NUMERICAL MODELING OF MAGNETIZED PLASMA COMPRESSED BY THE LASER BEAMS AND PLASMA JETS

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Magneto-inertial fusion (MIF) including magnetized target compression by high energy laser pulses is fast-growing area of research. Distinctive feature of this problem is presence of initial seed fields (the imposed external pulse magnetic field) and compression of a magnetic flux by laser beams (laser driver) and plasma jets (plasma liner). High-convergence uniform implosion and properly synchronized laser beams (laser intensity > 10^{20} W/m^2) are considered. Influence of external magnetic field on driver-fuel target interaction is discussed. Preliminary test results of magnetized plasma target compression by high energy laser pulses are shown. It can be argued that the magnetic field in terms of vortices plays a stabilizing role, which is manifested in the fact that the vortex structures dissipate in the presence of an externally applied magnetic field.

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INTRODUCTION

At present time systems with dense plasma for magneto-inertial fusion are of great interest. The aim of this work is to describe the processes of target compressing, heating and cooling under the conditions of a thermonuclear system with a high-temperature plasma, the development of a dense plasma device using compression of magnetized target in an externally applied magnetic field. We propose an innovative scheme with spherical and cylindrical target, compressed by a strong external source (laser with high energy pulses) for heating and achievement thermonuclear temperatures. In this case there is (a significant increase of seed fields up to the intensity of tens megagauss) a generation of ultra strong magnetic fields with laser compression. A numerical method for high resolution, developed in [1], has improved the dissipative and dispersive properties (significantly the modeling of turbulent flows) when the multidimensional convective flux discretization is implemented. A mathematical model of magnetized target radiation with multiple laser beams were developed, it describes the dynamics and kinetics of thermonuclear magnetized plasma.

MIF [2-5], often called MTF (magnetized-target fusion) is an alternate concept to magnetic confinement fusion and inertial confinement fusion. Note, however, that the proposed research is applicable to all versions of MIF/MTF and any fusion fuel cycle. In traditional schemes (direct and indirect drive) it is supposed to use a large number (~ 100) of irradiating beams, but it is extremely difficult to implement in a fusion reactor. Implementation of spherical compression of magnetized targets it can be possible to reduce significantly the number of irradiating laser beams, it allows you to get a clean and cheaper fusion not having the disadvantages of magnetic and inertial confinement fusion.

MODEL AND TEST RESULTS

The model describes the compression of the target with laser beams in a magnetic field of arbitrary configuration and can be used for numerical study of the formation of plasma in an external seed magnetic field and its heating during compression using high-energy external sources (drivers). The laser driven compression of compact plasmoids [6, 7] to fusion conditions is investigating. Interaction of a laser pulse with a plasma target with an externally applied magnetic field - a model of laser-driven implosion is presented.

Magnetohydrodynamic and radiation magnetogasdynamics simulation with thermal transport, laser deposition and target implosion in external magnetic field in one and two dimensions is necessary for high energy density physics, magneto-inertial fusion and numerous applications [8-10]. Benchmarking the simulation results against experiments is important for researchers to improve the design of targets.

An improved one-dimensional radiation-hydrodynamics code which simulates plasmas in cylindrical or spherical geometries is created. It solves single-fluid, two-temperature equations of motion with contributions from diffusion, convection, heat conduction. Electromagnetic processes are described by the Maxwell-Ohm equations in plasma with final conductivity. Radiation transport is considered within the framework of multi-group diffusion approach. The transport coefficients in the given system of the equations taking into account magnetized laser plasma. External and spontaneous magnetic fields are included in the model.

Numerical simulation allows studying a number of features of nonlinear plasma dynamics. It is marked, that radial expansion of a laser plasma jet (two dimensional effects) has significant influence on the dynamics of plasma formation. First results of non-linear effects modeling for different initial parameters and edge conditions are discussed in the paper. Mathematical method developed in [11] may be applied for both impact fast ignition and uniform compression calculations.

