LA-UR -81-2469

CONF-810427--39

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TITLE: OPTICAL TOOLING FOR ANTARES

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SUBMITTED TO: Los Alamos Conference on Optics '81
Los Alamos, New Mexico
April 1981

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FORM NO 836
ST NO 2629

Optical tooling for Antares*

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Abstract

The Antares laser system is a large (40 kJ) CO_2 pulse laser system. High energy pulses are transmitted between buildings over path lengths exceeding 90 m. The optical elements are contained within large steel assemblies (power amplifiers, turning chambers, and target chamber) which must be positioned with tolerances of 0.75 mm. The subassemblies of optical components must be prepositioned to a precision of 0.25 mm. This precision can easily be obtained by first order surveying techniques and instrumentation.

Although this accuracy is routinely achieved in geodetic network controls and high-precision engineering projects, the Antares optical tooling techniques had to be tailored to the geometry of the system. The basic theoretical optical train centerlines were established throughout the facility. These theoretical references had to be transferred onto solid reference surfaces, often around many physical obstacles. This paper describes the use of a combination of traditional surveying techniques and modern optical tooling methods throughout the integration of building reference planes and the erection of major steel assemblies. The design and measured assembly tolerances are compared.

Introduction

The main beam paths of the Antares laser are comprised of large diameter, long path length optical networks with many components, which could present numerous alignment problems: both in the initial component assembly and subsystem construction, as well as in the final system alignment verification.

The optical elements are contained in the initial pulse generating area (front end room), power amplifier, and target chamber, and are separated by path lengths up to 30 m. They are located in separate buildings which are connected by tunnels or tubes (Fig. 1). The optical pulses are amplified within a pressurized power amplifier shell, and then projected 55 m through a vacuum system to the target. As most optical elements are enclosed in steel chambers, it is difficult to obtain direct access for alignment purposes. Therefore, it was considered important to closely correlate the steel shell assembly to the system optical center lines from the initial construction of the facility through the assembly of the project.

The physical size and complexity of the optical assemblies requires subsystem assembly in remote areas (optical assembly shops). A typical subsystem is the "in-out" (I/O) optics shell into which will be assembled 24 mirror mounts with 1,000 cm^2 copper mirrors weighing in excess of 80 kg each, plus a number of smaller elements. All the elements have to be aligned to the subsystem datum lines within 0.5 mm. This made it necessary to set suitable references which connect the separated components and accurately correlate these to the optical grid defining the beam paths.

It was therefore decided to rely on optical tooling techniques for positional control and measurements and assign the responsibility for optical integration to a team attached to the optical engineering group.

In this manner, all aspects of alignment, from initial building construction through steel frame assembly to beam line trimming, were controlled by the system manager who is in charge of delivering the final product, i.e., the initially aligned optical beam lines from the front end to the target.

At the early stage of the facility construction a problem was encountered with the coordination between the measurement units used by physicists, architects, engineers, designers, and surveying instruments.

*Work performed under the auspices of the U. S. Department of Energy.
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While the architects prepare their drawings in fractions of inches, the engineers and surveyors work in decimals of feet. Mechanical designers specify decimals of an inch; our master instrument, a "Wild T-2" theodolite with an optical micrometer measures in decimals of mm, and the American jig transits and levels have optical micrometers in decimals of inches. The level rods are calibrated in decimals of feet and scales in decimals of inches. Physicists use the metric system. For the purpose of uniformity, in this paper all dimensions will be reported in metric units.

The optical reference grid

Antares is designed around a global coordinate system which originates at the target. The main orientation is north-south, with +Y directed northward, +X directed to the east, and +Z directed vertically "up". The alignment scheme consisted of defining the optical beam lines as they progressed backward from the target toward the initial pulse-origination point (the front end room) and establishing permanent target "off-axis" reference lines at various critical locations. Buildings, mechanical systems, and optical assemblies were positioned relative to the master grid (Fig. 2).

There is limited physical and optical access to some of these reference lines. There is no porthole connection between buildings along the Y axis, at X = 0, which made it impossible to establish a direct center line. Major walls separate the power amplifier and target facilities. The master grid level above the floor changes from about 5.5 m at the target location to 1.75 m at the turning chambers and 3.2 m in the laser hall.

