Implosion Experiment of the National User's Facility *

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1. Introduction

I don't describe implosion experiment so much as a discussion has perhaps some of differences in diagnostics, if one had not heard today. I report some of feature of symmetrical illumination facility that has been operating at University of Rochester for the last year, and presently scheduled beginning operation of 24 beam configuration. I first deal very briefly with a laser performance, secondly deal with the evolution of small minor technology that makes dramatic difference in laser system performance. Third I deal with series of the diagnostics that have become common place in our laboratory for high density diagnostics of purely compressed core. And finally from where we stand I would like to summarize the status of laser inertial fusion.

2. The Overview of Zeta Experiments

The 6 beam Zeta laser system at University of Rochester has been operating for the past year. Up to this time it has exercised more than 1200 shots on the target at the power level of 2 or 3 TW depending on target design.

The 24 beam system has been recently completed in the construction as shown in Fig.1. The first 6 beams was constructed in two beam clusters. The 24 beam operation of the facility will take place in November with 24 beam target irradiation facility being able in May or June of 1980.

During the last year the parameter space that we have operated for the purpose of looking at compression of laser fusion targets have been 6 beam symmetrical illumination using circularly polarized light, using the laser power of up to 4 TW in pulse width between 50 and 150 ps. The pulse contrast of this system has been in excess 10^8 . This particular laser system has no dye cells. The contrast between the laser pulse shape itself is obtained through very high resolution, high dynamic range silicon switching.

The experiment that has been conducting over the laser year involves the series of calibration experiment in exploding pusher mode, a series of experiment to test transport, and finally a series of experiment combined with energy deposition to achieve high density.

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3. Semiconductor Switch and Its Applications

The feature which gives this laser system extremely high contrast is essentially high resistivity S_i or GaAs switching, that has the feature as shown in Fig.3. It has a time constant of 1 ps. It is virtually jitter free, that is, has a jitter of less than 1 ps and has extremely wide band width. Figure 4 shows, in federative transmission of optical pulse width on the switch, feature of this switch which turns S_i from a very good insulator to a very good conductor over very brief time, very effectively, by extremely low incident port energy, μJ .

We use this technique for jitter free switch-out on the laser system. We use this technique in all about active pulse shaping with a rise time of 40 ps, and use this technique in all about the streak camera operation with 1 ps precision and with the jitter less than 1 ps. Allowing us to very carefully sweep out with diagnostics, the contrast ratio between what is the head of pulse and what is detailed pulse shape is 10^8 . An example of the technique of jitter free streak camera operation is shown in Fig.6. This schematic explains an important role in determining the zero time fiduciary associated with the incident laser pulse on target when we use x-ray streak camera to see first x-ray emission comes out relative to the initiation of laser pulse.

4. Zeta Experimental Program

The nature of laser used program (see Fig.7), this was the program conducted in 1979 and now completed, involved the series of experiment in which the fuel density was typically 1 to 100 times solid and neutron yield was in excess of 10^8 . These are the calibration experiments of illumination configuration. The second series of experiment was completed that involved the modeling of transport looking at both inhibited and uninhibited transport and x-ray emission and involved fuel density of roughly 10 x. During experiment 20 times liquid density is measured when neutron yield is 10^7 . Finally there are multi-layered targets which have been examined and continue to be examined which involve density in excess 20 gr/cm^3 .

The 6 beam illumination configuration is symmetrical illumination system (see Fig.8). In the transport experiment particularly, main diagnostic tools were x-ray streak camera, soft x-ray detector and spectrometer as well as bank of x-ray detector.

In explosive pusher experiment (the calibration experiment) not only pin-

hole camera but x-ray zone plate was used, as well as neutron yield as a major diagnostics. I'll come back to use spectral resolution of α time of flight measurement, as a crucial diagnostics to help to answer the question, Dr. Holtzrichter talks about α spectrum whether or not one can rely on α particle image for determination of the core condition.

5. x-ray Measurement: Pinhole camera, spectroscopy, streak camera and interferometer

The 6 beam illumination condition facility in its hard ware is something shown in Fig. 9, where we are looking in a port of streak camera. The feature of this particular system are that the illumination geometry is very symmetrical. Figure 10 is a symmetrical explosive pusher measurement one can not determine the large scale deviation from symmetry. This is not to say however that symmetry is good enough for greatful compression, not anywhere near good enough point at this time.