Thermal physical properties of particles and plasma are derived using correct the Reynolds number and the Prandtle number. The calculations of thermodynamic and optical media parameters occur with the aid of computer system Asteroid, developed by S. Surzhikov [12]. The viscous forces in a flux represent the sum of works of liquid friction, heat fluxes and plasma heating by laser radiation. The electron and ion thermal conductivity coefficients in the case of magnetized plasma are calculated.

The developed mathematical model for laser-driven magneto-inertial fusion (LD MIF) and plasma-jet driven magneto-inertial fusion (PJ MIF) [6] has been tested on problems related to axisymmetric pulsed plasma jets in an external magnetic field, taking into account their own broadband plasma radiation.

Figs. 1 and 2 show results of computer simulation studies of heating and compressing a target in magnetic field. Test calculations are performed without an externally applied strong magnetic field of stationary plasma jets and showed good agreement with well-known literature data [13]. A change in the structure of the flow pulse jet, which is accompanied by a decrease in the intensity side (towards the axis of the system) shock waves is observed for the simulation with magnetic field (0.1…5 T).

The central band changes its position relative to the output of the jet shear (behind or lost) compared to the tests. The toroidal vortex systems are typically observed out of boundary contact of triple configuration (point where three shock waves converge). Applying an external magnetic field suppresses vortexes (weaken their intensity) and leads (increasing magnetic field) to the disappearance.

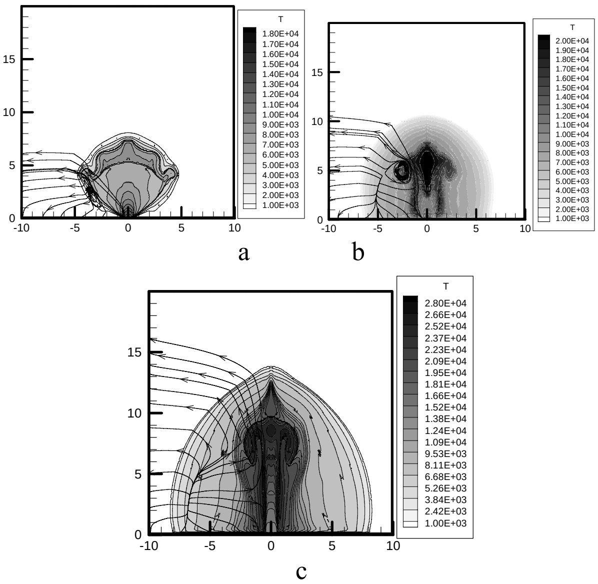

Fig. 1. The spatial distribution of temperature T [K] in a pulsed plasma jet: (a) without external magnetic field at time t=49.3 μs, (b) in the presence of an external magnetic field B=1.58 T at time t=46.6 μs, and (c) B=2.5 T at t=46.9 μs

It can be argued that the magnetic field in terms of vortices plays a stabilizing role, which is manifested in the fact that the vortex structures dissipate in the presence of magnetic field. We also note that the attenuation of the jet along the axis of the system is observed much later (approximately 2-fold), that is subject to an externally applied magnetic field.

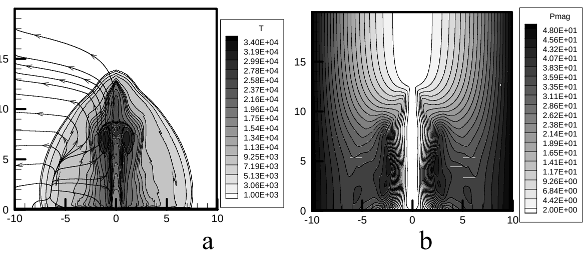

Fig. 2. The spatial distribution of (a) temperature T [K] and (b) magnetic pressure Pmag [bar] in a pulsed plasma jet with B=3.5 T at time t=37.6 μs

CONCLUSIONS

Magneto-inertial fusion (MIF) is an alternate fusion concept, represents evolution of traditional inertial confinement fusion with elements of magnetic confinement fusion, i.e. the concept with plasma of high density (n > 10^{27} m^{-3}) in ultrahigh magnetic fields (B > 500 T).