As previously mentioned, the optical elements are completely enclosed within a vacuum system, from the power amplifier to the target. Therefore a dual set of references is required: an external set used to locate buildings and steel vessels, and an internal set within the steel shells to set the optics. The set of external reference targets used for the initial alignment was transposed into the steel shells as they were being assembled.

The master grid is controlled by primary bench marks, which identify the latitudinal orientation and the reference elevation of 2207.518 m (7242.5 feet) above sea level. These bench marks were set by the survey crew of Los Alamos.

A base line was set in the laser hall at approximately Y = -55.8[illegible]0 m. Because of the lack of direct optical access to the X = 0, Y = 0 point, we completed a rectangular grid through port holes one and six, and shifted the grid north until it intercepted a point which was acceptable as the target location X = Y = Z = 0. This rectangle closed over a 200 m perimeter path within 3 mm, going around various obstacles.

As soon as the buildings were connected by the beam tubes, the rectangle was refined by using jig transits and autocollimation instruments. Loop closure was within 0.5 mm which results in a closure rate of approximately 3 in 10^6 and approaches the accuracy required for superior order geodetic control surveys, which is 1 in 10^6. The work had to be done at night, to avoid large scale air turbulence and thermally induced distortion within the (still exposed) beam tubes. The tubes are now covered with earth which will eliminate any thermal distortion problems in the future.

Though the control grid was initially set with the highest precision, it was difficult to maintain this precision. Numerous, small, stress cracks developed in the freshly poured concrete, into which the targets are set. Several cracks exceeded 1.5 mm in width. Repeated corrections were necessary to the main control points on the base line. Detected shifts of 1 to 1.5 mm in lateral directions over the entire complex are common.

After the reference grid was defined through the target building and laser hall, the beam tubes were positioned. These tubes form the vacuum shell to enclose the optical beams. Figure 3 shows an optical target being centered in beam tube flange No. 5, and a "Brunson" level and jig transit setup to control movement of the center target. This point was not critically toleranced. However, it is the main mechanical interface between the vacuum system and the power amplifier. The flange centers were used to define the "primary center lines". These are the center lines to which the power amplifiers were set.

The control grid was transferred from the laser hall into the basement to the front end room, by setting a 6 m optical tooling bar across the pit opening to the basement and using a "Wild T-2" theodolite with right-angle prism (Fig. 4). The prism swept the vertical plane through the primary center line, which was picked up in the bottom of the pit with a "Brunson" jig transit (Fig. 5) and transferred to the front end room.

North of the target, or in the +Y direction, two instrumentation stations along a vacuum tube were connected to the target vacuum system, with a closely controlled direct view of the target (Fig. 2). The tube is inclined downwards toward two subterranean instrumentation station bunkers. Using the inclined slope technique, the vacuum steel tube was pre-set with the "Wild N 3" level. A Keuffel and Esser (K and E) tooling laser was used to correct the tube center line pointing at a surrogate target at X, Y, Z = 0, and the tube flanges were positioned by retro-reflection from a mirror which was attached to the tube flanges. At a later date the controlled positioning of the mounting flange to the target chamber was performed using the same technique.

Optical tooling discussion

A basic optical tooling set-up, or "tooling dock", consists of the jig transits mounted in rigidly controlled relationship to each other and complemented by a level, to sweep three planes of a spatial grid. The standard dock employs horizontal tooling bars locked to each other accurately at 90° with control scopes, plus a vertical bar. Such a set-up can be used to measure linear dimensions to accuracies of 0.025 mm. The bars come in lengths of 3 to 6 m and can be joined to extend their range.

A small dock was used to survey the accuracy of the "space frame" model (Fig. 6). The space frame is designed to hold the target insertion mechanism and associated optics for beam acquisition and focusing. The model was made to 1/5 scale. The actual frame will be in excess of 4 x 6 x 6 m, constructed from stainless steel box beams with 12 mirror array planes set at different angles to accept 144 mirror assemblies. The intent was to verify the scale model prior to the frame manufacture. In the dock, the center position X, Y, and Z of each array plane was measured. An optical tooling laser (K and E) was then added and is visible in the rear center of the picture. By pointing this to reflectors attached to the mirror array planes (Fig. 7) the array centers could be traced through folding and focusing planes to a surrogate target.

