Numerical Analysis of Non-spherical Implosion for Fast Ignition Using Newly Developed Integrated Implosion Code

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abstract. One of the key issues in numerical analysis for the fast ignition is the controlling the hydrodynamic of imploding target to form a high density core plasma in non-spherical implosion. In order to study the issue, we have upgraded the integrated implosion code. Using the code, implosion of a non-spherical shell target with a conical target is simulated. As the result, we can conclude that the implosion with the cone which in not clean spherical geometry can make the high density core region also. In this paper, we will describe the detail feature of the integrated implosion code and the performance of the non-spherical implosion that is estimated by the present code.

1. Introduction

The fast ignition scheme is one of the epoch making method for the inertial fusion energy [1]. The numerical simulation plays an important role in estimating the performance of the scheme, designing the targets, and optimizing laser pulse shapes for the scheme. There are two key issues in numerical analysis for the fast ignition. One is the controlling the hydrodynamic of imploding target to form a high density core plasma in non-spherical implosion, and the other is heating core plasma efficiency by the short pulse high intense laser. In this paper, the development of integrated implosion code and a numerical analysis of the former problem are described.

In order to study the implosion dynamics, an integrated implosion code that includes all physics important in the implosion process should be developed. The details of physics elements should be studied and the resultant numerical modeling should be installed in the integrated code so that the implosion can be simulated with available computer within realistic CPU time. In the previous work, integrated implosion code, ILESTA-2D [2] has been modified to be an implicit arbitrary Eulerian Lagrangian code (ALE) for the robustness and saving the computational time [3]. The most difficult problem in the usage of the ILESTA-2D was adjusting the rezoning and remapping parameters of conventional ALE algorithm. In order to avoid such difficulty, we have developed new ALE algorithm which is based on CIP method (Constrained Interpolation Profile Method) [4]. This ALE-CIP method enables the code to execute accurate calculation and to capture the detail phenomena in the very wide dynamic range. The most of the basic numerical models for the implosion have been integrated to be a new 2-D implosion code, PINOCO (Precision Integrated Implosion Numerical Observation COde). Recently, we have extended the PINOCO for the simulation of the non-spherical implosion where accurate rezoning and material tracking systems are required.

For the validation, we have compared the computational results of 2-D Rayleigh-Taylor instability in laser driven planar foil target with the other computational results and theoretical model, and good agreement was obtained comparatively [5, 6]. In this paper, we show some simulated results of non-spherical implosion for the fast ignition scheme, and discuss about the characteristics of the implosion.

2. Numerical Methods

In the integrated implosion code, mass, momentum, electron, energy, ion energy, equation of states, laser ray-trace, laser absorption, radiation transport, surface tracing and other related equations are solved simultaneously. The hydrodynamic solver is the most important and fundamental algorithm. Because the scale ratio of the expanded plasma to the target shell thickness is extremely large, the implosion must be solved by Lagrangian coordinates to save the computational resources and to capture the large gradient values in the phase space clearly. Therefore, most of the conventional ALE implosion codes are based on Lagrangian method in which the computational grids move along with the target. In general, computational grids are destroyed when applying the Lagrangian method naively. In order to continue the calculation stably, it requires a sophisticated and expensive rezoning/remapping algorithm. In case of complicated simulations, it needs a graphical user interface for rezoning. To avoid such problem, a simple hydrodynamic solver was developed using CIP method. The CIP has some characteristics of Lagrangian method, although the fundamental formulas are done for Eulerian coordinates. To obtain pressure implicitly, we also applied C-CUP(CIP and Combined, Unified Procedure) which is a pressure-based algorithm and rational CIP method. These methods enable us to treat the ablation surface and laser absorption region stably. Because the dynamic range of the implosion is very wide, the calculation cost of the simulation on the Eulerian coordinate might be very expensive. Therefore, we have developed CIP code into the Arbitrary Lagrangian Eulerian code. This CIP method is also employed to track the interface between the different materials clearly also, which is a very useful when multi-material structure of target must be considered. In the energy equations, the Spitzer-Harm type thermal transport model is solved using the implicit 9-point differencing of the diffusion equation with ICCG method. For the radiation transport, diffusion type model is install in the code. But for the limitation of the CPU time, we have ignored the radiation in the calculated result here. For the laser ray-trace, a simple 1-D ray-tracing method is applied.

