Advances in Tape Target Technologies towards 1Hz Operation for EPAC and other High Repetition Rate Facilities

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Introduction

The development of lasers towards higher repetition rates and higher power has seeded an explosion in the number of user facilities and experimental shots that are available to the laser user community. These experiments are carried out across a broad range of plasma physics and material science areas from ion acceleration through to the structure of materials. In addition, the integration of free-electron lasers (FELs) with high power lasers opens areas of research that were not previous accessible. In one such example the European XFEL in Hamburg has integrated the D-100X laser built by the Central Laser Facility into the High-Energy Density (HED) instrument, and this will be able to carry out experiments at 1Hz and above with first experiments scheduled for 2023.

To meet the demand for such numbers of shots a stream of targets is required, at rates far above any that have previously been supplied for intense laser interactions. There are several promising routes to this target supply with solids, liquids gases and other solids being experimentally studied [1,2,3]. It is noted that with increasing energy, the problem of target supply is tied to the damage area of the laser shot, the generation of electromagnetic pulses (EMP) and the ability to hold and replenish at a suitable rate, as well as production rates for the samples and the cost associated with the increase in materials.

In response to this demand, we have continued the developments previous reported of a tape target delivery system [4,5] that has applications across a broad range of experimental platforms from the use as an interaction target to the use as a plasma mirror or a beam block. We discuss the development of a range of these systems in the CLF based on a standard architecture and results of a range of test experiments across different facilities.

Ultra-High Stability Tape Drive

Developments in tape target drives have been ongoing for many years, however, the stability requirements of a laser with a short focal length final optic and with targets that are of a mm in size are becoming more stringent. The Gemini laser facility, for example requires that a target is placed in a Z position of +/- 4 microns when using a F2 parabola and target sizes are often a few hundreds of microns in x and y. This requires a system that does not drift while runs many hundreds of shots.

In response to this requirement a system was designed [5] to support tapes of up to 50 metres in length, and using a chromatic confocal sensor the stability was measured to be just within this range at 8.3µm. Over the past year the Target Fabrication Group has continued to evolve the tape drive to ensure we have the most stable, robust drive available to the users.

To increase stability, we have utilised precision CNC machining capability to manufacture aperture plates for the drive that are flat to within a few microns flatness and that have a surface roughness of less than 50nm Ra. This allows the substrate to pass over the interaction point with a Z stability of approximately +/- 2µm or better. It was noted that the aperture plate collected debris as the tape was running and over a period this degraded the performance. A cleaned aperture plate was able to run at approx. +/-1µm for a period before it needed cleaning again. We also tested a 'barrel aperture' concept where a radius on the aperture plate was used to ensure the tape was held securely against the aperture. It was found that this could improve stability further to +/- 0.5µm. All the measurements are shown in Figure 1 and were taken using a chromatic confocal sensor with a resolution of <100nm.

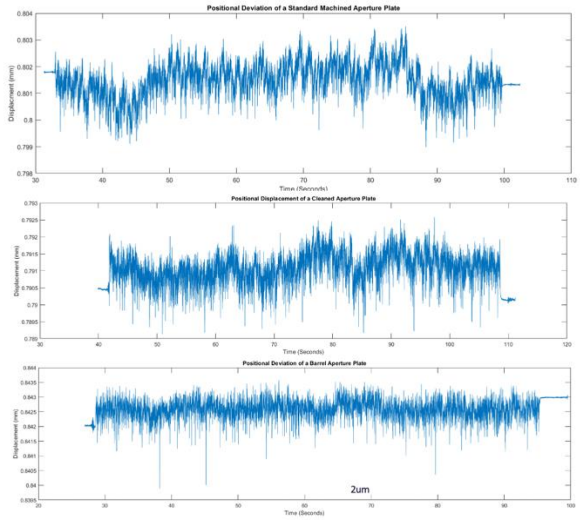

Figure 1. Tape Deviation on a range of aperture plates

This stability is roughly maintained when using a variety of tape materials, from polyimide through to copper, aluminium and stainless steel; however it is affected by the thickness of the material and a thicker harder material is more likely to not pull as flat across the aperture. Each material requires settings to be adjusted for the tensioning of the tape which can be done in the control system. This is also dependent on the substrate being spooled without any surface defects and crinkles and to achieve this the Target Fabrication group have designed and developed a pre-spooling system to avoid such problems.

The addition of rotary potentiometers has enabled the control system to adjust tension settings for each material, this is required to prevent both tearing of the tape and to maintain the stability.

Various debris mitigation measures have been developed including spool covers and shielding (as seen in Figure 2), as it was apparent that tape shrapnel was able to damage the motors and other mechanical parts. 3D printed covers are a cheap and effective means of mitigating this risk. EMP effects have been monitored in a number of experiments and control system failures are reduced with the appropriate positioning of the control box, having lead covers on the rotary encoders and with appropriate isolation and grounding of the drive components.