A conceptual sketch of the power amplifier assembly (Fig. 8) shows a basic dock 5.5 m high and more than 18 m long. Because of the clearance required for handling equipment and personnel access, the space requirement for the dock grew to about 25 m in length. The use of a platform lift on the side of the power amplifier precluded the use of continuous tooling bars. Therefore, the longitudual dimensions in the beam line direction were set on the floor, and individually mounted jig transits were used to find the floor targets, and optically lock them together.

The support pads of power amplifier stands were set to within 0.5 mm of design values, in their horizontal level as well as in beam line orientation. After setting optical targets (Fig. 9), the power amplifier shell segments were positioned with the first center being set to within 0.5 mm of the primary center line. The subsequent centers were then marked and their relative position was measured with jig transits and levels as shown in Fig. 10. The centers wandered within a tolerance circle of 1 mm, with a stack-up of errors leading to a mechanical center line mislocation of approximately 3.8 mm over a distance of about 12 m, or a pointing error of about 1 arc-second. This was well within the requirements of mechanical design and the optical automatic alignment system.

A major component to be aligned internally to the power amplifier is the electron gun. It is about 9 m long, 1.75 m in diam and weighs in excess of 20 tons, yet must glide into the power amplifier shell precisely to satisfy mechanical as well as electrical clearance specifications. Furthermore, this process must be repeatable, as the gun will be removed periodically for maintenance access. There are two sets of running surfaces to be coordinated -- the support rails within the power amplifier, and the guidance rails used for handling and inserting the gun. The center rail was set with transit and level to the mechanical center line. Four auxiliary tooling targets were then added, defining two planes radiating from the center downward at 150° and 210°. Two "K and E" alignment scopes were set to these targets (Fig. 11), and by rotating the scopes 30° the internal optical micrometers could be used for direct reading of rail displacement in radial orientation as well as straightness. A mechanical jig was used for control of individual assembly support points, and the optical reference lines made it possible to obtain overall straightness within 1.25 mm and level within 0.17 mm.

The removable handling fixture was then referenced externally to the optical master grid with standard adhesive targets. Subsequently, the fixture was quickly and precisely repositioned with the electron gun mounted on top of it, and the gun was inserted without difficulty (Fig. 12).

The setting of optical components inside the power amplifier is more involved. Not only is the access limited, but the beam sectors are not truly parallel to the system centerline. There is a slope from south to north toward the center at an angle of about 1 min 44 s. This precludes the direct use of gravity for setting levels and transits.

The back reflector shell is shown on its back, with an optical tooling bar supported across the mounting flange (Fig. 13). A special fixture was designed which permitted precise control of an alignment scope in the vertical position and this was then offset by 1 min 44 s through autocollimation from an inclined reference base. In conjunction with a chain of surrogate reference targets, the optical components were pre-set to be suffi- ciently close to their design position so that one beam sector could project through the power amplifier. All of the 13 optical elements were aligned well within the specified tolerances on the initial assembly of the power amplifier.

Conclusion

The Antares laser system presents extremely challenging alignment and assemuly problems. By providing a precise reference datum and good initial alignment of mechanical components, the assembly and mechanical alignment of two power amplifiers and one complete sector optical train within one power amplifier is easily achieved.

The main task for the future is to refine the optical alignment procedures to permit simultaneous installation of all 12 beam sectors, and to work out a satisfactory procedure for alignment of the target facility.

Acknowledgments

The authors wish to thank Ralph Alarid and his surveying crew of Los Alamos for their expert assistance.

Fig. 1. Antares High Energy Gas Laser Facility.