Non-stationary two dimensional radiation magneto-gas dynamic model is developed by authors [4]. The model is based on splitting method in terms of physical processes and spatial directions, that in spatially smooth solution allows to get seventh order of accuracy. Modified alternatively triangular three-layered iterative scheme is applied for the solution of radiation transport equations, where the time step selected via conjugate directions method.

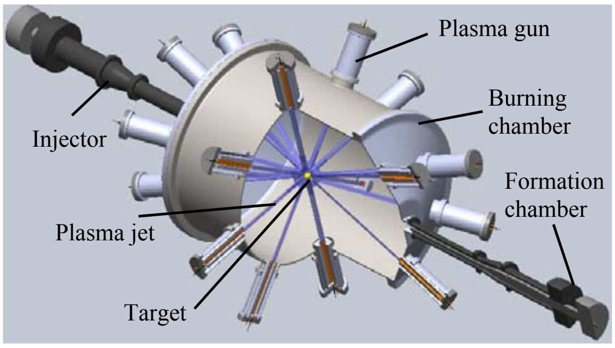

Fig. 3. Scheme of PULSAR – PUlsed Liner/Laser-driven System and Alternative Reactor

Thermal physical properties of particles and plasma are derived using correct the Reynolds number and the Prandtle number. Magnetohydrodynamic and radiation magnetogasdynamics simulation with thermal transport, laser deposition and target implosion in external magnetic field in one and two dimensions is necessary. Benchmarking the simulation results against experiments is important for researchers to improve the design of targets.

The mathematical model of magnetized plasma - laser beams of high energy pulses has been developed and scheme of a magnetized target fusion power plant is presented (Fig. 3). Mathematical method developed here may be applied for both LD and PJ MIF as well as for impact fast ignition and uniform compression calculations.

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ЗАМАГНИЧЕННОЙ ПЛАЗМЫ, СЖИМАЕМОЙ ЛАЗЕРНЫМИ ЛУЧАМИ И ПЛАЗМЕННЫМИ СТРУЯМИ

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Магнитно-инерциальный термоядерный синтез, включая сжатие замагниченной мишени мощными лазерами ─ быстро развивающаяся область науки. Отличительная особенность данной задачи ─ наличие начального затравочного поля (наложенного внешнего импульсного магнитного поля) и сжатие магнитного потока лазерными пучками (лазерный драйвер) или плазменными струями (плазменный лайнер). Рассмотрен случай однородного и синхронного лазерного облучения (интенсивность излучения > 10^{20} Вт/м^2). Представлены результаты выполненных тестовых расчетов для стационарных струй плазмы с учетом магнитного поля. Можно утверждать, что магнитное поле, с точки зрения вихрей, играет стабилизирующую роль, которая проявляется в том, что вихревые структуры диссипируют при наличии магнитного поля.

ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ЗАМАГНІЧЕНОЇ ПЛАЗМИ, ЩО СТИСНУТА ЛАЗЕРНИМИ ПРОМЕНЯМИ І ПЛАЗМОВИМИ СТРУМЕНЯМИ

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Магнітно-інерціальний термоядерний синтез, включаючи стиснення замагніченої мішені потужними лазерами, галузь науки, яка швидко розвивається. Відмітна особливість даної задачі ─ наявність початкового запалювального поля (накладеного зовнішнього імпульсного магнітного поля) і стиснення магнітного потоку лазерними пучками (лазерний драйвер) або плазмовими струменями (плазмовий лайнер). Розглянуто випадок однорідного і синхронного лазерного опромінення (інтенсивність випромінювання > 10^{20} Вт/м^2). Представлені результати виконаних тестових розрахунків для стаціонарних струменів плазми з урахуванням магнітного поля. Можна стверджувати, що магнітне поле з точки зору вихорів грає стабілізуючу роль, яка проявляється в тому, що вихрові структури дисипірують при наявності магнітного поля.