It is extention of 6 beam illumination to the 24 beam configuration, that we turn to improve the symmetry to study the basic target behavior. Now the thrust of this particular illumination configuration is to come as close as possible to joint theoretical-experimental-mutual replicaiton, that is, to replicate as close as possible in both theory and experiment the same phenomena, hence to do control experiment and not be confused, if possible, by two demensional effect which tends to confuse basic physics whether or not will be successful and 24 beam illumination remains to be seen.

Some of the diagnostics, which has stood and which one heard about, are compared with our one dimensional code calculations. We derived from our bank of x-ray detector x-ray spectrum with solid line being the x-ray measurement and dotted line being the prediction of code as shown in Fig.11.

X-ray spectroscopy has been standard tool in our laboratory for some time. The urn set of the emission of certain lines gives a way to the physical properties of the behavior of the compressed fuel. Figure 12 is monochromatic images if plastic coated microballoon, in which the lines of chlorine and silicon come from outer pusher, and the central argon spike comes from the fuel itself. The fuel in this case is mixture of fuel DT and argon.

This monochromatic image is just but the most superficial kind of diagnostics for spatial resolution. Indeed what one would like to do is to compare, as best we can in this high density regime, the line profiles actually measured and the calculated line shape (see Fig.13).

These line shape becomes complicated when you have combined spectra of both

the outer layer of target and inside. When you have a combination of argon emission and calcium in this case, the combined fitting, two or over all experimental profiles, is a sensitive function not only of the peaks and width between the peaks in $L_y\beta$ for argon but also of a half width of the slope. It is fairly said, in this regime of sensity and temperature, one must fit complete profiles, half width and amplitude. The total of profiles fitting is what is quite confidence in the density estimation.

When turning to time resolved x-ray measurement it is relatively easy and indeed standard at most major laboratory to have x-ray streak cameras. And a simple x-ray streak of the initiation of target absorption and alternated behavior of target can be shown in Fig. 15 by two burst as recorded on film. A microdensitometer trace of Fig.15 shows rather invidious profiles. The question is how do you relate this (profile measure) to the theoretical calculation to control the overall behavior of the target. One way is to resolve the x-ray emission spatially through pinhole. Figure 16 shows a spatially resolved behavior of the target which is now compressed in the center where most of the emission come from. One could pick out in time using as arbitrary zero, because one don't know where the zero is, the two peaks is this emission and then compared not only the time between the peaks but amplitude with some theoretical calculation including the complicated response of the x-ray photo-cathode.

One of experiment designed was to look at the effect of inhibited process and uninhibited transport. One expected to see a x-ray signal that might look something like a trace in Fig.17. The important time of interest is the time between the peak of laser pulse and the high point of the second peak. The first peak of x-ray emission come from initial interaction in outer layer of the target, and the second peak is related somehow to the target behavior in a center. This is not a collapse time. In all the experiment we see difference in this time for inhibited transport and uninhibited transport. One need to determine the position of this laser pulse relative to the x-ray pulse very accurately, that is, with accuracy better than 20-30 ps. So we take the 4ω timing pulse out of the laser system itself. There is superimposed two sections of photocathode which then provide not only time resolved x-ray emission but also the timing markers (see Fig.18). These makers are synchronized with the laser pulse. We evolved to do that again because of the jitter free switching. And we synchronized 4ω pulses with main laser pulse, x-ray emission pulse and the streak camera to obtain the full bandwidth of X-ray streak camera.

The bottom trace in Fig.19 is the 4ω timing pulses with the bounce time between ebullience to relate that time to the urn set of the first x-ray peak and urn set of the second x-ray peak. Then we can measure the time from the first

peak and urn set of the second x-ray peak. Then we can measure the time from the first peak of 4 ω pulses to the second x-ray peak and actually compared with one dimensional calculations.

There is the second technique which is under development in our laboratory. One technique we are developing in x-ray regime is x-ray interferometer. It is a kind of next step beyond back-lighting. And that has not yet been put in a dynamic situation to study laser plasma target. We are simply developing an equipment where we can see a fringe pattern from a complicated wedge that has a 150 μ m spacing between the fringes and the final structural spacing associated with problem deviations in the wedge as shown in Fig.20. The purposes to see what kind of resolution we can get in this fringe spacing in order to look a compressed target is spatial feature on the over 10 or 15 μ m.

