Commissioning of the Astra Gemini target inserter

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Introduction

In recent years the majority of solid target experiments conducted at the Central Laser Facility (and at other facilities) have required a relatively low number of targets per experiment. This was largely due to the limited laser repetition rates and the requirement to access diagnostics which often necessitates breaking vacuum, hence losing opportunities to acquire additional data. However with the development of the next generation of high repetition rate facilities, such as Astra Gemini, there is a renewed drive to maximise the rate of data acquisition. Firstly this demands the development of new, active diagnostics that require minimal user access during shots. Secondly a new approach is required to produce and then place and position targets ready for shooting in such a manner that interruptions to data acquisition are kept to a minimum.

This report outlines the development and commissioning of a new high repetition rate target inserter that was installed in the Astra Gemini target area at the Central Laser Facility. In this report the design and operational specification of the target inserter to select and position a large number of targets to a high degree of accuracy will be detailed, together with the results of the initial commissioning phase.

Target inserter outline

The target inserter and associated target alignment equipment have been designed and supplied by General Atomics (GA) as part of a collaborative development program with the Central Laser Facility. There are two main assemblies; the target inserter that was installed in Astra Gemini and a metrology station, used for determining target positions prior to insertion into the target chamber, that was setup in Target Area East (TAE).

The target inserter is housed within a separate vacuum chamber that is attached to the south wall of the Astra Gemini interaction chamber. A gate valve separates the two volumes. Targets can be loaded into the system, having first been mounted onto a target carousel (Figure 1). The carousel is capable of holding 50 target pucks, each of which holds a target mount that can be engineered to support a wide variety of targets [1]. Each puck is attached to the carousel via a vertically orientated kinematic mount.

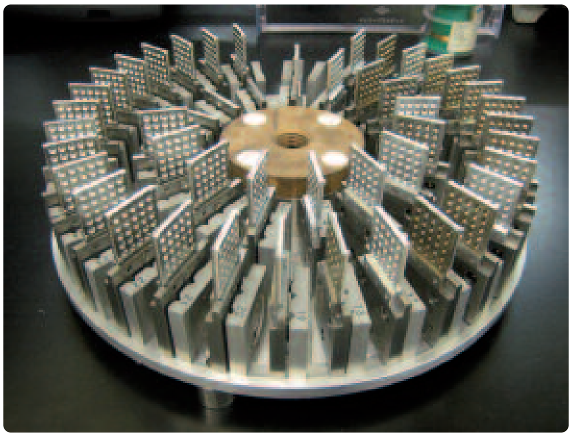

Figure 1. Target carousel mounted with a full complement of 5×5 target arrays. The carousel can hold 1250 targets with such an arrangement.

When a target is to be placed inside the interaction chamber, the carousel is rotated to position the desired target puck for selection. A gripper then descends to secure the puck and remove it from the carousel. The gripper is located at the end of the inserter arm which is fully retracted when housed in the target inserter chamber. This arm is then extended into the chamber, over a distance of 84 cm, until the gripper is positioned over target chamber centre (TCC) (Figures 2 and 3).

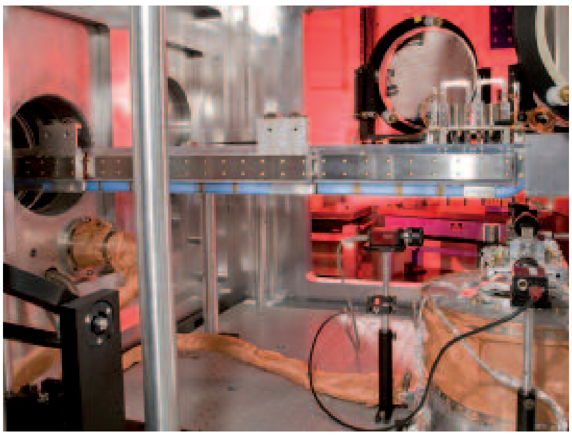

Figure 2. Target Inserter arm extending into the Astra Gemini interaction chamber to retrieve a target puck.

At TCC a hexapod is positioned which serves to position the target with sub-micron accuracy, providing motion along 3 axes together with 3 axes of rotation. On top of the hexapod is a small assembly that uses 4 small retractable magnets which secure the target puck in place (together with 3 magnets to secure an adaptor plate). The magnets are retracted to release the puck whenever a target is being removed. The gripper arm descends to place the puck on to the securing mechanism on top of the hexapod, and the arm is then retracted back into the inserter chamber. This entire process takes just under 60 seconds.

Once a target puck has been inserted in this way, the hexapod can be moved to align the required target ready for shooting. Once every target has been shot on the mounted puck, the above process is reversed to place the spent puck back into the target carousel. The inserter arm has two grippers mounted at the end and so is capable of placing a new target and removing an old target within the same operation cycle.

With the exception of the insertion of the target carousel into the target inserter chamber, the entire procedure of placing and aligning targets is operated using custom software, written by General Atomics using LabView. In its simplest form a puck number is selected to be picked from the carousel and then placed on the hexapod. Once placed, a pre-defined target is chosen and the hexapod moves the target to TCC ready to be shot. At this point fine adjustment of the target position can be performed before shooting, if required, using manual controls in increments from 0.5 µm up to 1 mm. This may be used to position targets to scan range of parameters such as distance from focus.

