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ABSTRACT

The National Ignition Facility (NIF), proposed by the Office of Inertial Confinement Fusion (ICF), will be used to demonstrate fusion ignition in a laboratory environment (1). The primary mission of NIF will be to support U.S. DOE Defense Programs. The facilities' secondary mission will be to support development of inertial fusion as a potential fusion energy source for civilian use (2). Target insertion is one of the technical issues which will need to be addressed before inertial fusion can become a practical energy source, and is one of the issues that can be investigated by experiments on the NIF.

Target insertion systems currently utilized at existing ICF facilities consist of mechanisms inside the target chamber to insert, position, and hold the target at the chamber center. These are not suitable for multiple shots in quick succession, as needed for energy applications. A study was performed to investigate various new techniques for target insertion in NIF.

Insertion concepts involving free-falling and artificially accelerated targets were developed and evaluated against a set of predetermined guidelines. Fixed structure holding systems were not considered due to the destructive environment at the chamber center. Conclusions drawn by the author suggest a system involving a fast retraction positioner would be suitable. A target would be positioned in a holder attached to a moveable arm. The holder is moved to a position slightly above the chamber center. The target is dropped and the holder/arm assembly is quickly retracted to avoid ablation effects. To improve target accuracy, a release system imparting near-zero torque and augmenting the target with additional mass to reduce drag effects would be employed. A plan illustrating a reasonable continuation of the project, leading ultimately to tests in NIF, is also presented.

I. INTRODUCTION

This paper documents a study (3) investigating concepts for target insertion systems for Inertial Fusion Energy (IFE) applications that could be tested in the National Ignition Facility (NIF). The study focused on concepts that would accurately place a target at the NIF chamber center while minimizing ablation effects. Guidelines and requirements developed for the study are listed below:

- Accurately insert target (hohlraum)
- Cryogenic survivability (radiation shielding)
- $(\Delta r)_{shot} \leq 20\ \mu m$ (distance from center of laser focus)
- $(\Delta Ø)_{shot} \leq 10\times10^{-3}$ rad (pointing angle for hohlraum alignment)
- Minimize debris generation
- No interfering thermal radiation shroud
- Single shot with possibility of repeated injection (IFE requirement)
- Maximum target exposure time to 300 K environment–0.2 s
- Minimize condensation of shot residue on in-chamber hardware

The study is in two sections: Target Insertion Systems that maneuver a target into a predetermined position within the NIF chamber and Target Release Mechanisms which ultimately release the target while minimizing external influences. Target dynamics were analyzed by utilizing the computer aided engineering software package “Working Model.”

Fixed positioning structures, such as those currently used at the LLNL Nova facility and planned for NIF non-IFE targets (1), are not presented in this paper.

II. TARGET INSERTION SYSTEMS

The insertion systems are represented by two groups: free-falling (represented by the Shielded Drop Tube and Fast Retraction systems) and artificially accelerated represented by the Injection Gun. Table 1 compares the calculated target dynamic envelope for each insertion concept.

A. Shielded Drop Tube

The shielded drop tube concept consists of a fixed vertical tube extending into the chamber. A target is prepared and loaded into a release mechanism, moved to the drop tube breach on the chamber's edge and released. The tube is located directly in line with the chamber center and the target free falls through the inner wall which is actively cooled (20 K) to provide thermal radiation shielding.

The shielded drop tube represents a simple concept requiring minimal technology development. Direct and indirect targets could be delivered with this method with modifications only to the release assembly. Liquid targets may be possible provided the targets be released directly from the target layering station.

B. Fast Retraction

The fast retraction concept (Fig. 1) is a development of the shielded drop tube utilizing the benefits of further shortened free fall time and lower target velocity. The system consists of two concentric telescoping cylinders which penetrate the vacuum chamber. Integral with the lower end of the inner cylinder is a transporting cryostat fitted with clamshell doors and containing the target release mechanism.

A prepared target is loaded into the transporting cryostat and lowered to the release point 20 cm above chamber center. The clamshelled doors open and the target is released. Simultaneously, the lower tube retracts upward 1.5 m above chamber center to reduce ablation damage. After ignition, the whole assembly retracts slowly out of the chamber for reloading.

The fast retraction concept will require some significant technology development. The system has an advantage over the shielded drop tube in that it can be mounted vertically or horizontally.

C. Injection Gun

The injection gun concept has been extensively studied in previous IFE reports (3). In an attempt to avoid designing another injection gun system, a general description and an evaluation based on NIF requirements utilizing data from the aforementioned reports is presented.

The injection gun concept utilizes a rifled tube through which targets are injected into the chamber in single or multiple order. The target is placed inside a sabot and loaded into a firing chamber. High pressure gas, electromagnetic, or electrostatic forces propel the target/sabot assembly down the tube. Rifling of the tube imparts an angular velocity on the assembly for spin stabilization. The target enters the chamber and continues until ignited at the chamber center (4).

This concept requires significant technological development before a viable design can be implemented. Target heating and impact of propellant gas in the chamber may also prove undesirable (4).

