GA–A25670

TARGET MOUNTING SYSTEMS REP-RATED LASERS

by
N.B. ALEXANDER, D.T. GOODIN, and R.B. STEPHENS

JANUARY 2007

GENERAL ATOMICS

DISCLAIMER

GA–A25670

TARGET MOUNTING SYSTEMS REP-RATED LASERS

by
N.B. ALEXANDER, D.T. GOODIN, and R.B. STEPHENS

This is a preprint of a paper presented at the 17th Target Fabrication Specialist Meeting, San Diego, California on October 1-5, 2006 and to be published in *Fusion Science and Technology.*

Work supported by
the U.S. Department of Energy
under DE-AC52-06NA27279

GENERAL ATOMICS PROJECT 30272
JANUARY 2007

GENERAL ATOMICS

TARGET MOUNTING SYSTEMS FOR REP-RATED LASERS

N.B. Alexander, D.T. Goodin, and R.B. Stephens

General Atomics, P.O. Box 85608, San Diego, California 92186-5608
neil.alexander@gat.com

GA is developing the target fabrication and insertion capabilities required for a >100 TW rep-rated laser to be built at Ohio State University. We will be assembling an integrated system that includes mass target production, separation and assembly onto carriers, rapid insertion and precise alignment. We will describe target-mounting methods we have investigated for holding targets on target carriers at a repeatable position with respect to location fiducials fabricated into the carriers. The effect of shaking the target carrier on the repeatability of the target location will be examined. Alignment of the target using the carrier fiducials will also be described.

I. INTRODUCTION

We are developing a target insertion and alignment system for the Science Center for Advanced Research on Lasers and Engineered Targets (SCARLET) at Ohio State University. The system is being developed to be suitable for a single beam, peta-watt class laser running at rep-rates of up to 1 Hz with 10 to 100 J/pulse expected. It is planned to insert up to 1000 targets/day and align them to within 10 μm of the desired location.

A variety of targets are anticipated. Many will likely be of 2 1/2 D style. These are targets that are thin rectangular blocks of one or more layers of material, potentially with some structure on the large faces such as steps, pits, or bumps. More complicated targets, such as cone-and-wire targets, are also of interest.

At these powers and energies, the experiment will occur in a vacuum. Debris from a shot target can easily damage successive targets. To avoid this target fratricide, targets awaiting a shot must be well removed and out of the line-of-sight of the target being shot. The electro-magnetic pulse (EMP) generated at these power levels also has to be taken into account when considering the target alignment system and target positioning equipment.

With these requirements and constraints we have selected a target insertion and alignment scheme that utilizes targets that are individually mounted to separate target carriers (Fig. 1). Targets are mounted to the carrier with thin fibers to minimize the influence of the carrier on the target/laser interaction. Fiber mounting of laser fusion targets is a long established technique,[1] however in this case considerable time is taken to align the lasers directly onto the target. Individual target/carrier assemblies allows the insertion system to keep the targets separated to avoid fratricide. The alignment is accomplished by using fiducial marks on the carrier. This allows the alignment to be optimized for the fiducial marks, rather than having to adjust to a continually changing target shape. An external metrology station measures the offset of the target from the fiducial marks on the carrier. The alignment system then uses this information to adjust for mounting location variations between target/carrier assemblies. The carriers will have identification codes to allow each one to be distinguished.

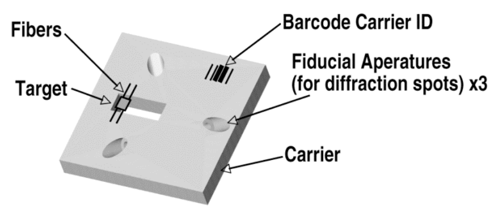


Figure 1. A target carrier is used for each target. Fiducial marks (apertures) are used to align target/carrier assembly to the laser and diagnostics.

