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REP-RATED TARGET INJECTION FOR INERTIAL FUSION ENERGY

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Inertial Fusion Energy (IFE) with laser drivers is a pulsed power generation system that relies on repetitive, high-speed injection of targets into a fusion reactor. To produce an economically viable IFE power plant the targets must be injected into the reactor at a rate between 5 and 10 Hz.

To survive the injection process, direct drive (laser fusion) targets (spherical capsules) are placed into protective sabots.[1] The sabots separate from the target and are stripped off before entering the reactor chamber. Indirect drive (heavy ion fusion) utilizes a hohlraum surrounding the spherical capsule and enters the chamber as one piece.[2]

In our target injection demonstration system, the sabots or hohlraums are injected into a vacuum system with a light gas gun using helium as a propellant. To achieve pulsed operation a rep-rated injection system has been developed. For a viable power plant we must be able to fire continuously at 6 Hz. This demonstration system is currently set up to allow bursts of up to 12 targets at 6 Hz. Using the current system, tests have been successfully run with direct drive targets to show sabot separation under vacuum and at barrel exit velocities of ~400 m/s.

The existing revolver system along with operational data will be presented.

I. INTRODUCTION AND REQUIREMENTS

A commercial IFE plant will need to be able to fire about 500,000 shots per day.[3] The targets must be injected with an exit velocity of around 400 m/s to ensure survival of the cryogenic targets in the target chamber.[4] The power plant will have an internal temperature of 500–1500°C.[4] To accomplish this goal we have designed a rep-rated revolver system to feed the targets to a light gas gun that will fire targets at 6 Hz.[5] In addition the experimental system must demonstrate operation at reduced pressure to be compatible with power plant chambers. Helium is used as a propellant for the light gas gun. It is controlled using a pilot operated fast acting valve (FAV)[6] to ensure precise timing for injection. The system also requires a latch mechanism to keep the sabot from being injected prematurely before the propellant gas has fully ramped up. To achieve rep-rated operation the system must be able to index at 6 Hz and have an absolute radial placement of less than ±0.0005". The next step in demonstrating the rep-rated injection system will be to perform a full 12 shot burst at 6 Hz.

The injection system described herein is adaptable to cryogenic conditions that will eventually be required for IFE target injection. For example, the capsule could be "layered" in a cryogenic fluidized bed, then "quickly" transferred into the sabot for injection. The sabot itself is designed to minimize incursion of room temperature propellant gas into the area containing the cryogenic target. The sabot also provides a thermal buffer to protect the cryogenic target during the few seconds it spends inside the revolver and while being accelerated in the (room temperature) gun barrel. This whole approach for cryogenic targets depends on getting the target from the cryogenic layering process to the target chamber center in a very short time period.

II. REVOLVER DESIGN AND COMPONENTS

The rep-rated revolver system uses a series of aluminum sabot holders or "cups" to contain the two-piece protective sabot encapsulating our simulated IFE target. Each cup has a Teflon sealing ring located between the cup and the front disc that is used to slide across the surface of the revolver housing while maintaining a seal as shown in Fig. 1. The twelve holders are located four inches radially from a main axis of rotation in the revolver assembly. A 1/4" thick disc is then used to fix the sabot holders at this distance from the main shaft at which it rotates. The disc is made from aluminum to reduce weight and the overall inertia of the system. During assembly the cups were individually lined up to the firing port of the revolver assembly to ensure an accurate sabot to barrel alignment during injection. The cups were then locked down into place.

Fig. 1. Showing backside of revolver disc with sabot cups pressed against front plate.

The main shaft is located fore and aft in the revolver assembly housing using precision bearings for both radial and thrust loading at the front and rear of the housing. These bearings are installed to support the main shaft and keep the shaft run-out to a minimum. The bearings are dry film lubricated with molybdenum disulfide to reduce out-gassing in the vacuum environment.

A flex coupler joins the main shaft of the revolver to the index drive. The flex coupler is designed to allow some on-axis angular misalignment of the main shaft to the index drive while maintaining extremely accurate radial translation for the sabot holders. In addition the coupler is used to preload the shaft so that the revolver cups stay firmly seated against the face of the revolver housing. It is important that we maintain this seal so that the propellant gas does not leak into the housing chamber during injection.

To get the shaft to the bellows coupler we must pass the shaft from inside the vacuum chamber back outside to ambient pressure. We use a Ferro fluidic seal to accomplish this, which uses a magnetic field to attract magnetically charged particles suspended in a liquid carrier. The particles are attracted to the field but are able to slide over each and still maintain a vacuum when subjected to movement such as in our case when the main shaft is rotated.