III. TARGET RELEASE MECHANISMS

Target accuracy is primarily a function of the boundary conditions at the moment of release. Any extraneous torques, accelerations, or off-axis release angles could have a detrimental effect on the target position when it reaches the chamber center. Several simple release mechanisms utilizing magnetic, electrostatic, or mechanical forces to hold the target were investigated. Each concept suffered from uncertainties of release torques due to the possiblility of the target sticking to a portion of the release mechanism.

Table 1
Insertion System Target Dynamics

	Shielded Drop Tube	Fast Retraction	Injection Gun
Free Fall Distance	5 m	0.02 m	5 m
Free Fall Time	1.01 s	0.2 s	0.2 s
Target Velocity at Chamber Center	9.91 m/s	1.96 m/s	25 m/s
Target Duration Time at Chamber Center	4×10^{-6} s	20×10^{-6} s	1.6×10^{-6} s
Release Angle Allowance	$0.23\times10^{-3\circ}$	$57\times10^{-3\circ}$	$0.23\times10^{-3\circ}$
Release Angular Velocity Allowance	5×10^{-3} rad/s	5×10^{-3} rad/s	5×10^{-3} rad/s

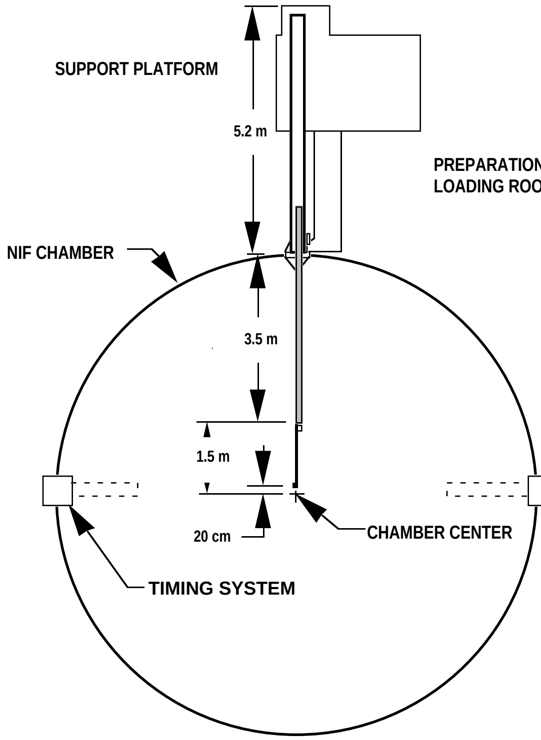

Fig. 1. Fast retraction system vertical installation.

Two concepts were investigated in an attempt to minimize the release point boundary condition influences. Near-zero net release torques are achieved by removing side load forces and applying release forces directly through the target centerline.

A. Spider Web

The spider web release mechanism (Fig. 2) suspends a target on a slender fiber directly in line with the target center line. A laser severs the fiber and the target free falls to the chamber center. Vibrational forces may prove problematic as the single fiber could promote a pendulum action. It may be possible to utilize retractable stabilizers which would hold the target steady until just prior to release.

B. Rotating Beam

The rotating beam release mechanism (Figs. 3&4) consists of a target held between the forks of a horizontal beam which is resting on a fulcrum. The fulcrum is at a distance away from the target such that the beam center of gravity is between the fulcrum and target. A trigger device on the opposite side of the fulcrum releases the beam which rotates about the fulcrum point. As the centers of gravity for both the target and beam will drop at the same rate, the forks will accelerate away from the target which will fall to the chamber center with no net torque or forces applied.

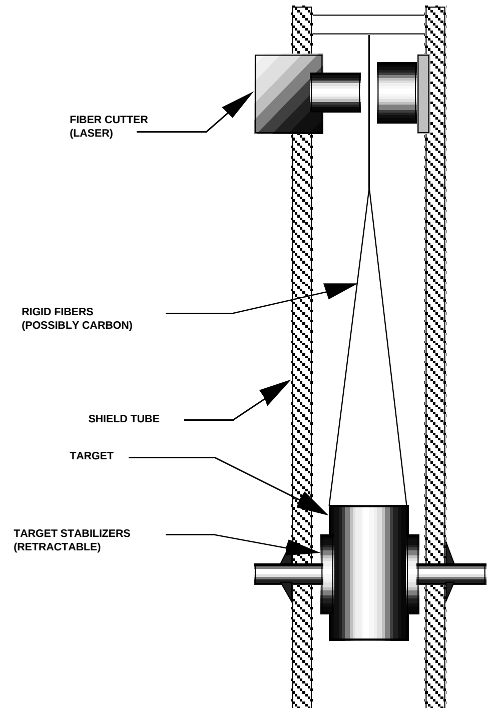

Fig. 2. Spider web.

