Experimental Testing and Fielding of the CLF Precision Tape Drive in the Gemini Target Area

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Introduction

High Repetition Rate (HRR) lasers are currently at the forefront of laser plasma physics experiments, following recent advancements in driver technology that have enabled their ability to shoot at rates well over 1 Hz for petawatt-class systems. Targets traditionally comprise precisely fabricated solid metal or plastic microtargets such as films that are individually manoeuvred into position and aligned to a few microns. For low repetition rate laser experiments target demands are easily met by manual assembly of simple “foils on stalks” and typically the Target Fabrication Group delivers ~300 such targets over a six-week experimental campaign.

The Extreme Photonics Applications Centre (EPAC), due for commissioning in 2024, aims to operate at a repetition rate of up to 10 Hz and thus brings an obvious target supply challenge that requires a change in both target design and delivery method (Figure1).

EPAC Facility

EPAC will provide a step-change in capabilities for laser-driven accelerator research in the UK, enabling a plasma wakefield accelerator (LWFA) facility, with multi-GeV electron beams and spatially coherent x-ray and gamma-ray beams, for cutting-edge experiments in plasma physics, laboratory astrophysics and condensed matter and material science.[1] The facility will operate at 10 Hz in both the long focal length area (EA1) and a short focal length area (EA2). EA1 will mostly be LWFA and applications using gas targets, whilst EA2 will mostly shoot solid targets.

		Repetition Rate							
		10 Hz				100 Hz			
		Number of shots	Tape distance (m)	Tape reel OD (mm)	Total debris (g)	Number of shots	Tape distance (m)	Tape reel OD (mm)	Total debris (g)
Active shot time	10 mins	6000	60	93	0.04	60000	600	161	0.42
	1 hour	36000	360	135	0.25	360000	3600	348	2.51
	8 hours	288000	2880	314	2.0	2880000	28800	961	20.1
	24 hours	864000	8640	530	6.0	8640000	86400	1660	60

Figure 1: Target requirements as a function of repetition rate and total running time

In order to deliver a targetry solution for EA2 the Target Fabrication Group working with the Electrical and Control Group have developed an ultra-high stability tape-drive system to deliver user-defined HRR targetry comprising different materials, geometries and thicknesses on a polyimide tape substrate.

EPAC Targetry Requirements & Challenges

Due to the requirement of a number of high repetition rate solutions for different experimental applications, a high-precision and highly versatile tape drive system has been developed that will be deployed for the following purposes:

1. Solid targetry – A tape drive with positional stability of X < 10 µm, Y < 10 µm and Z < 4 µm (Figure 2). Systematic error build-up in drive position, EMP loads, and debris must all be considered.
2. Beam dumps – Requires long lengths of tape material with lower positional accuracy.
3. Beam diverters and plasma mirrors – Limited spatial footprint of system and a form of λ/4 with beam stability of few µrad or mrad, depending on shot rate.

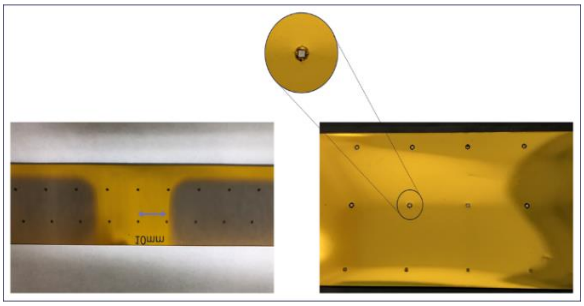

Figure 2: Coated and laser-machined polyimide tape [2][3]

Tape Drive Development

The tape drive has been through many iterations and design developments to produce a consistent stability in the focal axis of +/- 2 µm in a laboratory environment using polyimide tape. The stability has been monitored and recorded using a Micro-Epsilon IFS2403-1.5 chromatic confocal displacement sensor with a resolution of 200 nm (Figures 3 & 4).

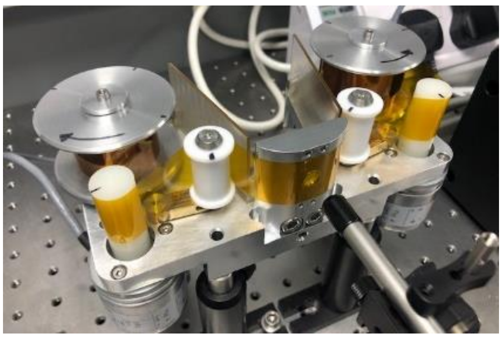

Figure 3: CLF Tape Drive Stability Testing using a chromatic confocal sensor

The tape drive is controlled with dedicated software through an HMI which allows the user to perform various operations, including jogging the tape to a user-specified position, constant driving at a velocity ranging from 0.1 mm/s up to 50 mm/s, or a series of repetitive moves. The system can be driven in both forward and reverse directions allowing for an increase in target supply on each spool of tape (Figure 5).