On the other hand, the development of the element code is also important in the project. In the integrated implosion, one of the most significant element code is the atomic physics code which dictates microphysics such as the radiative opacity and the equation of state. Recently, we have developed a detail configuration accounting (DCA) code based on the parametric potential method and a quicker code employing More's semi-classical atomic model. In the near future, integrated implosion code will be coupled with the database after its construction.

3. Computational Analysis of Non-spherical Implosion

Implosion of a non-spherical shell with a conical target is simulated. For the conventional integrated implosion code, it is very difficult to treat this kind of simulation because of the complex geometry that requires the sophisticated rezoning/remapping method and many times of trial and error during the execution. A target shell is made of polystyrene (ρ= 1.06 g/cm^3) which is uniform thickness of 8μm(Fig.1). The cone with an opening angle of 30 degrees is attached into the spherical shell. The similar kind of implosion experiment is performed on GXII laser facility at ILE Osaka University to demonstrate the fast ignition scheme [7]. To simplify the computational conditions, the cone is made of polystyrene (ρ = 20 g/cm^3), although it was gold in the experiment. The target is irradiated by the uniform green laser (λ = 0.53 μm, 1×10^{14} W/cm^2 on the initial target surface). The total numbers of grid point are 250x242, in which 60% of the points are moving along the shell in ALE algorithm. Axisymetric condition is assumed.

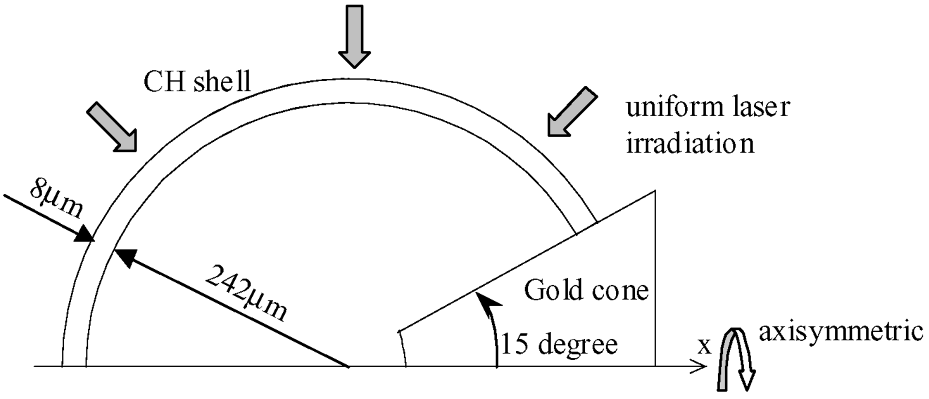

FIG.1 The schematic view of a CH shell with a conical target.

For the limitation of computer resources the radiation transports, and calculation of the hydrodynamic inside the gold are ignored here. Also, the laser ray-trace is simplified to be one-dimension. As a reference, time history of the density contours of a spherical implosion case is shown in Fig. 2, where t=1.36ns maximum density point is appeared and after then, other four contours are in expansion phase.

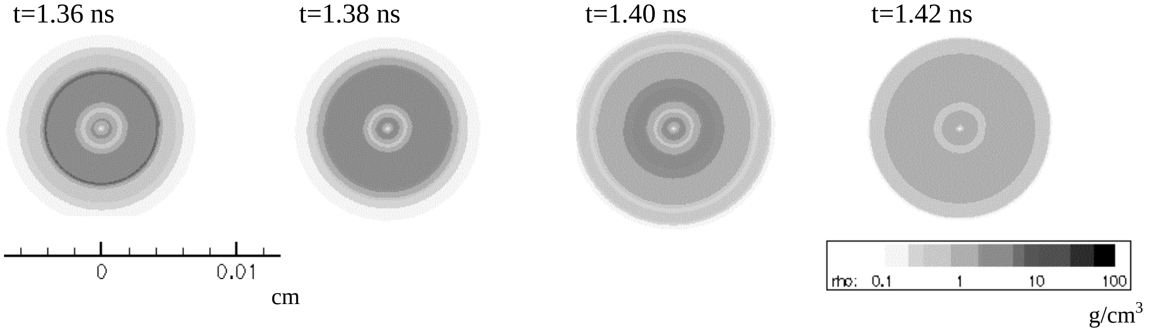

FIG.2 The time history of the density contours in spherical implosion case.