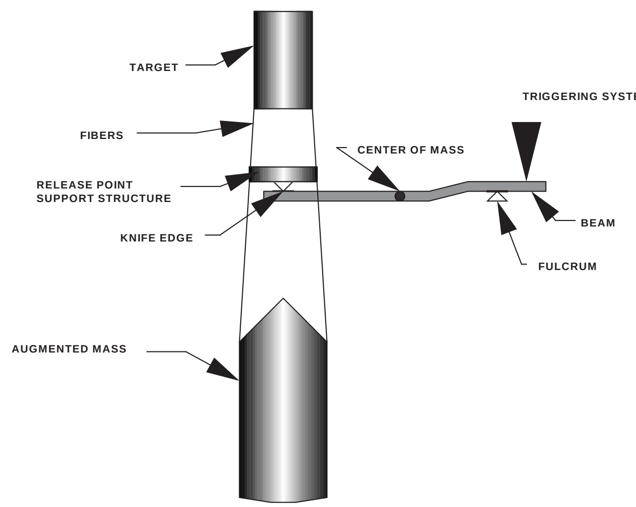

Fig. 3. Rotating beam with augmented mass.

C. Augmented Mass

Augmented mass is a concept intended to increase the accuracy of the aforementioned release mechanisms. Analysis conducted at General Atomics revealed that the acceleration of a free falling target in a 10^{-4} Torr environment is not zero g but rather approximately 10^{-3} g due to the drag forces caused by residual gases. An additional mass attached to the target can reduce the drag and destabilizing effects of residual gas. Upon release, the and the added mass will fall to the bottom of the chamber

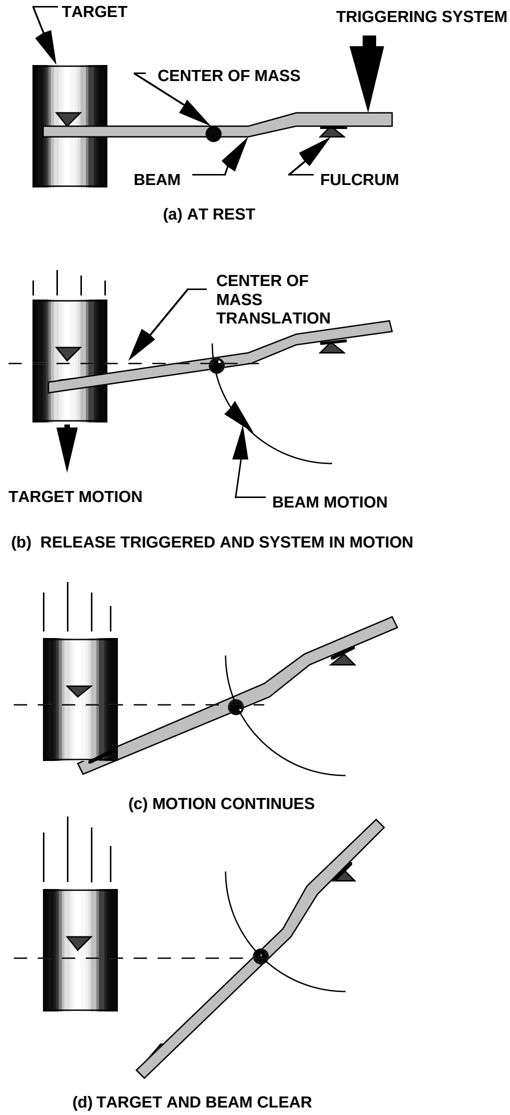

Fig. 4. Rotating beam.

target/mass assembly will pass through the chamber center while the target is imploded. Figure 3 illustrates an installation consisting of the rotating beam mechanism with an augmented mass target assembly. The relative distance between the target and the augmented mass or support structure must be chosen so as not to interfere with the laser beams. The fibers, likewise, must be slender enough to minimize beam interference.

IV. CONCLUSIONS

It is the opinion of the authors that a free-falling target positioning mechanism with a zero net-torque release mechanism is the best target insertion system for the National Ignition Facility. A system consisting of a fast retraction positioner and a release mechanism based on the rotating beam with an augmented mass would be the most reasonable. Placing the target release point close to chamber center will optimize successful target placement by lowering target final velocity and reducing release point perturbation effects. The capability of retracting the positioning structure to a safe distance will minimize ablation erosion effects. The suggested release mechanism would impart virtually no net influences on the target, resulting in ideal boundary conditions at the moment of release.

V. IMPLEMENTATION

This study has provided suggestions for a few reasonably viable insertion and release system desings. As these designs are developed only to a conceptual level, further analysis would be prudent before candidate systems are selected for testing.

The target release mechanism would be the subject for initial proof of concept testing. The insertion system would not necessarily require extensive testing at this time. A selected release mechanism prototype would be built and placed in a testing apparatus. This apparatus would be similar to a drop tower with vertical dimensions on the same scale as NIF and be capable of sustaining high vacuum. The release mechanism would be subjected to iterative testing to determine target placement accuracy, repeatability, and viability of concept. Targets modified with an augmented mass would be included in this testing.

Completion of release system testing will lead to detail design of the overall insertion system. The release system, positioning system and related external hardware will be developed. Completion of such activities will result in a presentable complete target insertion system.

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