution of pressure P (atm) and temperature T (kK) is shown in figures 1-2. Plasma velocity V and density ρ versus coordinate r at time $t = 8.5$ ns are given in figures 3-4. Plots of contact boundary (1st and 2nd) versus r are presented in figures 5-6. The distribution of the laser radiation W_{las} along the radial coordinate is shown in figure 7.

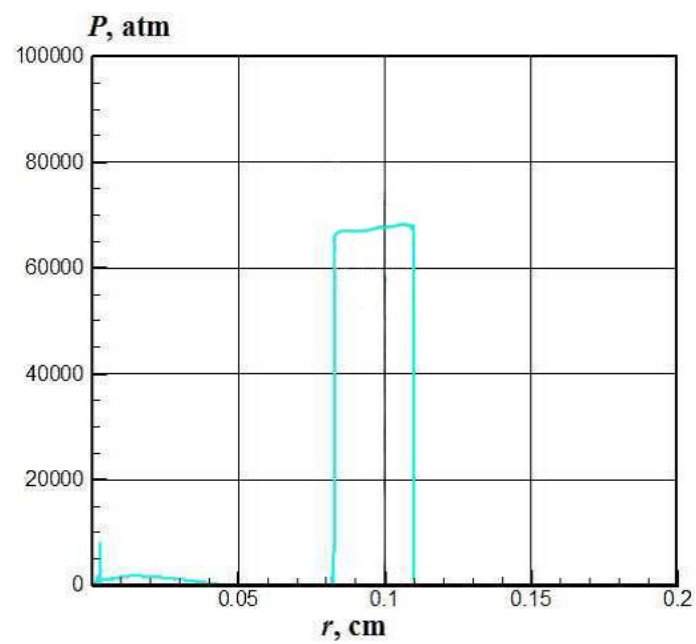


Figure 1. Spatial distribution of the plasma pressure (P) at 8.5 ns ($t_{Las} = 10$ ns).

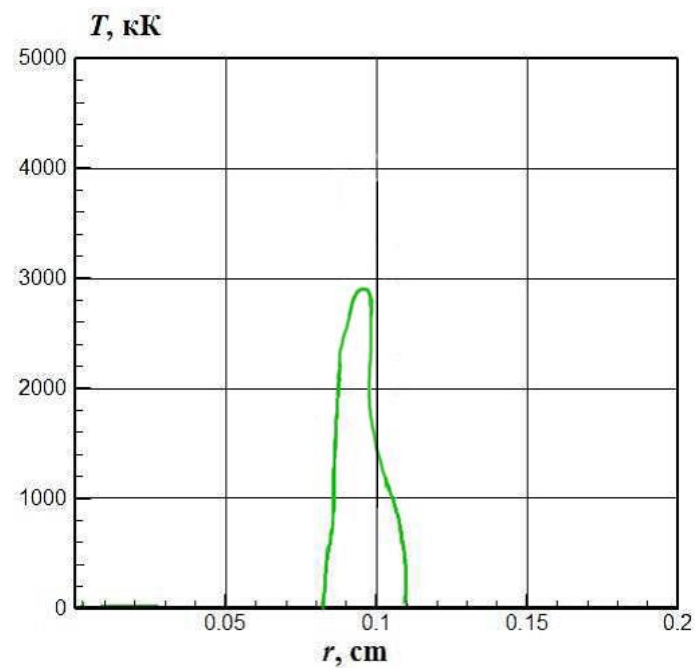


Figure 2. Spatial distribution of the plasma temperature (T) at $t = 8.5$ ns ($t_{Las} = 10$ ns).

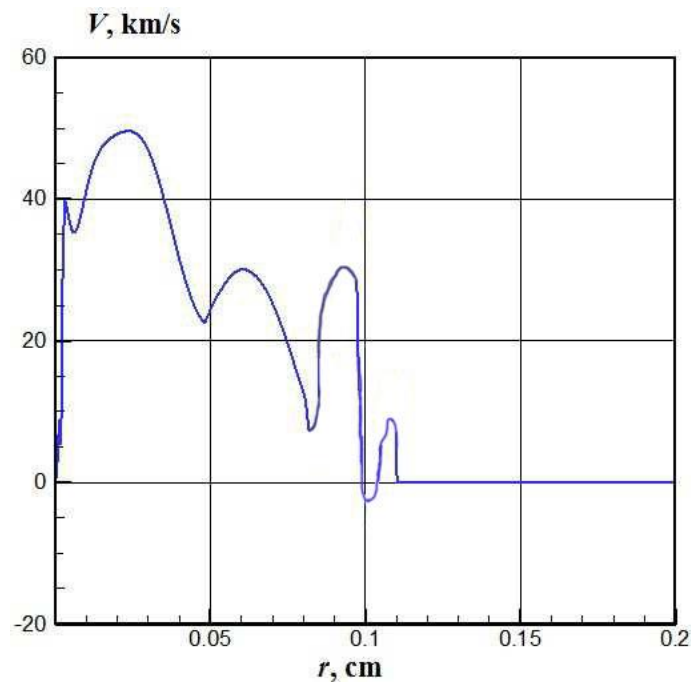


Figure 3. Distribution of the plasma velocity (V) at $t = 8.5$ ns along the radial coordinate.

