Investigation into the limitations of target positioning on Astra-Gemini

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Introduction

For experiments conducted on the Astra-Gemini laser system, the highest intensities are achievable using the *f*/2 parabola which focuses to a spot radius ($1/e^2$) of 1.6 μm [1]. The Rayleigh range of this focus is ~10 μm and so targets are required to be positioned at focus with of order micron accuracy. Furthermore, to maximize the output from the experiment it is desirable to move rapidly between targets in order to utilize the relatively high repetition rate of the laser.

We have found to date the most reliable method for consistent positioning of targets at focus is rear surface illumination with the focal spot camera [2]. This uses a 50x magnification long working distance objective to image the focal spot of the laser thus defining the desired plane. The target is then driven into place in the horizontal (x) and vertical (y) and brought to focus by moving the z axis until fine features are sharply imaged. This ensures that the rear surface is at the focal plane. If the targets are thicker than a few microns then a corresponding offset is then applied.

Although this technique has proved successful in recent solid target campaigns we have found that it is often time consuming (taking 15 – 20 minutes) with two primary causes for the difficulty aligning the targets. First: some of the motorized stages being used are unreliable or unsuitable for the task. Second: some materials lack obvious structure on the rear surface which is necessary to locate the target in focus, for example the thinnest carbon foils (<10nm) and targets with a high quality rear surface such as silicon.

In order to determine how we can reduce this alignment time we have set up an equivalent offline system to allow us to investigate the limitations of both the equipment and the methodology.

Equipment assessment

The standard *xyz* stage used in the CLF is the 602 model which uses 50mm travel servo motors and magnescale encoders. The motors operate in open loop with the position visible to the operator from the magnescale readout. While this stage is adequate for achieving the desired positioning accuracy, its motion is too slow for rapid motion between targets. This can be helped by changing the gear ratio of the motors to drive faster but at the expense of a lower positioning accuracy. We also suffer from magnescale failure which we intend to address by upgrading obsolete readout hardware.

The preferred option for motion control of arrays is to employ stepper motors. In this way the drive system can be operated in closed loop and motion from one target to the next is achieved by a single mouse click (or automated). To take advantage of the highest repetition rate of Astra-Gemini (shot every 20 seconds) it is essential to have at least the x and y motion controlled by stepper motors. Ideally the target selection ("windmill") rotation stage is also a stepper enabling a fast movement between target pucks but these stages tend to be too large to fit behind the target wheel. Because for most types of target, the x and y motion does not require micron accuracy, our existing standard stepper motors are ideally suited to this task. For the z motion to bring the target to focus, our current hardware may not be sufficient as discussed in the next section.

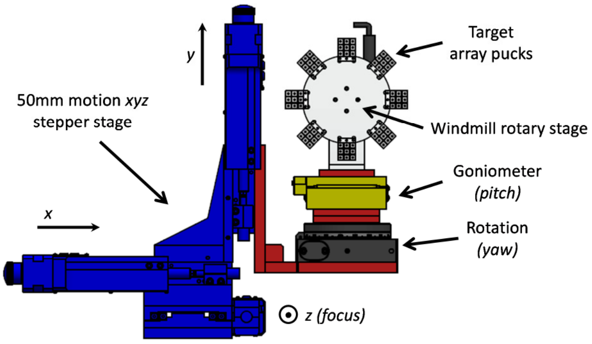

Figure 1. The arrangement of motorized stages required for target alignment. The target array is mounted on an xyz stage with a rotation stage and a goniometer for yaw and pitch. A vertical rotation stage enables selection of the puck.

Another reason for delay in the target motion is the necessity of moving the focal spot camera away from the rear of the target when the laser shots are taken. On some experiments other diagnostics also need to be moved into place before the shot. These motions are achieved using long stages with stepper motors which have an "in" and an "out" position. We have a reasonable stock of 120 mm and 300 mm stages which have been converted from manual to motorized control. While these stages are adequate for non-critical items we have found them to be unreliable with loss of position and motor failure a cause of many delays. For this reason we have invested in an extra four high quality 150mm range stages which are currently being brought into operation. With this type of stage it is possible to bring the focal spot camera into position rapidly (few seconds) and with sufficient accuracy.

Stepper motor trial

We conducted a trial to assess the performance of a stepper motor *xyz* stage for aligning targets. A copper target array substrate was attached to a standard CLF target wheel and mounted on a 50mm motion stepper stage. This is shown in Fig. 2 along with a view of the rear surface of the copper imaged with the microscope objective. Because there were no actual targets mounted we aimed for the crossbars in the substrate as the position of the focus.