The fiducial marks are a set of three apertures machined into the carrier. These have their optical axes set to be orthogonal, or nearly orthogonal, to each other. The fiducials are used both during assembly and during alignment of target to the laser. During assembly, the offset of the target to the fiducials is measured in the metrology station. Alignment is accomplished by three pairs of lasers and area CCD cameras (Figs 2 and 3). Each of the three diffraction spots is imaged to locate each spot in two dimensions. These six positions allow the carrier to be located with respect to all linear positions and angular orientations. Since the system is afocal, both the cameras and the laser may be located outside of the vacuum chamber at a considerable distance from the target. This mitigates EMP damage to the cameras and lasers.

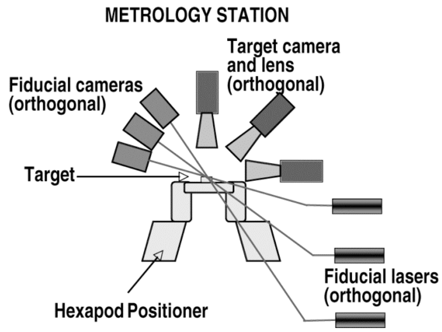


Figure 2. The metrology station is used to establish to offset of the target from the fiducial marks on the carrier. Three orthogonal positioned apertures are used as fiducials. Each target is positioned to the same location in front of the target cameras. The offset of the diffraction spots produced by the lasers on the fiducial cameras is recorded for used by the alignment system on the laser chamber. A hexapod is used to move the target carrier is all six degrees of freedom.

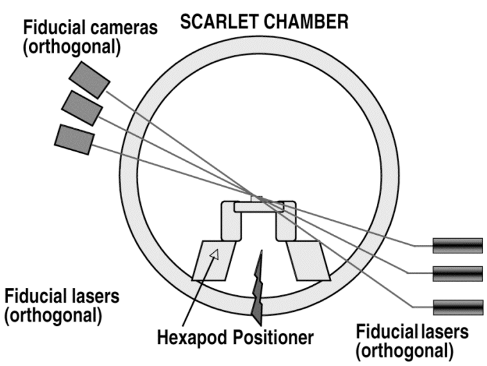


Figure 3. The target carrier is aligned using the diffraction spots produced by the lasers passing through the apertures on the target carrier. The spots are images by the CCD cameras. The offset of the target to the apertures measured previously by the metrology station is applied to bring the target into alignment. The electronic alignment equipment, CCD cameras and lasers, are located outside of the vacuum chamber for reduced EMP exposure.

The scheme of a target mounted in a carrier, with alignment to fiducials on the carrier requires two key features. One, that the fiducial alignment scheme must be highly repeatable. Two, that the target maintains a repeatable position with respect to the carrier. Movement of targets on the carrier will corrupt the offset measurements made on the metrology station. Shipping and handling by the insertion equipment has the potential to cause target movement (e.g. stretched fibers). We have examined these two issues and report on them below.

II. TARGET ALIGNMENT

Diffraction spots have been previously used for precision, long distance alignment[2,3] of particle accelerators. In these cases, the Poisson spot produced by a spherical obstruction was used. In our case, with its shorter camera to object distances, it is possible to use the spot produced by Fresnel diffraction through an aperture. In Fresnel diffraction, the spot pattern varies with the number of Fresnel zone occurring in the aperture. To get a pure Fresnel zone pattern the aperture diameter, D_n, and the aperture to camera distance, r_0 are related by,

$$I(E) = F(E) \bullet \exp[-\int \mu(E,\rho,Z)dx] \quad , \qquad (1)$$

where λ is the wavelength of the laser illumination, and n is the zone integer. Each odd zone number produces a pattern with a central bright spot. We have found that zone 3 produces a pattern with good contrast between the central bright spot and the surrounding dark ring; see the "2°" image in Fig. 4.