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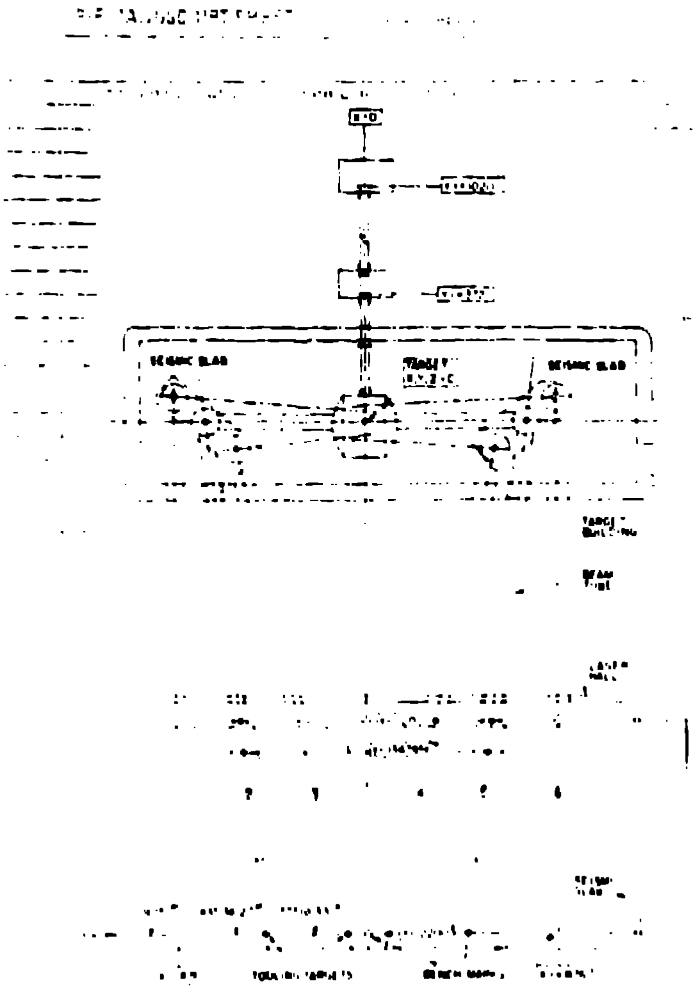

Fig. 2. Master control grid for the global coordinate system.

Fig. 3. Setting center of beam-tube flange.

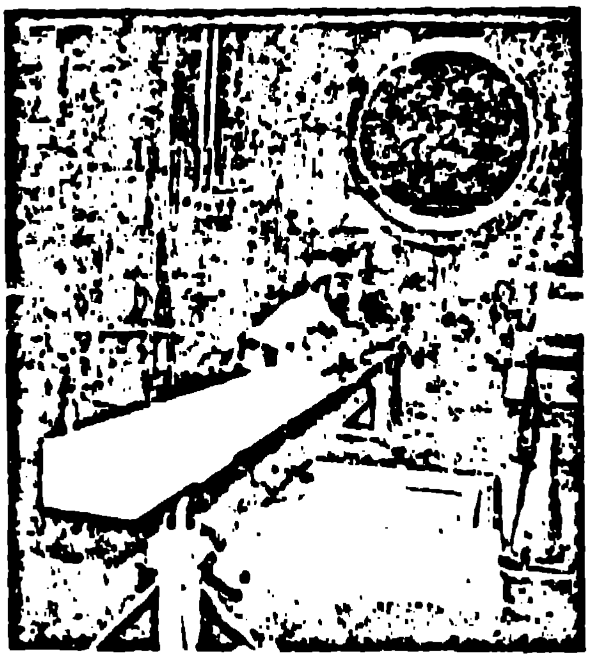

Fig. 4. Transferring beam reference line into optical pit.

Fig. 5. Transferring beam reference line through pit into Front End Room.

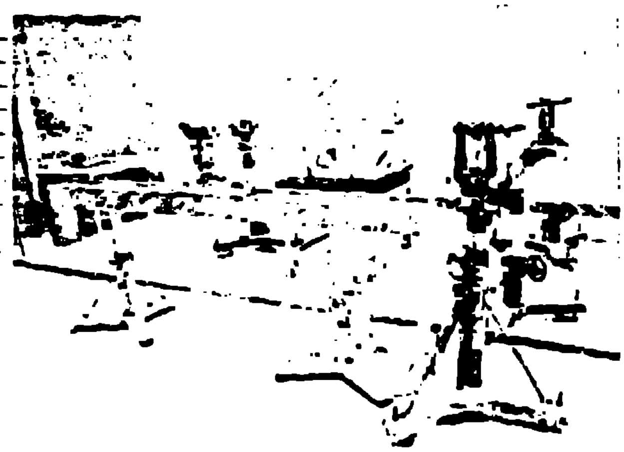

Fig. 6. Tooling dock for space frame model.

