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EXPERIMENTAL TARGET INJECTION AND TRACKING SYSTEM CONSTRUCTION AND SINGLE SHOT TESTING

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Targets must be injected into an IFE power plant at a rate of approximately 5 to 10 Hz. Targets must be tracked very accurately to allow driver beams to be aligned with defined points on the targets with accuracy ±150 µm for indirect drive and ±20 µm for direct drive. An experimental target injection and tracking system has been constructed at General Atomics. The injector system will be used as a tool for testing the survivability of various target designs and provide feedback to the target designers.

Helium gas propels the targets down an 8 m gun barrel up to 400 m/s. 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. Targets will be optically tracked with laser beams and line-scan cameras. Target position and arrival time will be predicted in real time based on early target position measurements. The system installation will be described. System testing to overcome excessive projectile wear and debris in the gun barrel is 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 Hz.

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 ±150 µm for indirect drive and ±20 µm for direct drive.

An experimental target injection and tracking system has been designed and portions of the system required for single shot operation have been constructed at General Atomics (GA). 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 INSTALLATION

We renovated a building at GA for IFE target fabrication and injection research and development. Figure 1 shows the building after renovation. The target injection and tracking system design as required for twelve shot operation is concisely described in Ref. 3. The portion of the system required for single shot operation as photographed in Fig. 1 is nearly 30 m long.

The system uses compressed He gas at approximately 0.7 MPa (100 psia) to accelerate ~6 g plastic projectiles down an 8 m gun barrel to speeds up to 400 m/s. The barrel (Fig. 2) has a smooth 15 mm diameter bore with a short section leading from the revolver chamber (Fig. 3), three main sections, and a slotted gas diverter at the muzzle end. Each main section has a pressure sensor, to sense the

Fig. 1. The IFE target fabrication and injection facility before and after renovation.

Fig. 2. Multi-section gun barrel installation.

Fig. 3. Targets are loaded into the revolver chamber.

time that the target passes each sensor and indicate pressure drop in the barrel.

Direct drive targets are protected from heating and mechanical damage in the gun barrel by placing them in sabots (Fig. 4). A pin in the chamber 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 which has an angled rod that extends slightly in to the sabots path, but not into the smaller-diameter targets path. High-intensity light sources and a high-speed camera have been installed (Fig. 5) to photograph sabot deflection (Fig. 6).

Position detectors (Fig. 7) use laser light sources with photodiodes and line scan cameras to accurately measure the timing and position of passing targets. Data from

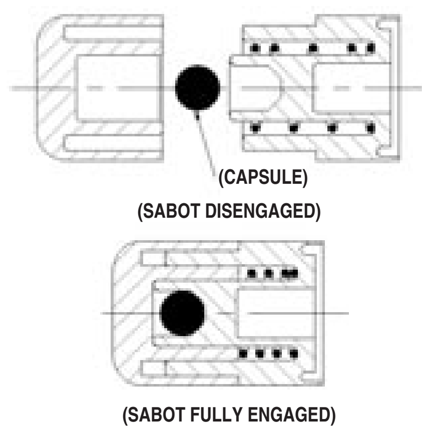

Fig. 4. Spring-loaded sabot protects the target from the barrel and warm gas during acceleration.

Fig. 5. Sabot deflector with light sources and camera.

Fig. 6. Sabot hitting deflector bar.

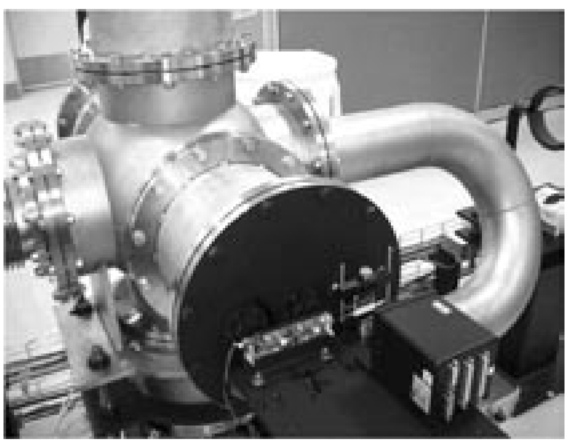

Fig. 7. Target tracking detectors use photodiodes for timing and a line scan camera for position measurement.

position measurements early in the target's trajectory are used to accurately predict the time and position that the targets will pass a final position detector. The target tracking system design is discussed more fully in Ref. 4.

III. OPERATIONAL TESTING

Delrin sabots were manufactured to begin our testing program. Initial projectile velocities were inconsistent, and in some cases the projectiles were moving quite slowly at the exit from the barrel. There was also material from the projectiles left behind in the barrel after a few shots. It appears that the sabot material on the surface melts and leaves fibers behind. MoS_2 powder was added to the barrel and coated on the sabots to provide lubrication but still left material fibers in the barrel. We have now tested thirteen materials (Delrin, Vespel SP1, Vespel SP3, Rulon, Peek, Garolite, Celazole, Kynar, FEP, Torlon, Polycarbonate, PTFE, and UHMW). Of these materials, only Vespel (polyimide), Rulon, and Garolite did not leave significant material behind (PTFE and UHMW could not be adequately machined). Garolite is the least expensive of these materials, so is currently the leading candidate sabot material.

We calculate that the residual gas remaining near the breach of an 8 m gun barrel operating at 6 Hz with a helium propellant pressure of 0.54 MPa (80 psia) would be about 13.5 kPa (2 psia). This residual gas pressure may provide some lubrication for the projectiles. So we have performed tests with back pressure and some into a vacuum of approximately 6.6 Pa (50 mTorr).