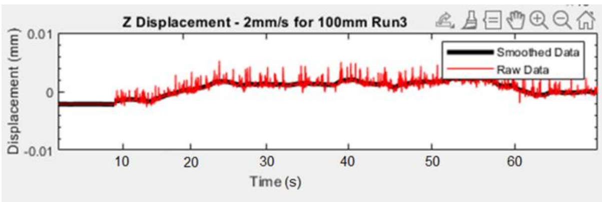

Figure 4: CLF Tape Drive Stability Recording in the laser (z) axis obtained using a chromatic confocal sensor

Figure 5: Tape Drive Control Software on the HMI

Thermal Studies Prior to Access to Gemini TA3

Because EPAC will require the drive to run throughout the day at high repetition rates in vacuum experimental access was granted in Gemini TA3 in 2021 to study the robustness of the drive within a harsh high power laser (HPL) environment. Prior to the beam-time, a thermal study of the drive over a period of six hours in a dedicated vacuum chamber was performed and showed no negative impact on the drive's performance at elevated temperatures (<85°C) due to the lack of convective cooling.

Experimental Access – GEMINI TA3

During deployment as part of an experimental access campaign in Gemini TA3 (Figure 6), the drive experienced issues with over-tensioning and un-spooling leading to critical errors and jamming of the system. The drive was used on full-power shots (12 J before compressor) and, because no camera was present on the system, it was difficult to diagnose the exact cause; however a combination of deployment procedures and EMP were thought likely.

Access was granted for a further two days after deploying a series of protection measures to improve the robustness of the system against EMP, debris, and shock. Design changes were implemented to electrically isolate the encoders from the optical bench as well as encasing them in Faraday cages. The differences between laser-only and electron-producing shots were investigated, and over 400 shots were taken with zero non-recoverable errors following the modifications to the system. It was concluded that almost all errors were linked to excessive coiled cabling in the area and the position of the electrical control box for the drive with respect to the target chamber centre (TCC). Unlooping the cabling and positioning it underneath the optical bench, as well as lowering the controller to ground level and shielding it with lead bricks, was found to be critical for future beamtimes.

Figure 6: Tape Drive in-situ behind gas cell in TAW3

Further Experimental Access

A third run was commissioned as part of a commercial experiment after addressing the above findings from the previous experiment.

The drive performed flawlessly over the campaign and a further several hundred shots were taken with the drive subjected to, and surviving, intense electron beams. EMP data was taken using B-Dot and D-Dot probes (Figure 7) and is currently under analysis at the CLF.

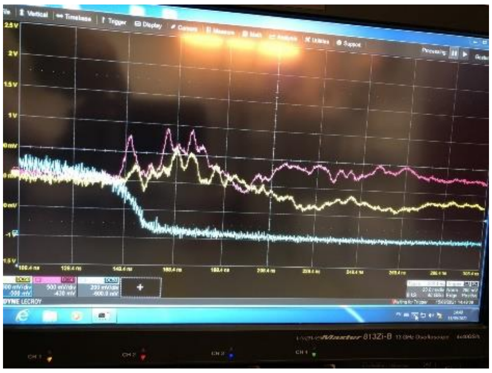

Figure 7: B-Dot, D-Dot Probe traces

Future Work

Further experimental access time on HPL facilities will be critical to identify potential concerns with debris, EMP and shot-to-shot stability. The CLF currently has a tape drive on loan to TIFR, India, as part of the collaboration with the Extreme Photonics Innovation Centre (EPIC), and one at the University of Strathclyde for deployment studies. A CLF tape drive will also be dispatched to ELI in mid-2022 as part of the Impulse funding.

As part of the EPIC collaborative project a production system is under development to mask, thin-film coat, etch and laser-machine long tape substrates all within a single target production chamber with the aim of making tens of thousands of targets in a single run.

The Target Fabrication Group is in the process of designing a tape drive system to couple to the Scitech Precision Ltd excimer laser enabling machining of bespoke targets onto a continuous tape drive spool as part of the development work.

Work is also continuing to produce a tape drive capable of ultra-high specification in form and flatness, to enable the drive to be used as a plasma mirror and beam diverter.

The overall project goal is to have a flexible tape targetry capability fully operational and available for user-access for the beginning of high rep-rate solid target experiments on EPAC in 2024.

Acknowledgements

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References

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2. *"Development of patterned tape-drive targets for high rep-rate HPL experiments", S. Astbury et al, CLF Annual Reports 2017-2018*
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