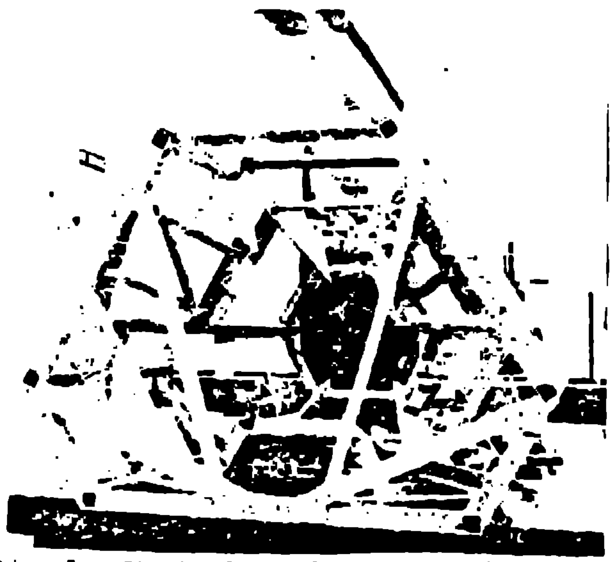

Fig. 7. Check of angular orientation of mirror array planes in space frame model with tooling laser.

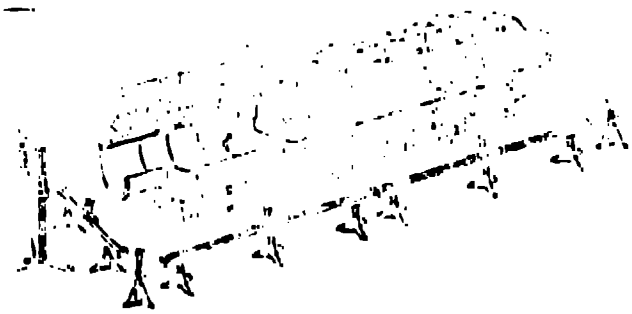

Fig. 8. Tooling dock for power amplifier (schematic view).

Fig. 9. Setting center of power amplifier shells.

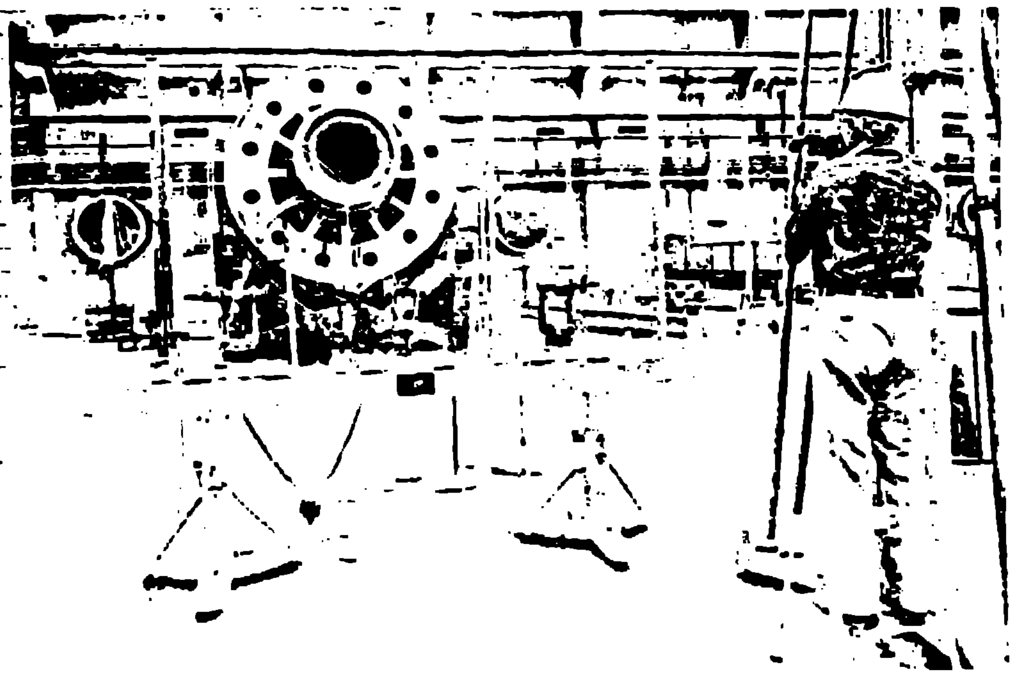

Fig. 10. Aligning power amplifier shells to beam line.