Direct drive targets require a two-piece separable sabot (Fig. 2) to keep the target insulated from the heat and gas load generated by the injection process. The current sabot incorporates a coil spring to separate the two pieces of the sabot from the IFE target where they are later removed and in a full-scale plant, recycled. To keep the assembled sabot and target engaged in the revolver system the sabot holders are pressed against the front housing of the revolver. When the sabot is rotated into firing position the revolver is designed with a latch pin to keep the sabot engaged while in front of the firing port before it is injected. The latch pin is a lightweight aluminum pin coupled to a low profile solenoid and a return spring. The return spring keeps the pin down in front of the projectile. It is preloaded to keep the sabot in place even when the fast acting valve is opened at 100 psig forcing the sabot forward down the barrel. With the gas valve fully open at 100 psig and our current sabot diameter we have a 27 lb force driving the sabot forward. The latch is at a 45° angle, which then requires a 19 lb preload to keep the latch pin seated while the gas pressure is ramping up before the shot. In addition to the preload the total load increases to a maximum of 37 lb of force to completely compress the spring and retract the pin out of the way for firing. The solenoid we use is a low profile solenoid that generates 80 lb of force for the required stroke and has a retraction response time of 20 ms with no additional mass. With the added inertia of the latch pin assembly we are seeing a response time of 30 ms. Figure 3 shows a single shot movement of the latch pin with an attached linear variable displacement transducer (LVDT) The figure shows that the latch is completely out of the way in 30 ms. The pin will bounce slightly when fully retracted but it is actually retracted farther than required from the bore allowing for this without coming back and contacting the sabot.

The rotation of the revolver system is controlled by a Camco index drive specifically designed to meet the time and accuracy needs of our system. The drive uses a heavy-duty mechanically operated cam and roller system designed for high accuracy indexing, with zero backlash, for extended periods of time. Operating at 6 Hz gives us a time between shots of 167 ms to rotate to the next

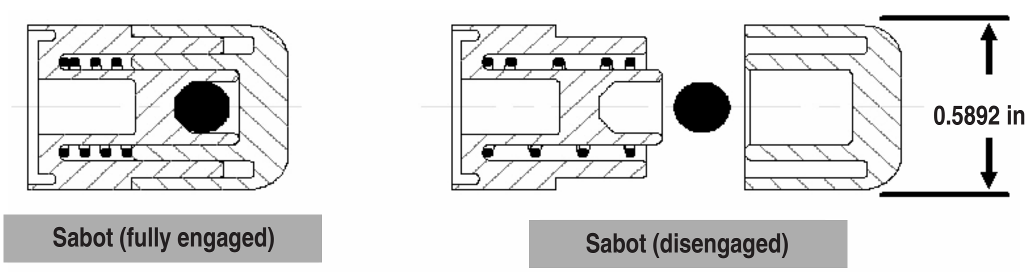

Fig. 2. The two-piece sabot including sabot spring.

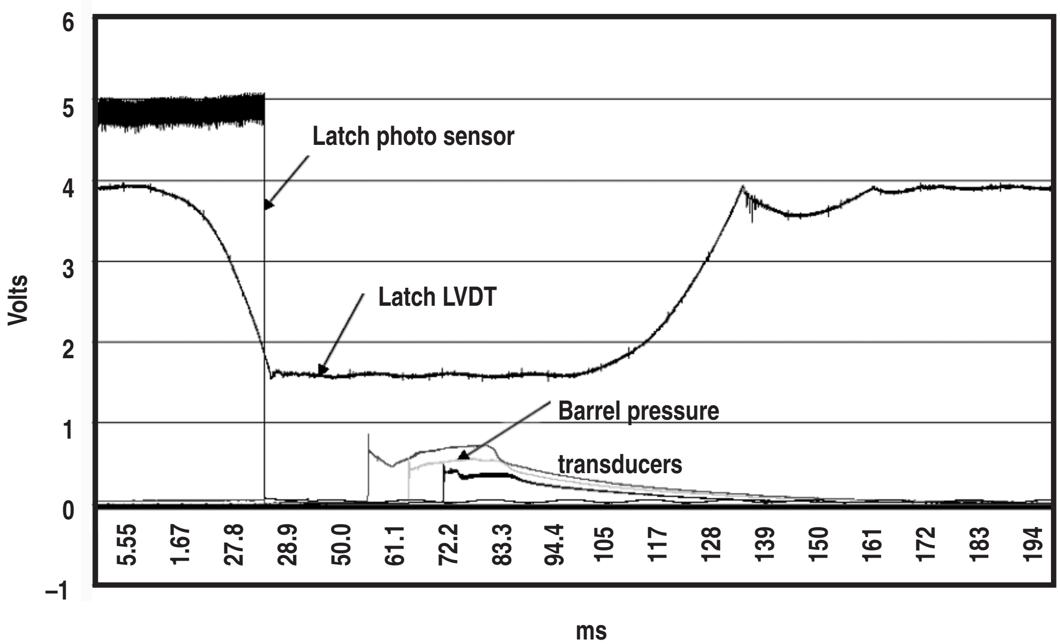

Fig. 3. A single shot timing graph showing latch movement

position. From previous testing we need 111 ms of total time to operate the fast acting valve, pull up the latch and have the sabot exit the barrel. With this in mind we have 56 ms left to rotate into position. The cam lobe on the index drive was then designed to give us this dwell and movement. The drive is a mechanical, cam driven piece with a fixed motion and dwell period for each cycle. The index drive system is extremely precise and is able to give accurate indexing of each position to ±0.00024".
Integrated into the drive system is a friction driven clutch that is adjusted to slip should the revolver system misfire or jam. If the clutch does slip a photo sensor turns off the main power to the controller and prevents any damage to the revolver assembly. This allows us to document any problems and prevent further damage.

