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Shadow Imaging Study of Z-Pinch Dynamic Hohlraum

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Abstract**—**In order to obtaining the dynamic evolution image of Tungsten array for foam padding, and to research the form of interaction between Tungsten plasma and foam column, a shadow imaging system of four-frame ultraviolet probe laser (266nm)has been designed on 1MA pulse power device. The time resolution of the system is 2.5ns, and static space resolution is superior to 70μm. The radial shadowgraphy image reveals the whole process from the melting and expansion of solid wire to the interaction of the precursor plasma and the foam, from the pinch to rebound inflation. The image shows the continuous interaction of Tungsten plasma and foam in a form of "Raining" within a time of about 50ns, the plasma shell structure has not been found in the whole period of pinch. The quantitative analysis indicates the minimum pinching speed of the foam column is 1.0×10^6cm/s, and maximum pinching speed is 6.0×10^6cm/s, and the axial stagnation diameter is approx 1mm.

Keywords**—**Dynamic hohlraum, Shadowgraphy image, Foam evolution.

I. Introduction

THE research on Z-pinch hohlraum is the key point in study of Z-pinch ICF(inertial confinement fusion), of which, the embedding foam dynamic hohlraum(Fig. 1) is one of the sources nearest to black body radiation which can be achieved at soft X-ray waveband laboratory, meanwhile, it's also the most powerful X-ray source for radiation transport fundamental research and ICF of indirect driven[1], therefore being extensively concerned in all kinds of hohlraum study. At present, the research on dynamic hohlraum in lab mainly focus on the aspect of diagnosis of radiation field, measuring X-ray power radiates from axial diagnosis hole and X-ray image[2,3], the energy spectrum of tracer element has been measured by part of experiments[1,4]. These hohlraum experiments are mostly carried out on Z generator with large pulse current; however, on the device of small pulse current, for instance, about 1MA, there will be many difficulties to measure axial hohlraum radiation field. On the one hand, the temperature of hohlraum radiation is low on this kind of device, the intensity of X-ray radiation strength is also very low, it means that the diagnosis hole on the hohlraum for axial measuring should not be too small; on the other hand, no entering of Tungsten plasma at the axial diagnosis horizon shall be allowed as far as possible, otherwise, the plasma radiation will generate remarkable interference to the result of measurement, therefore, it is vital importance to select suitable axial diagnosis hole with proper size.

In addition, it has an important reference value to know the dynamic evolutional process of interaction between Tungsten plasma and foam column for improving physical design of dynamic hohlraum, but the experimental report on this aspect is rarely seen. This article has obtained the evolution image of whole process from solid Tungsten inflation / melting to interaction of precursor plasma and foam, from foam pinch to rebound expansion, through radial ultraviolet shadowgraphy image, and work out the minimum diameter of the foam pinched to the core and providing the support data for the design of axial diagnosis hole; meanwhile, these diagnosed result has also provided the scaling data for simulating program of hohlraum dynamics.

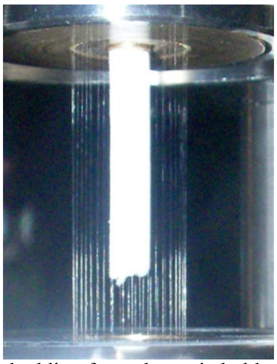

Fig. 1 Embedding foam dynamic hohlraum

II. Four-Frame Shadowgraphy System

The laser for experiment is 12ns in pulse width and having an output capacity of 30mJ/266nm laser pulse energy. 12ns pulse exported by laser shall be divided into two beams, the effective width of relative time delay is approx 30ns, the time resolution of the system is based on the time-gated image intensifier of the record units. The system has an ability of four-frame imaging, the time resolution is approx 2.5ns, the static space resolution is superior to 70μm, the beam path diagram of the shadowgraphy system incident unit and frame imaging unit are indicated in Fig. 2.

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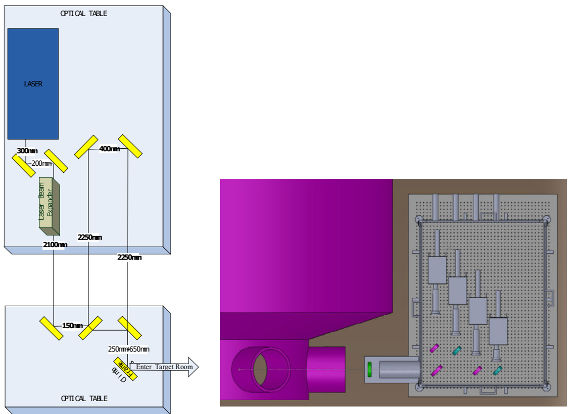