We note that this trial tests only the simplest case of a thick "rough" target with easily visible surface structure at zero degrees angle of incidence. As part of this we confirmed that the rear surface illumination technique works for a target in a non-normal geometry by rotating the target (on a stepper mount) and compensating for the offset using the z position. However, we have not yet attempted a full mapping and simulated run with a non-normal array. We also know from user experiments that the process is more difficult with certain

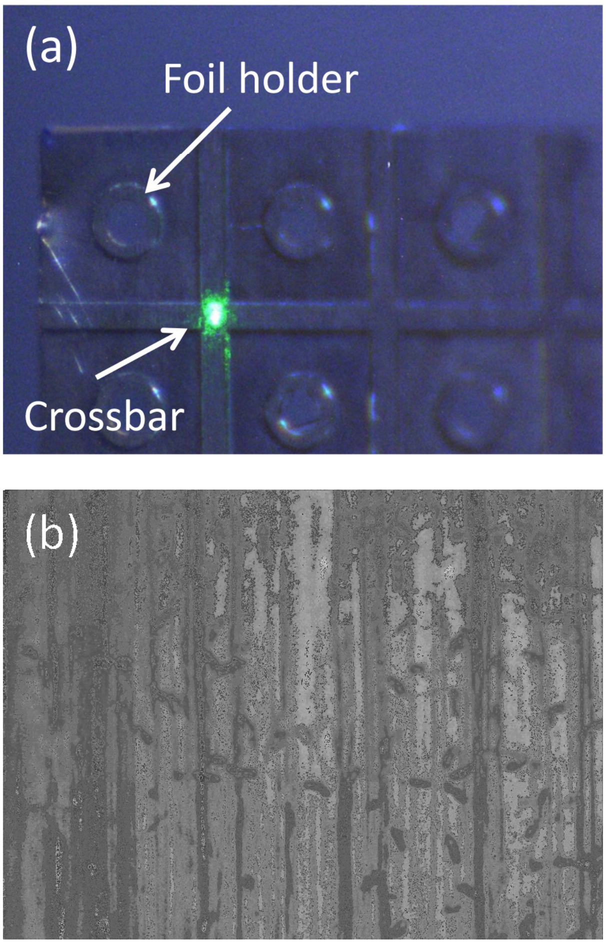

Figure 2. (a) Standard CLF array for holding foil targets. For the test we positioned the "focus" at the crossbar. (b) Fine features on the rear of the array imaged through the 50x magnification focal spot camera.

materials and our next goal is to repeat these tests offline with real targets to confirm the limitations on alignment speed from sources other than the mechanical hardware.

To increase the shot rate on the experimental run, the array can be mapped in advance by stepping the known *x* and *y* distances between the targets. The *z* position for each target can be determined using the rear surface illumination and documented. For 12 positions on the substrate this process took about 20 minutes. The speed of positioning was then tested in real time, including the motion of the focal spot camera in and out of position between simulated shots. To save time, the drive system software allows the user to gather the required motions onto a single page on the drive system as shown in Fig. 4 (these are duplicates – the original stage setups remain unchanged). In this way, all the required motions between shots are single-click operations apart from the *z* position of the target. Because of the pre-mapping the *z* position can be entered as an absolute value. The software also allows users to employ a trigger from the laser and automate selected motions after the shot.

We found in most cases that this positioning was accurate and that the target focusing looked identical to the image observed during the mapping procedure. For some positions on the array, the target looked out of focus, but we could achieve the correct plane within a few seconds with a small adjustment on the *z* axis. This may have been caused by user error, or by hysteresis on the motor. (We discovered that because of hysteresis it is necessary to always approach *z* positions in the same direction.) Following this procedure we were able to conduct this simulated run at greater than 1 shot per minute.

In order to map and shoot an entire wheel of targets it is a requirement that the rotation stage used for puck selection (the "windmill") as well as the target pitch and yaw are also high quality stepper drives. Currently we are in the process of sourcing suitable stages for this upgrade.

The accuracy of the *z* motion was assessed by imaging group 7 of a USAF resolution test chart and stepping through the focus in 1 micron steps. The quality of focus was quantified by measuring the contrast between dark and light line pairs in element 1 for each *z* position and is plotted in Fig. 3. Four consecutive scans are shown in which for the first and third scan the stage position increased from 17.800mm to 17.820mm (red points) and for the second and fourth the direction was reversed (black points). Scans in the same direction display a good consistency but hysteresis is visible causing ~2 μm offset between scans in opposite directions. We also found that our current stepper motor and controller are not optimized and are often unresponsive for such small motions. For this reason we intend to trial a piezoelectric actuator with a strain gauge reader for fine control (10nm resolution) of the target focusing.