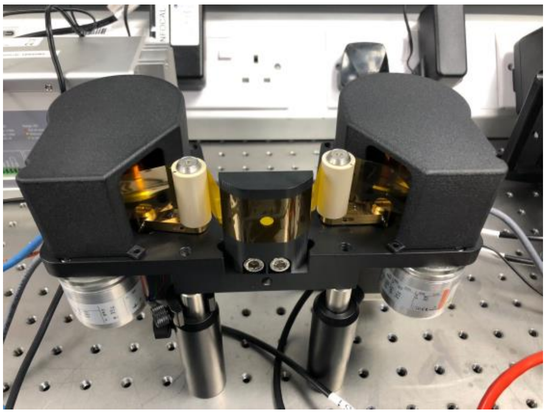

Figure 2. A shielded tape drive system

Experimental Fielding as a Target

The tape drive system has now been dispatched to multiple high power laser institutes across the world and we have performance data on the stability of the drive from initial experiments. One such experiment was carried out at the University of Strathclyde where the drive was used to field Kapton tape on the SCAPA laser system to characterize laser driven ion acceleration. The target was irradiated in a week-long experiment with over 1000 shots taken. The stability was monitored by the measurement of the signal of the reflected energy (Figure 3) which showed a linear relationship implying a good stability.

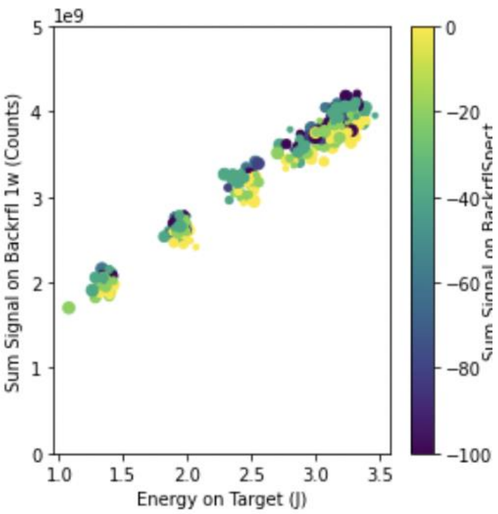

Figure 3. Total back reflected light from the target

Beam Removal Tape Drive

In some experiments such as using a laser wakefield accelerator for x-ray imaging it is required to remove laser beam from the propagation direction of the x-ray and electron beams [6] and the experimental configuration often requires a beam block to be in a limited area. A tape drive system was designed for this based on the architecture of the high precision system but in a more compact area. This system uses ½” Kapton tape and has a footprint of less than 100mm x 50mm.

The cost to manufacture and supply this system is a fraction of the ultra-high stability tape drive and the control system is simplified for simple constant moves and incremental moves. The front plate can be adjusted using micro-Thorlabs posts to give increased flexibility to the user allowing the plate to be moved out from the front of the base plate to get closer to an interaction area.

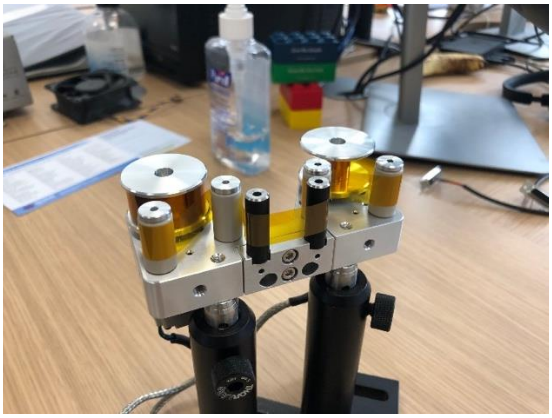

Figure 4. The small footprint 'beam-dump' drive

The stability of the system is lower than the high precision drive due to the reduced operation space and is in the order of +/-10µm. However as this is being used as a beam diverter and not a target the reduction in z positional stability is not a concern.

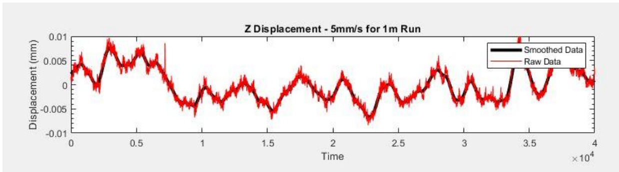

Figure 5. Stability data for the small footprint drive

Tape Drive Systems as a Plasma Mirror.

The development of the EPAC laser facility [7] as a 10Hz high power laser user facility requires not just target delivery but also requires the supply of plasma mirrors that can be replaced at high rates. Currently glass slabs are used [8] as the substrate and this limits the shot rate of the system before letting up the vacuum chamber. In a facility such as EPAC a system is needed that will be able to provide large numbers of plasma mirrors without breaking vacuum. The tape drive system has a stability that makes it a candidate for use as a plasma mirror, however the requirement for a plasma mirror is also that the flatness (and roughness) of the area from which the beam is reflected is to a very tight tolerance.