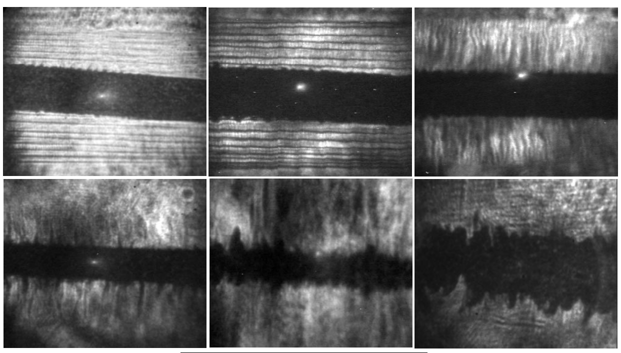
(a) (b)

Fig. 2 Incident unit (a), Frame imaging unit (b)

III. Experimental Results and Analysis

The experiment was carried out on the pulse power device of "Qiang Guang-1" at Northwest Nuclear Technology Research Institute, the load pulse current peak is about 1.3MA, rising time (10%-90%) is approx 80ns,The load of embedding foam dynamic hohlraum is indicated as Fig. 1, Tungsten array diameters are both 8mm and 12mm, they consist of 42 pieces of Tungsten filaments with same diameter of 4.2µm, the diameter of foam column ($C_{15}H_{20}O_6$) is 3mm.

Firstly, taking Φ8mm Tungsten array as example, the pinch evolution image at typical moment based on sequence of different time shall be listed at Fig. 3, in which, some light spots on certain images is resulted from self-defect of imaging system, the zero point of time reference in shadowgraphy image is the X-ray power peak moment of each shot.



-69.5ns (289#)	-45.5ns (288#)	-24.3ns (292#)
-13.7ns (303#)	0.2ns (301#)	15.9ns (302#)

Fig. 3 Dynamic evolution of dynamic hohlraum

It is clear in Fig. 3, visible interaction between the precursor plasma and the foam column can be found approx 70ns prior to X-ray peak, at this moment, the Tungsten diameter has expanded from initial 4.2µm to 70µm~200µm，at subsequent time, the movement trace of precursor plasma pinching inwardly can be seen clearly. At the time of 45ns prior to X-ray peak, a large quantity of residual mass still remain at the position of static wire; at the time of 24ns prior to X-ray peak, the residual mass at tungsten former position can not be found on the shadowgraphy image, at this moment, most Tungsten mass may has been melted away, and the plasma with action of internal explosion core-gather with mutual melted into "Spine" shape and developing inwardly; at the time of 14ns prior to X-ray peak, the main mass of Tungsten plasma has acted onto the foam, at this moment, the foam diameter has been compressed obviously, from Φ3mm to Φ2mm.

It can be seen obviously from above process, within a time of 50ns, the Tungsten plasma continuously enter into the process of interaction with foam in way of mass incremental form, this type of action is difficult to form a hohlraum wall and will further affect the quality of hohlraum radiation field in the foam. The average diameter at the mixed boundary of the foam column and partial Tungsten plasma is only Φ1mm at the vicinity of X-ray peak. At the time of 16ns after X-ray peak, the rebound expansion which pinched into core can be seen, at this moment, the mixed body of the foam and Tungsten plasma has expanded to about Φ3.6mm. The hohlraum dynamic evolution image of Φ12mm and of Φ8mm which reflected by tungsten shadowgraphy image are consistent.

Following, the "standard point" of reference time of probe laser shadowgraphy image in different shots, is to make a judgment for its rationality for whether adopting of radial X-ray peak moment of each shot or the time point of certain characteristic of temporal waveform of load current.

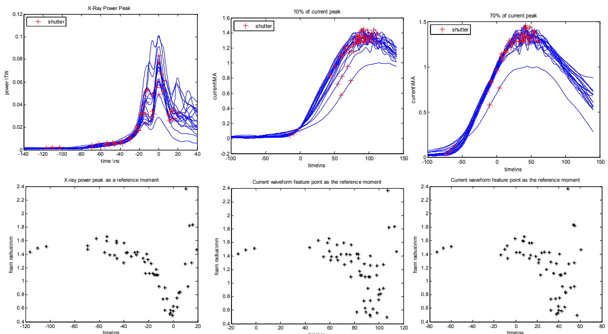


Fig. 4 Diagrams of frames timing and foam radius evolution with different reference time point

For the sake of answering this question, at first, we should make an interpretation on average radius of the foam column (covered with tungsten plasma) at different moment corresponding to X-ray peak value at each shot, and then, according to the time of relative current waveform of X-ray peak value at each shot, the interpretation data of the foam column shall be interacted to the moment of the current waveform characteristic.

