GA–A24200

EXPERIMENTAL TARGET INJECTION AND TRACKING SYSTEM

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R.W. PETZOLDT, N.B. ALEXANDER, T.J. DRAKE, D.T. GOODIN,
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GENERAL ATOMICS

DISCLAIMER

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This is a preprint of a paper to be presented at the 15th Topical Meeting of the Technology of Fusion Energy, November 17–21, 2002, Washington, DC, and to be published in *Fusion Science and Technology.*

†Anderson Engineering, San Diego, California 92122

Work supported by
the Naval Research Laboratory
under Contract No. N00173-02-C-6007

GA PROJECT 39083
JANUARY 2003

GENERAL ATOMICS

ABSTRACT

Targets must be injected into an IFE power plant with an accuracy of ± 5 mm at a rate of approximately 5 to 10 each second. Targets must be tracked very accurately to allow driver beams to be aligned with defined points on the targets with accuracy ±200 mm for indirect drive and ±20 mm for direct drive. An experimental target injection and tracking system has been designed and is being constructed at General Atomics to investigate injection and tracking of both direct drive and indirect drive targets. The design is modular to allow testing of alternate target acceleration and tracking methods. The injector system will be used as a tool for testing the survivability of various target designs and provide feed back to the target designers. This 30 m long system will be the centerpiece of a Facility for developing IFE target fabrication and injection technologies.

A high-speed high-flow gas valve[a] will provide helium propellant gas to the targets. To avoid target damage from excessive acceleration, an 8 m gun barrel is being built to achieve 400 m/s target speed while not exceeding 10,000 m/s^2 acceleration. Direct-drive targets are protected in the barrel by sabots that are spring loaded to separate into two halves after acceleration. A sabot deflector directs the sabot halves away from the target injection path. Gas expansion chambers and orifices, keep propellant gas out of the target-tracking region. Targets will be optically tracked with laser beams and line scan cameras. High-speed computations will calculate target position in less than 2 ms based on the output from the line-scan cameras. Target position and arrival time to a plane in the reaction chamber center will be predicted in real-time based on early target position measurements. The system design, construction progress, and early testing results will be presented.

I. INTRODUCTION

In an Inertial Fusion Energy (IFE) power plant, driver beams deliver an intense pulse of energy to a target containing cryogenic deuterium-tritium (DT) fuel. The energy pulse causes the fuel capsule to implode and initiates fusion reactions. To achieve high gain implosions, the targets must reach the target chamber center with a symmetric layer of DT ice at about 18.5 K and with a smooth ice surface finish. Targets must be injected with an accuracy of ±5 mm at a rate of approximately 5 to 10 each second.

For direct drive IFE, the target consists of a spherical capsule that contains the DT fuel.[1] Direct drive targets are the base-case option for laser-driven IFE. For indirect drive IFE, the capsule is contained within a hohlraum that converts the incident driver energy into x-rays to drive the capsule.[2] Targets must be tracked very accurately to allow driver beams to be aligned with defined points on the targets with accuracy ±200 mm for indirect drive and ±20 mm for direct drive.

A primary near term goal of the U.S. IFE program (Phase I) is to develop the design basis for a proof-of-performance-level integrated research experiment (IRE). A credible target design, fabrication, and delivery system together with successful proof-of-principle driver beam development are prerequisites to an IRE. Operation of the IRE, plus successful target ignition experiments are prerequisites to a high pulse rate engineering test facility, and subsequently a Demo plant leading to a commercial fusion power plant.

General Atomics has been assigned responsibility for the target injection and tracking work in support of the IFE development strategy. As part of this work, we must address the following critical issues:

- ∑ Ability of targets to withstand acceleration during injection
- ∑ Accuracy and repeatability of target injection
- ∑ Ability to accurately track targets

∑ Ability of targets to survive environment in chamber (thermal, gas, debris)

Major task areas within our overall plan to address these issues include target thermal response, target injection and tracking accuracy, target acceleration response, and target property measurement. An experimental target injection and tracking system has been designed and is being constructed at General Atomics as a test bed for work in the first three of these task areas. The experimental target injection and tracking system will facilitate development of target tracking technology. It will also develop target injection methods to accurately and rapidly place targets in a hot chamber and test the survivability of various target designs.

II. SYSTEM DESIGN DESCRIPTION

The target injection and tracking system design layout is shown in Fig. 1. The system is nearly 30 m long.