In order to minimise the time required to align targets once placed at TCC, a separate metrology station was set up in Target Area East so that the coordinates for each target could be pre-defined. This system consists of a second hexapod together with a robotic arm to pick and place targets from a carousel. In order to cross-reference the two target stations the first hexapod was used to position a 6 µm diameter wire at TCC in the Astra Gemini chamber such that the laser focused on the wire tip. The XYZ position of the hexapod was saved at this point. The same wire was then carefully moved over to the metrology station, where three high magnification cameras were used to focus on and reference this same wire tip position as a duplicate TCC. This second referenced position was then used to align any targets to the laser interaction position in advance of them being placed inside the chamber. Target positions determined at the metrology station TCC are used to position the targets at the Astra Gemini TCC. Fine manual adjustment of the target position can then take place if required once the target is ready to be shot.

Commissioning

Following installation of the target inserter and metrology station, characterisation and testing of both systems was undertaken during solid target radiological commissioning of Astra Gemini. This consisted of running the target inserter, initially using just alignment wires and dummy targets, before a series of data sets were obtained using the Astra Gemini laser.

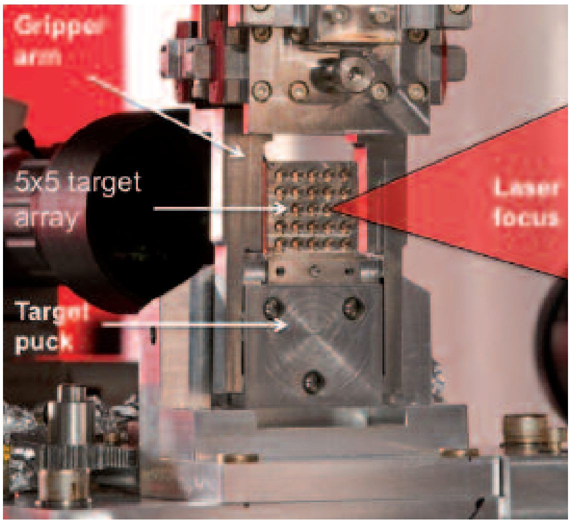

Figure 3. Front view of a target puck being secured onto the hexapod at TCC by the target inserter gripper arm. A 5×5 target array is attached to the puck.

Placement and removal of a fine (6 µm diameter) wire was found to be highly reproducible, with a variation on the positioning of +/- 5 µm. This was measured using an array of high magnification cameras inside the chamber. This error can be largely attributed to slight variations in the seating of the target puck on the hexapod puck holder.

The insertion of multiple dummy targets was then performed to check the target focusability over the full extent of hexapod motion. Each puck typically supports an array of 5×5 targets (see Figure 3), although many other target configurations are possible. It is important that the hexapod has a sufficient range of motion to be able to provide a number of focus positions for each target. The hexapod was found to satisfy this requirement, having a useable volume of approximately 20×20×6 mm. The time taken to translate in one axis to the next defined adjacent target position on the target array was approximately 5 seconds.

During radiological commissioning a series of data sets were taken using the target inserter to insert and remove target pucks. This served to not only assess ease of aligning targets with the inserter, but also to highlight any hardware or software bugs.

The first target pucks were aligned using the metrology station. The process of defining a single target on a typical target array took around 3-5 minutes depending on the target material and complexity. However it was found that judging the placement of each foil at the referenced interaction point was limited by the depth of focus of the alignment cameras. This was approximately +/- 30 µm. As a result the retro alignment laser inside Astra Gemini was used together with the hexapod controls to fine focus targets to an accuracy of typically +/- 5 µm. The installation of a replica retro laser system in the metrology station has been proposed in order that targets can be more precisely aligned offline.

Due to a lack of time, many targets were aligned manually in Astra Gemini before each shot. While this process was broadly successful, with the time taken to move to and focus the next target taking as little as 1 minute, this is only suitable for the simplest foil targets. More complex targets will need to be aligned in advance using the metrology station in order to maximise the rate of data acquisition.

There was found to be little or no electromagnetic interference (EMI) to any of the target inserter hardware despite the hexapod remaining powered on during shots. Many of the target inserter motor systems were powered off using the software for each shot and were brought back online afterwards in under 30 seconds.

Future development

During the initial commissioning of the target inserter in Astra Gemini several issues were encountered that highlighted the need for continued development.

Firstly the footprint of the hexapod is to be addressed. While the hexapod exhibited a high degree of accuracy and reproducibility in positioning targets, the amount of space it took up around TCC was judged to be excessive. The possibility of replacing the hexapod with a more compact XYZ stage is currently being examined.

Secondly, issues were encountered whereby the picking and placing of target pucks on top of the hexapod was not performed correctly. This led to lengthy realignment procedures on several occasions. The problem has been attributed to small misalignments of the target inserter chamber with the main interaction chamber that most likely resulted from multiple cycles of the vacuum system. A new method of correcting for any possible position offset is now being developed.

Finally the target inserter software is being revised so as to provide a more streamlined interface for the user. It is important that the target inserter software is user friendly while providing a more complete manual mode should it be required.

Conclusion

A collaboration between General Atomics and the CLF has led to the development and installation of one of the first high repetition rate target characterisation and insertion systems. Using pre-defined positions for each target, the target inserter is capable of aligning targets at a rate equal to, or greater than that of the Astra Gemini shot rate (currently 1 shot per minute). Up to 25 targets can be shot on each target puck, with a ~1 minute changeover time between pucks.

During the initial commissioning phase the target inserter was found to be able to align targets to a retro reference with a high degree of accuracy. However software and hardware bugs uncovered during the initial testing phase limited the target inserter deployment during its first full-scale experiment. Future work on the target inserter system will see upgrades to both the user interface and several aspects of the hardware design, together with extensive testing. It is then expected that the target inserter will be fielded on future solid target experiments in Astra Gemini.

Acknowledgements

The authors would like the acknowledge the help and assistance provided by the staff at the Central Laser Facility; particularly that of the engineering and target fabrication group.

References

1. C. Spindloe – 2009 CLF Annual Report.