All frames imaging moments shall take as reference of the moment of X-ray power peak, 10% amplitude moment of the current peak and the moment of 70% amplitude of current peak, as indicated at first line of Fig. 4, the cross on it represents the shooting moment of each image for which at the position of corresponding time waveform;

The 2nd line in Fig. 4, it is the evolution image of the foam pinched radius along with time goes on, with a reference of corresponding sequence of shooting time; it can be seen that the physical image development in the process of foam pinching process, there are three periods with X-ray power as a point of reference time, namely, pinching–stagnation–rebound expansion. The data for which taking current waveform characteristic as reference is somewhat chaos, so taking X-ray power peak as reference time point is more reasonable.

In following, taking X-ray power peak as reference moment, 3-order polynomial fitting has been conducted on evolution curve of foam column radius along with sequence of time under three conditions of Φ8mm、Φ12mm and non classification (in Fig. 5), the Expression obtained from fitting, solving the instant pinching speed (Fig. 6), minimum pinching speed of unclassified load foam column is 1.0×10^{6}cm/s，and maximum pinching speed is 6.0×10^{6}cm/s.

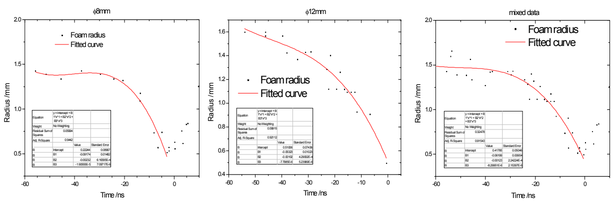


Fig. 5 Curve of foam radius evolution

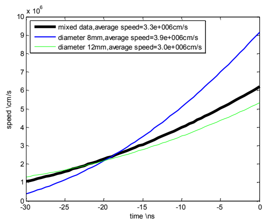


Fig. 6 Pinch speed evolution

The evolution curve of radial pinching speed of the foam column in Fig. 6 has a cross point, the radial pinching speed of Φ12mm tungsten array foam column is bigger before this moment, as time goes on, radial pinching speed of Φ8mm tungsten array foam column is more and more bigger, since the statistic data of Φ12mm tungsten array is not adequate, so this conclusion should be supported by more experimental data..

Fig. 7 indicates the time evolution of radial X-ray power of the foam column tungsten array at different shots, it can be seen in the Fig, the X-ray power shows the structure in double peaks; the first X-ray peak is located mainly within the range of 10ns ~ 16ns prior to the main X-ray peak (the one with a maximum amplitude), it can be deduced from the dynamic evolution process of the tungsten array, the main X-ray peak is the eruptive X-ray radiation at the time when foam column pinched to the core; However, the first X-ray peak shall be the foam plasma internal energy which transformed from motive energy carried by a large amount of tungsten plasma and being released in form of radiation energy. So the shadowgraphy image corresponding to the first peak moment exactly right reflects the pattern of interaction between main tungsten plasma and foam column. The shadowgraphy image corresponding to this moment is indicated in Fig. 8.

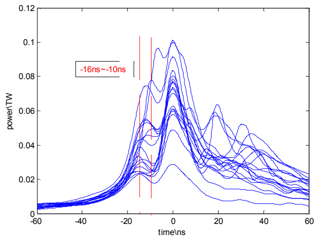
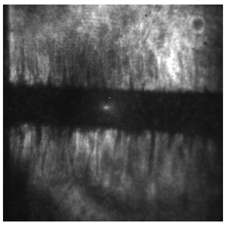


Fig. 7 Radial power of different shots



Φ8mm -13.7ns

Fig. 8 Shadowgram of first X-ray peak timing

IV. Summary

The radial four-frame image of Z-pinch dynamic hohraum has been obtained by diagnosis form of probe laser shadowgraphy image. The shadowgraphy image at different moment and different time indicates the centripetal movement from tungsten expansion/melting to precursor plasma, a series of dynamic evolution process image from interaction of precursor plasma and foam column to pinching – stagnation – rebound expansion.

The time evolution description of the shadowgraphy image, within a time of approx 50ns, the tungsten plasma continuously interacts with the foam at a form of “Raining”, the shell structure has not been found in the whole process of pinching, it is indicated via an analysis of the quantitative data, its max pinching speed is 6.0×10^{6}cm/s, and the min pinching speed is 1.0×10^{6}cm/s, the axial stagnation diameter is about 1mm, this figure has provided a quantitative reference data for the selection of axial radiation measuring diagnosis holes.

The experimental result reveals that the number of frames should be further enhanced in the future shadowgraphy image measuring, it will benefits the utilization rate of a single time experiment, and enables the dynamic evolution process of the hohlraum more proper, and further enhance the time resolution. And thereby raises the system dynamic space resolution and betters the image quality.

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