6. Reaction Product Measurement

Now let me turn to reaction product measurement. α time of flight measurement have been used in KMS Fusion and elsewhere. One of the feature of these measurement is that with the DT reaction and contain information, for example, of the temperature of the middle region on the half width. More over if one compare the α particle traces with a fiduciary, you can essentially determine the overall deviation of the peak and hence something about potential of the expanding target. One can win α image from the core. That image is not confused by significant electrostatic potential that exist on the target being compressed and expanding. Here is two cases which have identical neutron yield and almost identical laser power, 1.3 and 1.2TW, and listed in Fig.21. The upper trace was a case of a larger target, and lower was a smaller target. The difference between these two cases is whether the laser pulse exist when the emission of nuclear particle occur. In th case of shot #1843 the laser pulse was gone when, in fact, the neutrons were produced. That phenomena is explained in Fig.22 which shows the position of the laser pulse. In one case the laser pulse still overlap with the emission time, and the other case does not or hardly has overlapping. The potential has been measured looking at the shifting of α particle spectrum as well as broadenning in the case that the potential is generated during the absorption process of the laser on a plasma. And a plasma can generate the potential of up to 400-500 keV with no problem. Now the beauty of this is the α particles are basically test particles, and in principle we should be able to form the compressed region from the nuclear emission by following the potential about the particle produced through the chamber. We should be able to map in time and space.

The potential of the pellet during the expansion phase in turn should be related to the overall behavior of the target.

A calculation of a typical α particle spectrum is shown in Fig.23. We compare a measured spectrum with the one dimensional code we use for designing these experiments. A major neutron yield was 10^8 with the predicted neutron yield of about 10^8 . The mean α energy was 3.02MeV and code-predicted energy of plasma 2.8MeV. A temperature derived from present measurement was 2.2KeV, and the predicted temperature was 2.3KeV. Figure 23 shows that kind of agreement that we seek enduring these basic experiment. Quite wide α and proton energies are important diagnostics. Figure 23 is an example of α traces and reluctant proton traces on the same shot that can be measured the ratio to determine temperature. This was a shot of plasma by 2TW laser with yield of 3×10^8 , and α energy and proton energy are around 3MeV.

If one compares the experimental data with the calculated data, one can compare the neutron yield that now is easy but relative insensitive. In the case of the power of 1.3TW the measured yield is 2×10^8 and the predicted yield is approximately 2×10^8 . The measured ion temperature is 3.2KeV, and we can calculate the temperature of 2.7KeV. At higher power the measured temperature is 4.1KeV with predicted temperature of 3.7KeV (see Fig.25).

Figure 26 is a slide Dr. Holtzrichter shows the progress of density in g/cm^3 . These open dots are the Livermore points. The Zeta experiment, the middle section of experiment are in that region, and that is where Zeta facility presently operating at about 20 times liquid density of DT.

7. Summary

We summarize in Fig.27 the status of laser fusion, that is, fusion requirements and experiments to date.

Fig. 1.

ZETA EXPERIMENTS OVERVIEW

LPR
LLP

LASER

- Six beam symmetrical illumination
- Laser power – 3 TW, 50 – 150 psec
- High Pulse Contrast $> 10^8$

EXPERIMENTS

- Zeta-X, exploding pusher
- Zeta-T, fast electron transport
- Zeta- μ , radiation cooled targets – high density

E594

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

ZETA EXPERIMENTAL PROGRAM (1979)

EXPERIMENT	TARGET	PURPOSE	VELOCITY	IMP. TEMPERATURE	PULSE WIDTH	WAVELENGTH	STATUS
X	THIN WALL MICROBALLLOON	EXPLOSIVE PULSED SCALING	2.3 km/sec	1.0 Kev	100 μ s	10 ³	DIAGNOSTICS INITIATED
Y	THICK WALL MICROBALLLOON	TRANSPORT MODELING	1.2 km/sec	1.0 Kev	1.00 μ s	10 ³	DESIGN COMPLETE - INITIAL SHOTS TAKEN
P	STRUCTURED TARGET	HIGH DENSITY COMPRESSION	1.0 km/sec	1.0 Kev	100 μ s	10 ³ - 10 ⁴	INITIAL DESIGN

Fig. 7.

Fig. 8.

Fig. 9

Fig. 10.

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

Fig. 18.

Fig. 22.

Fig. 23.

Fig. 24.

Fig. 25.

Fig. 26.

Fig. 27.