A study was carried out on a range of tape materials to determine which one would be the best for plasma mirror operation, this was based on previous work [9] and our results showed that the surface roughness of a range of plastic tapes varied. We tested VHS tape, PVDC, Mylar, Polypropylene and Kapton with VHS tape being the smoothest tape and mylar the worst, with examples shown below in Figures 6 and 7 and the collated data in Figure 8. VHS/PVDC tapes are idea for a plasma mirror system but are non-ideal for a target carrier or a target as they have impurities, Kapton is an excellent choice for a target carrying material as it machines well with both excimer and YAG laser systems.

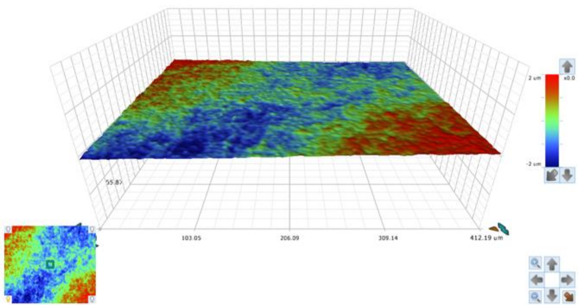

Figure 6. Surface roughness scan of VHS tape

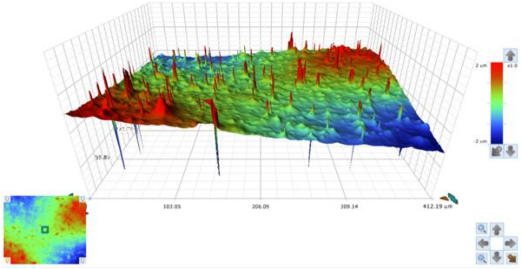

Figure 7. Surface roughness scan of Mylar tape

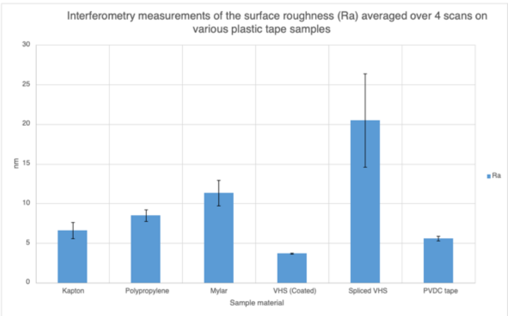

Figure 8. Collated roughness data for a range of tapes

Tests were carried out to look at the reflect beam from a moving tape and look at the stability of the beam during operation. In Gemini TA1 we used an experimental setup with a beam spot size of the order of approximately 2-3mm. In this set up a relatively stable reflected beam can be achieved and monitored. The set-up monitors the drift from a centroid point of a reflected beam from the drive at a known distance. The images and the positional deviations are shown below. With data for drift in x and y in µm and mrad. It is seen that the stability in x, which is the direction of travel of the tape, is better than in y. This is because the tape is being stretched across an aperture in the x direction and this leads to a waviness on the tape in the y direction due to the stress imparted.

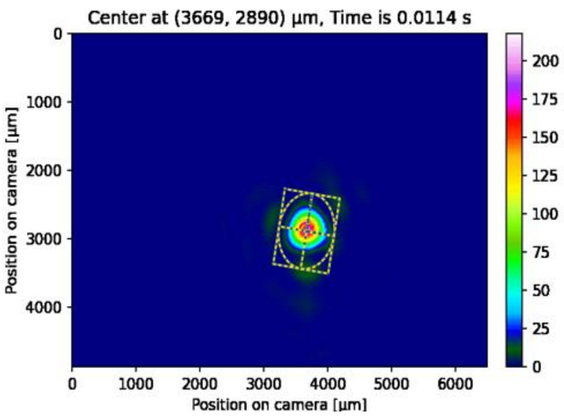

Figure 9. The captured beam profile

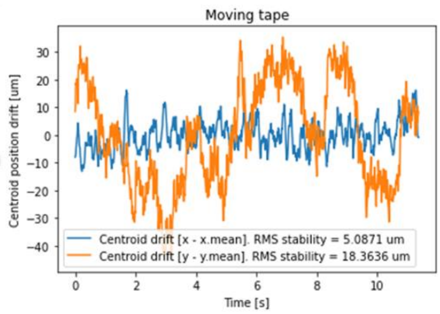

Figure 10. Beam stability in µm

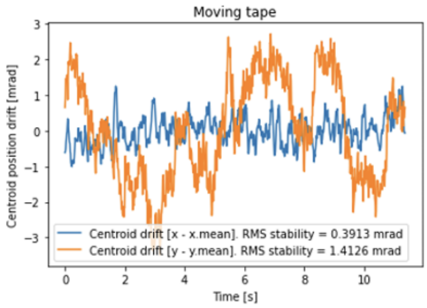

Figure 11. Beam stability in mrad

Future Work

We are continuing to collaborate with the groups in the Extreme Photonics Innovation Centre (EPIC), India, to develop a system to manufacture targets in large numbers for deployment onto the tape drive and to understand debris production and mitigation mechanisms. We also will be coupling a custom tape drive to the Scitech Precision Ltd excimer laser to machine multiple targets onto the tape while it is mounted onto a spool system to cut down on production times. These systems aim to be operational for the beginning of high rep-rate solid target experiments on EPAC.

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