The fast acting valve's (FAV) key operating requirement is that it must open and close in short time durations (~10–40 ms) at the required 6 Hz.[6] This requires an accurate timing system to signal both the FAV and the latch mechanism. Timing for both the latch and the FAV is mechanically driven using cams attached to the drive shafts of the index drive. The cams trigger multiple photo sensors arranged on the drive shafts to control open and close times for the latch and FAV. To verify open and close times in relation to the signals we use LabVIEW to record the photo sensor output signals. The FAV has a shock sensor mounted to its housing so that we can record when the armature of the valve is fully open. The latch mechanism has an LVDT attached directly to it to give motion of the pin with respect to time. In addition we have multiple fast response pressure transducers on both the outlet to the valve and on the outlet of the revolver to measure injection pressure all the way down the barrel.

III. INITIAL TESTING

Dry fire testing of the revolver was performed to set up the timing cams and set the sabot cups into the correct positions. We determined the accuracy of the system to create the signal for both the fast acting valve and latch mechanism. Our initial testing showed that the initial position was slow due to the rotational inertia of the index drive's DC motor. With LabVIEW we were able to see an almost 27% increase in indexing time when compared to all shots after. We have since modified the system to fire on the second rotated position so that we are able to maintain a ±0.2 ms accuracy for timing and pulse length for both the latch and FAV (Fig. 4).

Single shot testing was performed to ensure proper alignment of sabot cups to the barrel to each position. We then moved to rotating single shot testing with the index drive. We have performed multiple three rep-rated shot sequences using two-piece direct drive sabots injected at 6 Hz at a 400 m/s exit velocity.

IV. FUTURE PROGRAM EXTENSIONS

After completion of the planned program operation at a full 12 shots at 6 Hz we will evaluate a continuous rep-rated revolver system to be added to the current burst mode system. To accomplish this task we will need a live feed mechanism to keep the sabot engaged while it is inserted into the loading port located at the front of the revolver.

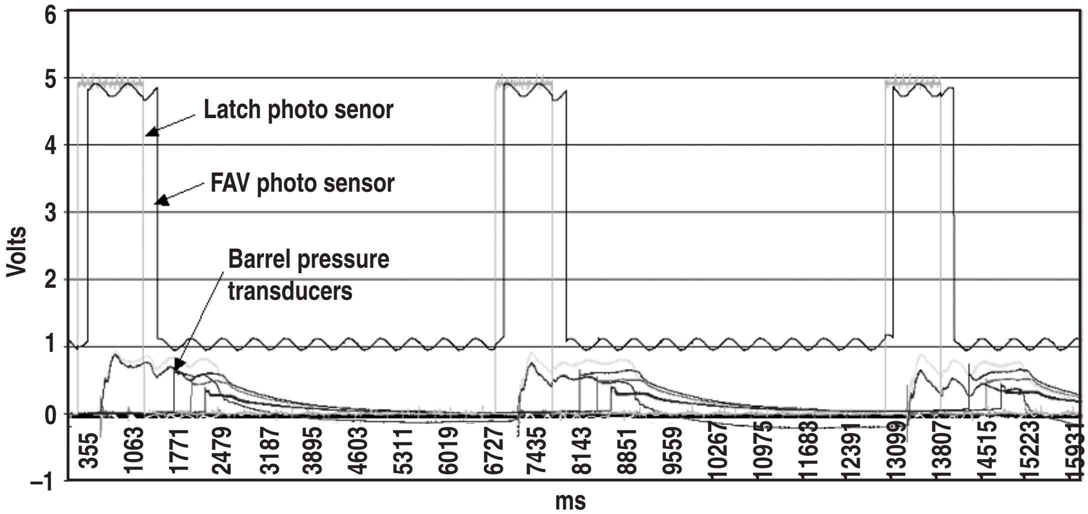

Fig. 4. LabVIEW recorded 3-shot rep-rated sequence.

V. CONCLUSIONS

We have demonstrated a viable solution to rep-rated operation for target injection for IFE direct (two piece separable) and indirect (one piece) drive targets. Although the current system is designed for a burst of up to 12 shots at 6 Hz the system would also lend itself to a continuous operation for a full-scale mock up. Mechanical timing has shown very good results with respect to timing jitter with the capability of placing targets within ±1 ms at the simulated target chamber center. We have been actively using this system to perform in-flight target placement and target tracking studies.

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