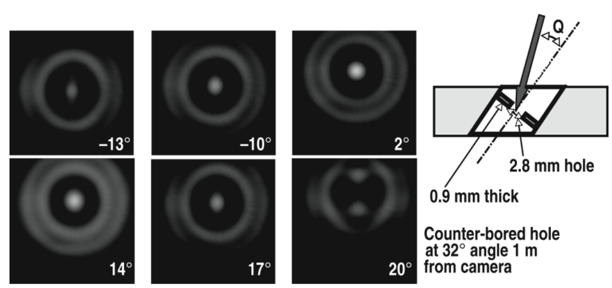
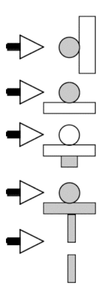


Figure 4. The Fresnel diffraction spots shown are zone 3. The laser wavelength is 632 nm. Zone 3 provides a bright central spot surrounded by a high contrast dark band. Note that the spot is maintained for significantly large tilt angles of the incident laser light.

Repeatability of the diffraction spot measurements was tested. For Poisson spots 4 mm steel spheres were used. They were attached to either aluminum plates or glass microscope slides using either glue or magnets. For an aperture, a 2 mm diameter hole was drilled in an aluminum plate. A helium-neon laser, wavelength 632 nm, was used to illuminate each of the diffracting elements. A CCD camera was set up 0.5 m behind the diffracting element. The diffracting element was attached to a precision optical micrometer stage that allowed the target to be translated transverse to the laser beam-camera axis. The position of the diffracting element was determined from the centroid of the central bright spot. Since the system is afocal, motion of the diffracting element is directly replicated on the image plane of the camera. Thus the pixel pitch of the camera, 10 μm, can be used to translate the pixel displacements of the spot into linear displacements. Central spot sizes were approximately 160 μm is diameter. The central bright spot thus contained a substantial number of pixels, which allows spot location to be determined to a small fraction of a pixel. Data series were taken where the diffracted element was translated in steps of 100 μm several times in one direction, and the location of the central spot noted at each step. Ten steps were used for Poisson spots and four steps were used for Fresnel spots. Each data series would relocate the target to the same locations using the optical micrometer stage. Data series were compared by taking the difference of the camera reported positions of each step of the series. The average of the differences and standard deviation of the differences of all the steps were computed. The results are displayed in Table I. Most of the diffracting elements show repeatability at or near the one-micron level, well below the desired 10 μm.

Table I. Repeatability of
Diffraction Spot Alignment Schemes



Sphere Attachment and Beam Alignment	Difference of Data Series 1 & 2 (μm)	Difference of Data Series 2 & 3 (μm)
Sphere glued Through glass	1.50 ± 1.10	0.35 ± 0.60
Sphere glued Tangent to glass	–0.53 ± 1.15	0.60 ± 1.08
Sphere magnetically held Tangent to glass	–0.47 ± 0.88	0.07 ± 0.77
Sphere magnetically held Tangent to Aluminum	0.53 ± 1.75	–0.29 ± 1.36
2 mm hole in 1/8" Aluminum	0.75 ± 0.43	0.00 ± 0.41

Considering both the difference average and its standard deviation, the Fresnel spot had a better repeatability in both comparisons. From a volume manufacturing point of view, we also prefer machining apertures into carriers, to the assembly of spheres on to carriers by gluing or other fastening technique. Since targets will not be mounted perfectly parallel to the carriers, the carriers will have to be reoriented (tip, tilt, rotation) to the fiducial laser beams. Thus, it is important that the apertures (holes) produce central spots despite being somewhat tilted with respect to the beam. Tilting the aperture changes the path-length of different parts of the beam as they pass through the aperture. Examine Fig. 5, the biggest path-length differences occur between paths 1 and 3, and paths 2 and 3.

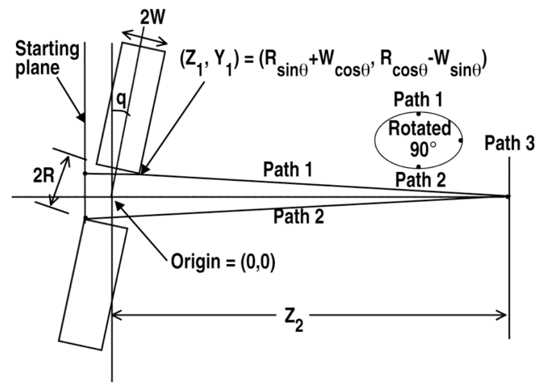


Figure 5. For a tilted aperture (hole), light ray paths have different lengths. Consider light grazing top (path 1), bottom (path 3), and side (path 3), of hole.