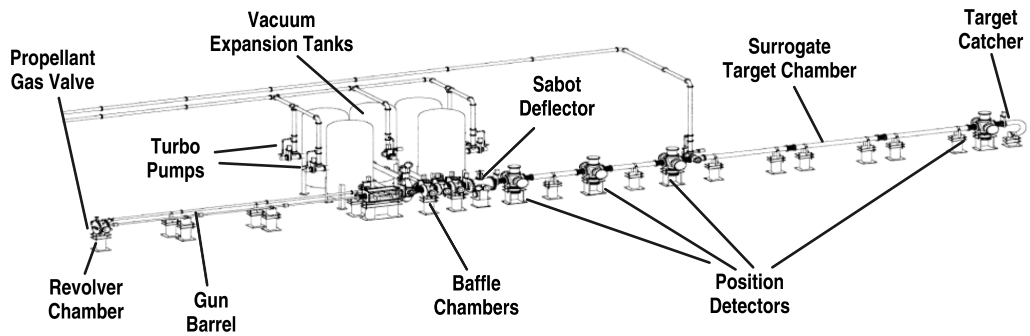

Fig. 1. Target injection and tracking system overview.

A high-speed high-flow gas valve designed and built by Oak Ridge National Laboratory will provide helium propellant gas to the targets. It is required to open (or shut) in less than 2 ms and have a large flow rate with a small pressure drop (e.g. 5% pressure drop at 415 psia pressure and 4000 scfm flow rate.) A photograph of this valve is shown in Fig. 2.

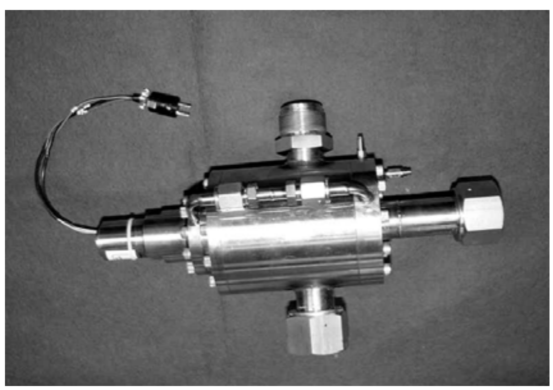

Fig. 2. High-speed propellant gas valve.

Targets are loaded into a twelve-slot revolver (Fig. 3) that is located in the revolver chamber and positioned with a servomotor. This loading mechanism is intended to allow up to twelve targets to be fired in two seconds.

To avoid target damage from excessive acceleration, an 8 m gun barrel is being built to achieve 400 m/s target speed, while not exceeding 10,000 m/s^2 acceleration. The barrel has a smooth bore with a short section leading from the revolver chamber, three main sections, and a slotted gas diverter at the muzzle end. Each main section has a pressure sensor, to sense the time that the target passes each sensor and indicate pressure drop in the barrel. Radial alignment of the sections is achieved with Morse tapers.

Fig. 3. Revolver target loading assembly is part of the revolver chamber

Direct drive targets are protected from heating and mechanical damage in the gun barrel by placing them in sabots (Fig. 4). A solenoid controlled latch keeps the spring compressed prior to the target acceleration. The inertia of the leading half of the sabot keeps the spring compressed during acceleration. Once the target leaves the end of the gun barrel, the spring forces the two halves of the sabot apart and away from the target. The sabot then is diverted from its trajectory by the sabot deflector (Fig. 5) which has an angled rod that extends slightly in to the sabots path, but not into the smaller-diameter targets path.

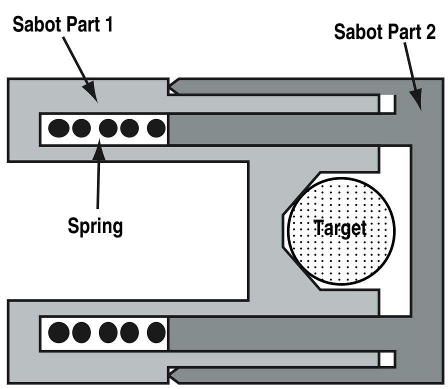

Fig. 4. A spring-loaded sabot contains the target during the acceleration process

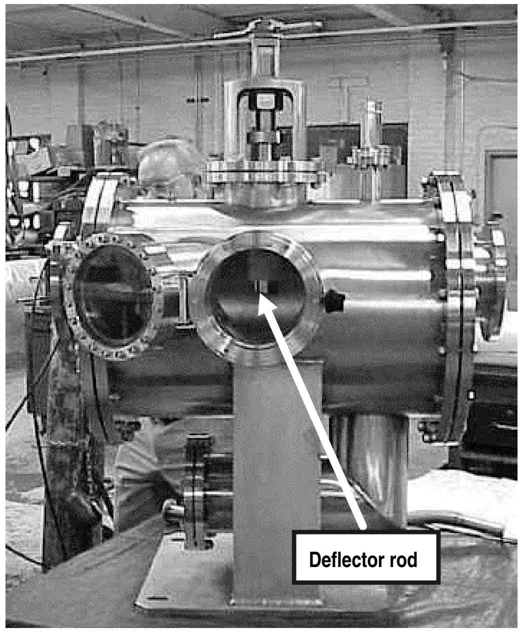

Fig. 5. The sabot deflector redirects the sabot parts and allows the target to proceed undisturbed

The propellant gas will be diverted away from the target-tracking region by a series of baffle chambers and gas expansion tanks. There are 2 cm diameter openings between baffle chambers to allow the targets and sabots to pass through. There is 6 in. (15 cm) diameter piping to direct the gas from each baffle chamber into the five 3 m^3 vacuum expansion chambers. These tanks are sized to minimize pressure increase in the target-tracking region during a twelve shot burst. They would be replaced by large capacity vacuum pumps in a power plant for continuous operation.