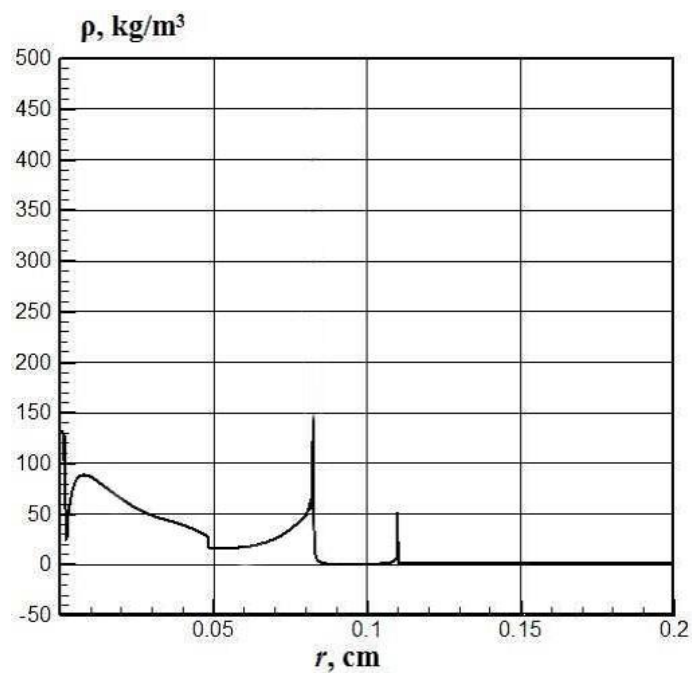
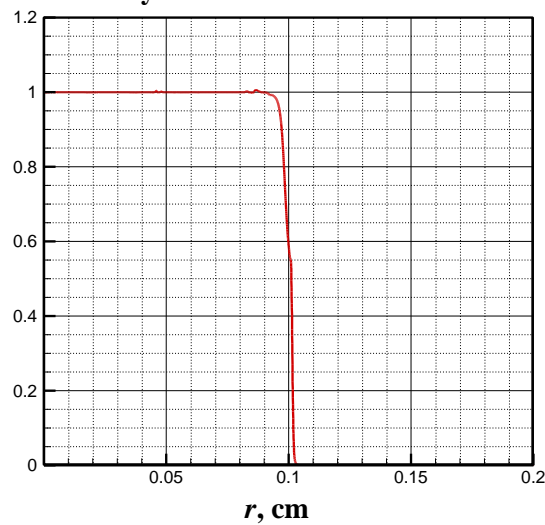
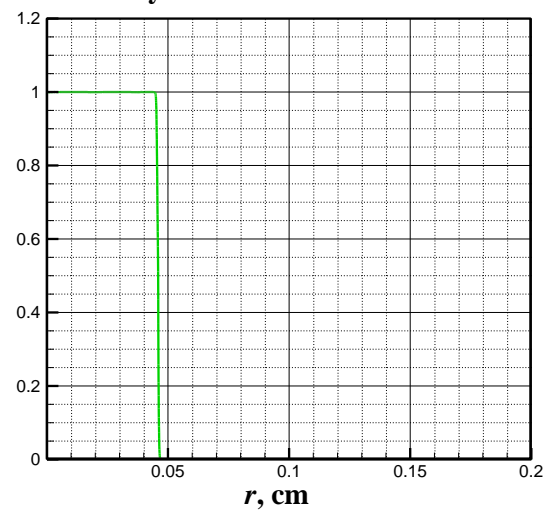
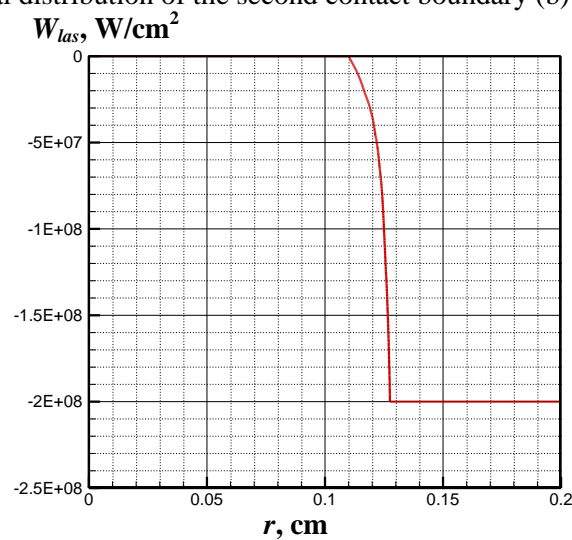


Figure 4. Distribution of the plasma density (ρ) at $t = 8.5$ ns ($t_{Las} = 10$ ns).

The key parameters of the laser-target system are calculated. Calculations carried out for the Nd laser radiation for forming rectangular impulse shape (duration = 10 ns). The radiant flux value is $q_{las} = 2 \cdot 10^{14}$ W/cm². A thin metallic cylindrical shell material is Al. The target radius is 0.1 cm.

1st contact boundary**Figure 5.** Spatial distribution of the first contact boundary (a) at time $t = 8.5$ ns.**2nd contact boundary****Figure 6.** Spatial distribution of the second contact boundary (b) at time $t = 8.5$ ns.**Figure 7.** Distribution of the laser radiation (W_{las}) at $t = 8.5$ ns ($t_{Las} = 10$ ns).

4. Conclusion

We have developed a model for laser-driven magneto-inertial fusion - laser-driven target implosion in an externally applied magnetic field. The main plasma parameters (pressure P , temperature T , velocity V and density ρ), and laser energy W_{las} along the radial coordinate are calculated. Numerical modeling of the laser target compression process showed the following. The central part of a target is optically transparent for both laser and own broadband plasma radiation during compression. However at the same time heat flow density on the first wall of the reactor chamber at a certain moment of time can reach 10^8 W/cm². The magnetic pressure P_{mag} during compression of a target changes in time and is comparable to the static pressure P , reaching values 10^6 atm. The maximum values of plasma pressure and temperature are observed after reflection of a shock wave from a geometrical axis of symmetry at $t \approx 5$ ns.

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