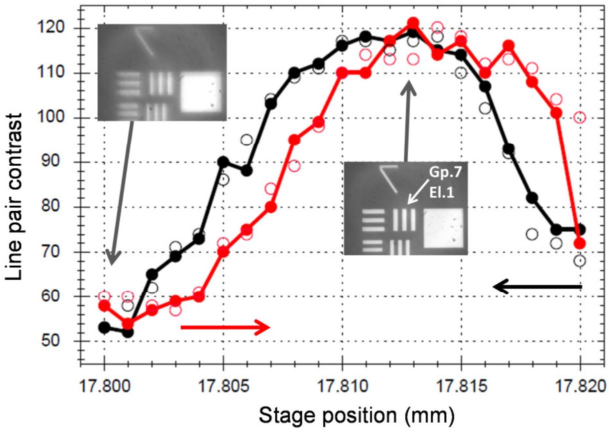

Figure 3. Contrast of group 7, element 1 line pairs on the resolution target as the *z* position motor is scanned through focus in 1 μm steps. Four consecutive scans increasing (red) and decreasing (black) the stage position.

Conclusions

Positioning of targets into the *f*/2 focus of Astra-Gemini is challenging because it requires micron accuracy and a reasonable repetition rate (shot per minute). We are in the process of testing the limits of our current methodology as well as developing new techniques [3] for future higher repetition rates (>Hz). As a first step in this process we have upgraded some of the motor equipment in the CLF, in particular the stepper motors used rotation and for long "in/out" motions. We tested the use of a stepper *xyz* stage for the target mount and concluded that while this allows for rapid rastering of the targets (in *x* and *y*), the current *z* stepper motion is difficult to use. Our next step will be to test the usability of a piezoelectric actuator to perform fine focusing.

By mapping the target wheel (a process that can take place independently of laser availability) a list of *z* positions can be obtained corresponding to *xy* positions on the array. This allows the next target to be positioned within seconds of a laser shot taking place, provided that diagnostics that need to be moved in and out between shots (e.g. focal spot camera) are on fast, reliable stages. The next stage in this investigation will be to diagnose the added complications of aligning "real" targets such as ultrathin foils (<100nm), highly polished surfaces and low density foams in order to address specific issues that arise on experimental campaigns.

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Current Step: 01
Start Date: 31/07/2014
End Date: 31/08/2014
Start Time: 05/08/2014 09:23:41
Project Status: Active
User Name: Dan Symes
Central Laser Facility Name: TA2
Step Name: SHOTS

Magnescales 1 Channels 1 to 8
Magnescales 2 Not Fitted
Magnescales 3 Not Fitted
Magnescales 4 Not Fitted
Status \ Running \

Focal spot camera IN/OUT: Current Position 0mm; Magnescales not fitted; Units mm; Selected Position 0mm; Absolute
Target Horizontal: Current Position 15mm; Magnescales not fitted; Units mm; Selected Position 15mm; Relative
Target Vertical: Current Position 8mm; Magnescales not fitted; Units mm; Selected Position 8mm; Absolute
Target Focusing: Current Position 21000µm; Magnescales not fitted; Units µm; Selected Position 21000µm; Absolute
Plasma mirror Horizontal: Current Position 34mm; Magnescales not fitted; Units mm; Selected Position 34mm; Relative
Diagnostic 1 IN/OUT: Current Position 0mm; Magnescales not fitted; Units mm; Selected Position 0mm; Relative
Probe Lens In/OUT: Current Position 120mm; Magnescales not fitted; Units mm; Selected Position 120mm; Relative

Parker Controller Not Started
Parker No. 5

Figure 4. Screenshot of the drive system software where all motions necessary between shots have been assembled on a single interface allowing "single-click" operation of each.

References

1. D. R. Symes et al., *Implementation of adaptive optics on the Astra-Gemini beamlines*, CLF Annual Report, 2012-2013.

2. D. C. Carroll et al., *An imaging system for accurate target positioning for fast focusing geometries*, CLF Annual Report, 2011-2012.

3. N. Booth et al., *Target alignment in Astra*-Gemini, CLF Annual Report 2012-2013.