SESSION IF

Wednesday, 21 October 1998, at 2.20 p.m.

Chairman: M.H. Key (United States of America)
later: B.A. Hammel (United States of America)

INERTIAL FUSION ENERGY

Paper IAEA-CN-69/IF/2 (presented by V.P. Smirnov)

DISCUSSION

R.J. GOLDSTON: Do you see any way of making this a repetitively pulsed energy source?

V.P. SMIRNOV: Liner implosion can provide a cost-effective way of studying the high gain pellet physics needed for some approaches to inertial fusion energy. With this data we shall develop this technology to rep-rate operation. However, it is too early as yet to discuss such operation.

Paper IAEA-CN-69/IF/3 (presented by O. Willi)

DISCUSSION

T. DESAI: Your results show decay of instability after 1.7 ns and this is not acceptable for ICF studies. Can you comment on this issue and your further efforts in this direction?

O. WILLI: You are right. It is absolutely essential to reduce the imprint level for direct drive laser fusion. We have difficulty in establishing the exact imprint level at the onset of Rayleigh-Taylor instability and, furthermore, saturation is of crucial importance. We hope to find solutions to the imprinting problem by means of various beam smoothing techniques, buffering schemes, broader band waves like KrF lasers, and so on.

T. DESAI: A self-generated magnetic field at the ablation surface can also restrict the growth of instabilities. What effect of this mechanism do you observe in your study?

O. WILLI: We have no measurements or evidence of magnetic fields at the ablation surface from an experimental point of view. However, theoretical simulations may provide some answers.

K. MIMA: Is electron beam propagation in solid material relevant to electron propagation in a fast ignitor? Electron beam propagation is sensitive to the electrical conductivity of background plasmas. What are the plasma parameters where the electron beam propagates?

O. WILLI: Although it is a solid target before interaction, an electron beam is generated very quickly, ionizing a channel through the target and producing a plasma up to several keV with temperatures similar to those observed in the plasma corona of an ICF capsule. Collimation of the electron beam is still observed in the simulations, even when the resistivity is reduced by a factor of 10. The background electron density is of the order of $10^{29}m^{-3}$ and the temperature increases to a few keV while the beam is propagating, with a somewhat lower value in the target.

V.P. SMIRNOV: What is the value of the electron beam current in your experiment?

O. WILLI: Approximately 20 MA. This is larger than the limiting Alfvén current but there is a return current.

Paper IAEA-CN-69/IF/4 (presented by H. Nishimura)

DISCUSSION

D.H. CRANDALL: Regarding laser imprinting, the Naval Research Laboratory group in the United States has the smoothest laser - a krypton-fluoride (KrF) laser. Their work on imprinting is the best and they have found that laser smoothing, even with glass lasers not as smooth as KrF lasers, could be adequate for direct drive inertial fusion. Foam buffering remains interesting, but is probably not required.

With respect to the direct-indirect drive hybrid experiment with foam buffering that you report, it will not be easy to distinguish the various sources of distortion (degradation) of capsule compression. Presumably, laser imprinting, foam buffering processes and capsule surface smoothness are all acting in your experiments. Are you confident that you can tell which processes are dominating your results?

H. NISHIMURA: Previous work on smoothing by a foam layer focused mainly on plasma formation by supersonic radiation heat wave and homogenization by electron thermal conduction. In the present work, however, the influence of rippled shock waves, particularly of wavelengths longer than the thickness of the foam layer, on perturbation growth has recently been demonstrated. Hydrocode simulations show large growth of the perturbation after the rippled shock passes through the foam-shell interface where a sharp density jump exists. Even with the smoothest KrF laser, therefore, low modal non-uniformities determined by the number of beams and/or the power imbalance among them cannot be easily excluded. The growth of long wavelength perturbation found in the planar experiments may provide further evidence.

As you pointed out, various sources of distortion - including the rippled shock - affect implosion performances, and it is not easy to identify a dominant process, particularly in the capsule implosion. In the present experiments, therefore, the highest fill pressure was selected to attain the lowest gas convergence, in order to eliminate the influence of low-mode non-uniformities on implosion performance. In addition, we expected the foam buffering to eliminate high mode non-uniformities from laser imprinting. Nevertheless, the X-ray image of the imploded shell shows non-uniform shell implosion, almost corresponding to the drive beam geometry. Thus, we tentatively speculate that the degraded implosion performance found in the compression experiments is due to the growth of long wavelength perturbation brought about by the limited number of drive beams.

Paper IAEA-CN-69/IF/5 (presented by M.H. Key)

DISCUSSION

D.H. CRANDALL: Gain in inertial fusion is a complex subject. You have suggested high gain (330) is possible at the National Ignition Facility (NIF) using combined direct drive compression and fast ignition. Without a fast ignitor, gain depends on a “spark plug” effect that depends on high compression of the capsule and, in turn, on careful control of shocks during compression. With a fast ignitor, the “spark plug” is partly in your control. Can you say, in simple terms, how this ignitor helps to give higher gain?

M.H. KEY: Gain is the ratio of energy output from the fusion burn to laser energy input for compression of the fuel and formation of the ignition spark. In all cases, that is indirect drive (ID), direct drive (DD), and fast ignition (FI), operation well above the ignition threshold is required for high gain. Then the internal energy of the spark is, by definition, small relative to the internal energy of the fuel and can to a first approximation be neglected here.

The burn efficiency scales as $\rho r/(\rho r+H)$ where ρr is the radially integrated density x radius and H is a constant. Optimized designs use close to $\rho r=0.5$ H and differences in burn efficiency can to a first approximation be neglected.

The central issue is the laser energy used to compress the fuel which scales as $\eta\alpha\rho^{2/3}$, where η is the efficiency of converting laser energy into compressed fuel energy, α is the ratio of the internal energy of the fuel to the Fermi degenerate minimum and ρ is the fuel density. The same higher value of η applies in FI and DD arising from direct laser irradiation of the pellet relative to the lower η of indirect X-ray drive in ID. ID therefore has lower gain than DD at fixed driver energy and the relevant comparison is therefore between FI and DD.

Lower fuel density can be used in FI for two reasons. Firstly, it is necessary for high gain that the laser energy used to form the spark be a small fraction of the whole (operation well above the ignition threshold). The spark internal energy scales as ρ^{-2} and in FI the spark is at the fuel density (isochoric) rather than at a small fraction of the fuel density in DD (isobaric). FI can thus use lower ρ to satisfy the above threshold condition. I should add, there are subtleties in quantifying this advantage due to differences in isochoric and isobaric spark energies for ignition and in laser to spark coupling efficiencies. Secondly, the hollow shell fuel configuration used in DD requires a higher fuel density for a given ρr and a given fuel mass, again leading to higher fuel density in DD.

Finally, it is possible to use a lower adiabat ratio α in fast ignition because the fuel compression is at lower density and there is no need to form a central spark. Under these conditions ablative suppression of Rayleigh Taylor instability is less critical and a lower α can be used.

The net advantage of FI gain relative to DD gain therefore derives from the $\alpha\rho^{2/3}$ scaling of the internal energy of the fuel with lower values of ρ and α in FI. Quantification of this advantage requires more detailed analysis but the qualitative origin of the advantage is clear.

Paper IAEA-CN-69/IF/6 (presented by R. Kodama)

There was no discussion.