We have four pressure transducers (PT) that are relevant to estimating target speed and acceleration in the gun barrel (PT 1002, 3001, 3002, and 3003). They are located at the following positions relative to the fast acting valve sensor.

PT 1002 = 0.00 m (downstream side of propellant valve)

Initial target position = 0.54 m

PT 3001 = 2.60 m (first barrel section)

PT 3002 = 5.05 m (second barrel section)

PT 3003 = 7.52 m (third barrel section)

PT 3001 to 3003 have nearly instantaneous pressure rise pulses to indicate when the sabot passes them. PT 1002 could be used to indicate when the target leaves its starting point, but it is less instantaneous. We use the sharp voltage of the shock sensor on the propellant valve that indicates the valve is open (plus 0.5 ms for gas to travel to the projectile) as the assumed starting time for projectile motion. The data from a typical shot with a Garolite projectile is plotted in Fig. 8. The valve open time and the time that the projectiles passed the pressure sensors is plotted vs sensor position for several consecutive Garolite shots in Fig. 9 (Shot G8 appeared to shoot well but did not trigger the data collection software). Similar charts for many of the other materials tested were much less consistent (thus, the selection of Garolite as the sabot material).

We calculate target average velocity between measurement points. We assume that the average velocities were achieved at the midpoint in time between the measurements. The average accelerations can then be calculated as the change in average velocities divided by

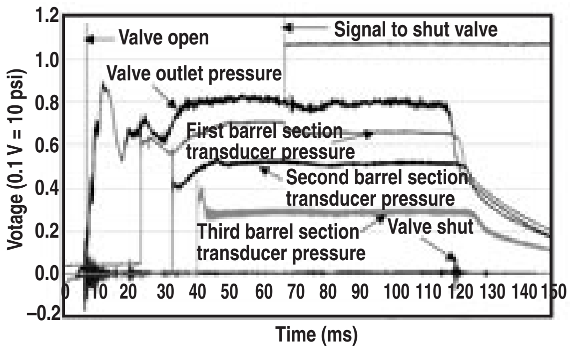

Fig. 8. Sensor output vs time for a Garolite shot.

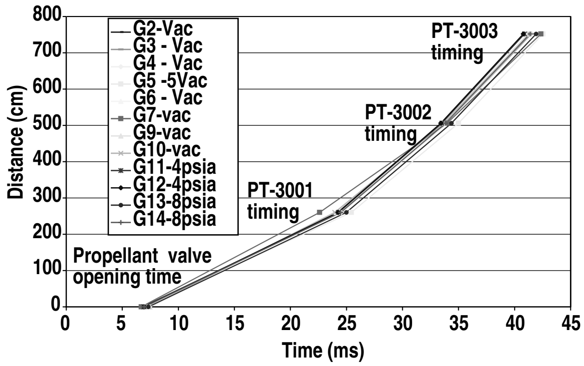

Fig. 9. Projectile position vs time for several Garolite shots (initial target position is 0.54 m).

the time differences between those midpoint times. The average acceleration from the time that the shock sensor voltage increases (plus 0.5 ms) until the target passes PT 3001 can be calculated from the average velocity to PT 3001 divided by half the time between those sensor readings. These calculations were done for the first fourteen Garolite shots and are shown in Table I Shots G1 through G10 with shot into a vacuum (no data is available for shot G8). Shots G11 and G12 were shot with 27 kPa (4 psia) He back pressure and shots G13 and G14 were shot with 54 kPa (8 psia) of He back pressure. The velocities are consistent to a standard deviation of 3% to 4%. The acceleration does drop to about one half of its initial value as the projectile travels down the barrel.

IV. SUMMARY AND CONCLUSIONS

The experimental target injection and tracking system has been built and testing has begun. Substantial debris from Delrin sabots was left behind in the barrel. The fibrous nature of the debris indicates that the Delrin on the surface of the sabots was melting in the barrel. Thirteen materials have been tested by shooting solid cylinders down the barrel. Garolite, Vespel, and Rulon do not leave detectable amounts of material in the barrel. Garolite is much cheaper than the other materials and is therefore the leading sabot material at this time.

Table I.
Calculated velocities and accelerations for Garolite shots

Run	V01 (m/s)	V12 (m/s)	V23 (m/s)	a1 (m/s^2)	a2 (m/s^2)	a3 (m/s^2)
G1	120	263	328	14139	10790	7740
G2	120	263	328	14057	10746	7798
G3	122	261	326	14357	10571	7633
G4	123	261	330	14737	10563	8111
G5	115	257	327	12772	10373	8101
G6	126	263	332	15337	10634	8257
G7	134	216	294	17418	6149	7906
G9	128	258	326	15954	10110	7964
G10	128	253	321	16014	9638	7920
G11	122	267	334	14528	11072	8083
G12	123	268	335	14667	11168	8142
G13	120	262	326	14040	10672	7548
G14	121	262	327	14256	10705	7602
Average	124	257	325	14845	10200	7922
Standard Deviation	4.73	13.03	10.09	1145.75	1281.12	222.98

The velocities are consistent to a standard deviation of 3% to 4%; we expect ultimately a capability of ± 1% with the gas gun, adequate to achieve the required timing of ± 1 ms at chamber center.

Our next step is to continue testing with Garolite to achieve sufficiently small target tumble and accuracy with solid cylinders. We will then proceed to target tracking testing with solid cylinders. We will verify proper cylinder deflection and collection in the sabot deflector. We will then conduct sabot separation and deflection testing. Proper sabot separation and deflection will allow target tracking testing with spherical targets.

ACKNOWLEDGMENT

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