In Figure 3, a time history of the density contours of the implosion with a conical target is shown. In this case, although, the edge of the shell is delayed under the influence of the conical target, the shell target is compressed enough. And the shell is still imploding after t=1.36ns when the maximum compression is observed in the spherical implosion case. Finally, the integration of the density along the x-axis at t=1.40ns is nearly 80% higher than that of at t=1.36ns until t=1.45ns.

This means that the duration of the high optical depth along the fast ignition beam is nearly 90ps in this case. The similar elliptical shape and relatively long life core plasma was measured in the experiment[7].

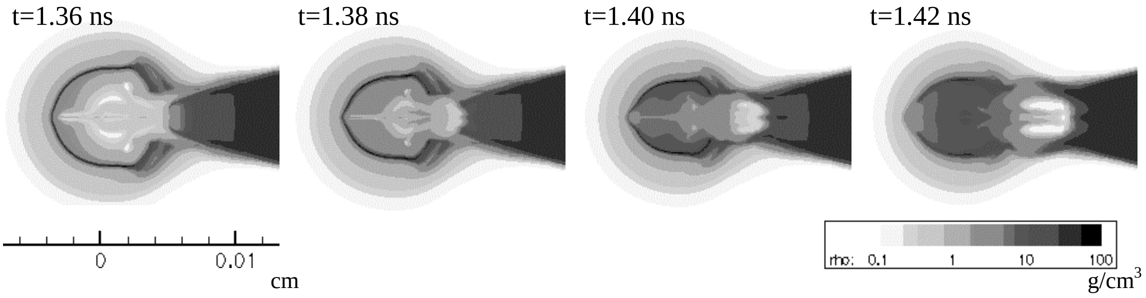

FIG.3 The time history of the density contours in the implosion with conical target case.

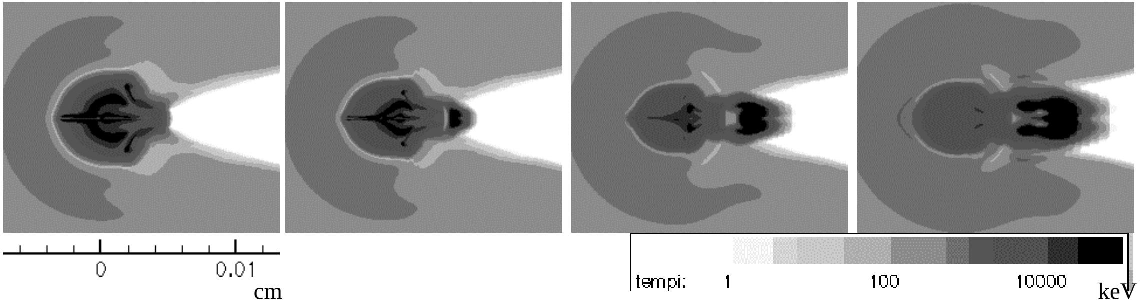

FIG.4 The time history of the ion temperature contours in the implosion with conical target case.

Figure 4 shows the ion temperature contours at the same time as Fig.3. Because of the effect of the tip of the cone, the hot spark is shifted to the right-hand side of the mass center toward the cone surface. A complicated shock is traveling to the center and then reflects to the right on the axis, which move the hot spark to the right. From these results, we can assume that the implosion with the cone that is not spherical geometry can make the high density core region whose life is longer than that formed by the spherical implosion. This phenomena can be controlled by optimizing the shell structure and laser beam power balance[9].

For the fast ignition scheme, it is very essential to simulate an entire extent including relativistic laser plasma interaction, the ignition, burning, and so on. Because of the difference of the characteristic time and space, it is impossible to simulate those phenomena in a single code, we have plan to couple the present integrated code with PIC code for the relativistic laser plasma interaction, and Fokker-Planck code for calculation of energy deposition and fuel burning. Those codes exchange appropriate physical quantities with each other during the execution using multi-platform system[8].

4. Summary

The computational simulation for the fast ignition which has a shell with conical target is performed using a newly developed integrated implosion code PINOCO.

The calculated result suggests that the high density core plasma can be formed in the case of non-spherical implosion with conical target as well as the case of spherical target. The detail quantitative analysis is necessary in the future works. In the future, we will design the optimized targets for the fast ignition experiments, as well as the reactor scale targets.

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