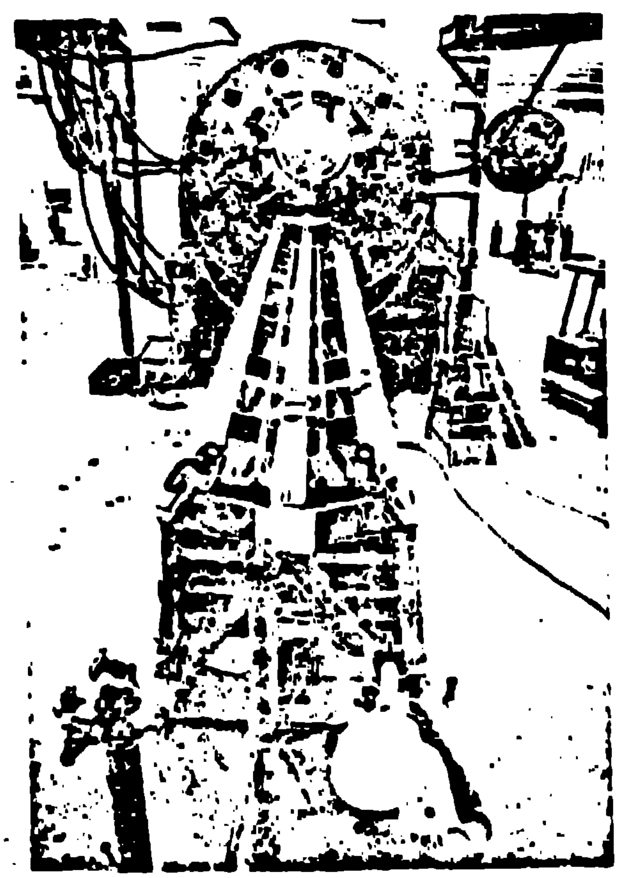

Fig. 11. Optical tooling set-up used to align external and internal electron-gun rails.

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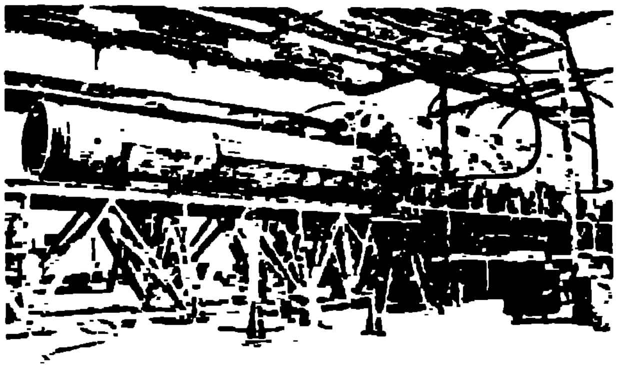

Fig. 12. Insertion of electron gun into power amplifier.

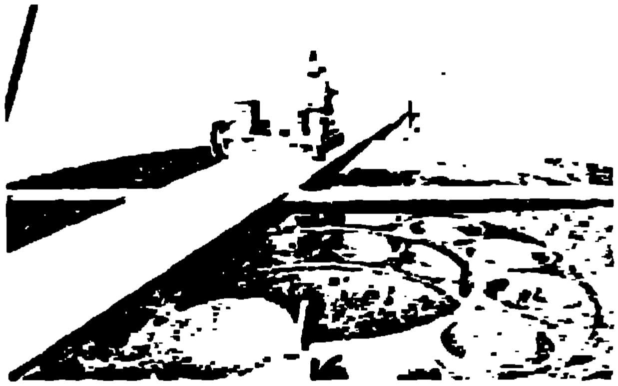

Fig. 13. Optical tooling adapted to set off-axis reference lines for back reflector elements.