The path lengths for these paths are

$$\text{Path } 1 = 2Z_1 + \sqrt{(Z_2 - Z_1)^2 + Y_1^2} \quad , \tag{2}$$

$$\text{Path } 2 = \sqrt{(Z_2 - Z_1)^2 + Y_1^2} \quad , \text{ and} \tag{3}$$

$$\text{Path } 3 \approx \sqrt{(Z_2 + Z_1)^2 + R^2} \quad . \tag{4}$$

The path-length difference should be much less than a wavelength of light for the central diffraction spot to be well formed. For small hole thickness and diameter, and small tilt angles, the path-length difference is proportional to Wθ, indicating that thinner apertures will be more tolerant of tilt. The effect of tilt is shown in Fig. 4, where the aperture diameter is 2.8 mm, the aperture thickness is 0.9 mm, the aperture to camera distance is 1 m, and the wavelength is 632 nm. Acceptable spots are observed from –10° to 17°, or averaging under the assumption of some misalignment ±13°. In this case, the difference between path 2 and path 3 is 0.3λ. The spot criterion is just met, indicating that further tilt will degrade the central spot. This is seen in Fig. 4. The ±13° tilt range exceeds the expected misalignment of targets to their mounts, so apertures are expected to work as alignment fiducials.

III. TARGET MOUNTING AND POSITION REPEATABILITY

Target position with respect to the carrier must not change in order to allow the target to be aligned using fiducial marks on the carrier. Targets could move due to stretching of the fibers or slippage of the glue joints caused by forces exerted on the target/carrier assembly during shipment and handling by the insertion equipment. To test the stability of the target's position, we have shaken mounted targets with known accelerations and measured the target's position before and after.

The targets were mounted to two parallel fibers stretched across an inside cord of a washer (Fig. 6). The fibers and the targets were attached using UV curing glue. An additional target was attached to the washer so that the corners of the washers nearly touched. Since the targets are micro-machined, the two corners of the two targets provide clean hard edges to measure between. One target being firmly fixed to the washer is the reference for the carrier. The fibers are 7 to 10 μm diameter carbon fibers. The targets are aluminum, 1500 μm square by 50 μm thick.

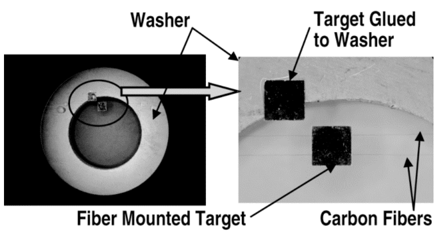


Figure 6. Aluminum targets were mounted using two parallel carbon fibers to a washer. The top target is attached to washer as a reference. The bottom target is glued to the fibers. The corner-to-corner distance between targets is measured. The washer represents the target carrier.

Targets were shaken with a one-axis commercial shaker table [Fig. 7(a)]. The distance separating the corner of the mounted target from the corner of carrier reference target was measured optically with a 4× telecentric lens and a CCD camera. The targets were backlit with a monochromatic mercury-line light-table [Fig. 7(b)]. Not shown is a light shield that wrapped around the lens and descended down to the light table. Out-of-plane target movement will be examined at in future experiments.

Initial results are shown in Fig. 8. In this set of data, the target was shaken at ±2 g's peak-to-peak for 10 minutes at various frequencies and directions. Each data point is the average of measurements taken from ten different images of the target. Pixel to linear distance conversion was taken as the pixel size, 4.65 μm/pixel, divided by the lens magnification of 4. This was verified with an optical resolution target. The shaking did not move the target significantly with respect to the alignment goal of 10 μm, with the exception of sample run 6. A lighting issue (incomplete replacement of the light shield) is suspected, since in subsequent tests the measurements of the target returned to their original separation.