Position detectors use photodiodes and line scan cameras to accurately measure the timing and position of passing targets. Data from early position measurements are used to accurately predict the time and position that the targets will pass a final position detector. The final position detector is located at a position corresponding to the center of a power plant reaction chamber and will verify the accuracy of the target position predictions. Separate cameras measure the target's horizontal and vertical position. The target tracking system design is discussed more fully in Ref. 3.

III CONSTRUCTION PROGRESS

We are currently building the portion of the system that is required for single shot operation and single axis tracking. The baffle chambers and vacuum expansion tanks are replaced by 6 in. (15 cm) tubing. As of October 2002, major equipment fabrication is nearly complete and equipment installation has begun in our newly refurbished building 22. We have the equipment stands, propellant gas valve, sabot deflectors, position detection chambers, and target catcher. The revolver chamber and gun barrel are still in fabrication.

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IV. PRELIMINARY EXPERIMENTS

Sabot separation and deflection experiments were carried out. On four consecutive shots, separation of the sabot halves from the target was achieved. The sabots were deflected smoothly about 15° (a few degrees greater than the sabot deflector plate angle), without significant slowing. The target tumble prior to reaching the deflector plate was quite small (less than a few degrees and therefore not noticeable in the photographs) and did not affect the function of the deflector plate. Two of these four shots used solid plastic targets and two used hollow 4 mg GDP targets. Figure 6(a-c) shows a photographic record of the sabot deflector operation taken at 4,000 frames per second with a high-speed video camera. The target is barely visible between the sabot parts and is not deflected. There were a few tests in which the sabot halves were not well separated prior to reaching the deflector plate. This was probably due to excessive friction between the two halves. However, we believe that the successful shots that we did have indicate a high probability of success.

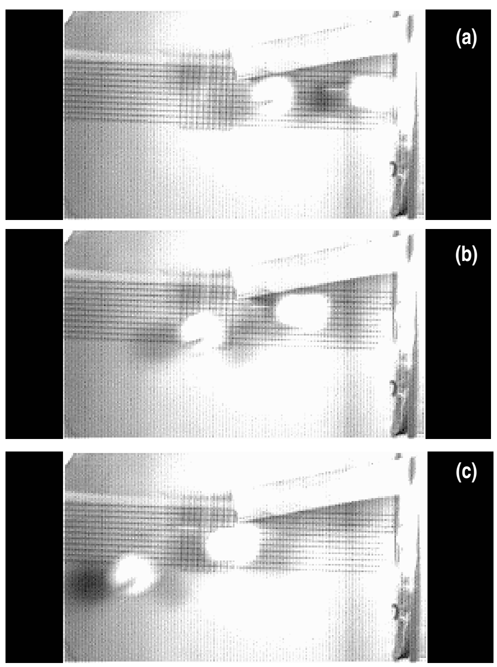

Fig. 6. Photographs showing sabot deflector operation.

We mounted the target tracking illumination laser, line-scan camera, and optics in a target position detector assembly and conducted testing of the laser-based tracking system with positioning of a stationary target using translators. The illumination was guided through the windows of the vacuum chamber. A three-axis translation stage was mounted onto the equipment to allow the target to be precisely located. When the target was moved away and returned to the same location, the position measurement results were reproducible to ±2.5 mm. The position measurement results are not quite linear. Over a range of 8 mm in target position, the position error from a least squares fit straight line was ±31 mm. Over a range of 1 mm the position error from an end point fit straight line is ±10 mm. We believe that a source of the non-linearity is non-uniformity and interference in our laser illumination. Alternate illumination sources (such as LED's) will be tried to improve position measurement accuracy.

V. SUMMARY

We are building an experimental target injection and tracking system to verify the survivability of targets during acceleration, the accuracy and repeatability achievable and the ability to track targets with the required accuracy. Most of the equipment for single shot operation has been fabricated and is now being installed in a newly refurbished building at General Atomics. Preliminary sabot separation and target tracking testing had promising results.

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ACKNOWLEDGMENTS

Work supported by Naval Research Laboratory under Contract No. N00173-02-C-6007.