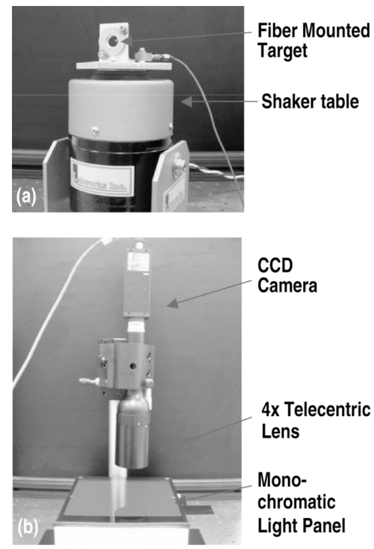


Figure 7. (a) Targets were shaken with a shaker table. (b) Targets were imaged to measure their separation.

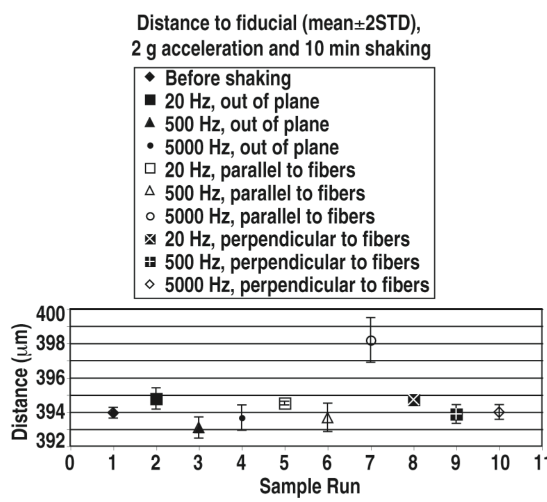


Figure 8. Target to carrier reference fiducial separation did not change after shaking.

The initial results are encouraging, but limited in scope. Further tests are planned. These include adding a side view, using higher accelerations, using other types of fiber, examining the effect of impulse loads such as having the carrier dropped into a kinematic mount, and putting the carrier through an real shipping cycle.

IV. CONCLUSIONS AND FUTURE WORK

We have developed a target-mounting scheme for high power, rep rated lasers based on a target that is fiber mounted into a carrier, with alignment of the target based on fiducial marks on the carrier. The two key features required for this scheme have been investigated. The alignment scheme of using zone 3 Fresnel diffraction spots as the fiducial marks has been shown to be repeatable at levels well below the desired 10 µm. Initial tests on the mounting of targets on two parallel carbon fibers has shown that the target position on the carrier is also stable to much better than the desired 10 µm. However, further tests of this are needed using more strenuous accelerations and shaking of the target carrier assembly.

ACKNOWLEDGMENT

This work supported by Ohio State University and Department of Energy contract number DE-AC52-06NA27279. The authors wish to thank R. Petzoldt for his analysis and experiments on the diffraction spots, and thank B. McQuillan, J. Bousquet, and D. Frey for their work on the target mounting experiments.

REFERENCES

1. B. A. BRINKER, J. M. CAVESE, J. R. MILLER, S. G. NOYES, S. SHEBLE, L. T. WHITAKER, "Inertial Fusion Target Mounting Methods: New Fabrication Procedures Reduce the Mounting Support Perturbation," *J. Vac. Sci. and Technol. A* **1**, 941 (1983).

2. I. FEIER, H. FRIEDSAM, M. PENICKA, "The Poisson Alignment Reference System Implementation at the Advanced Photon Source," *Proc. of the Fifth International Workshop on Accelerator Alignment, Advanced Photon Source,* Argonne National Laboratory, Illinois (1997).

3. L. V. GRIFFITH, "The Poisson Line as a Straight Line Reference," *Proc. of the First International Workshop on Accelerator Alignment,* Stanford Linear Accelerator Center, Stanford University, California (1989).