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Alignment Telescope For Antares

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Abstract

The Antares Automatic Alignment System employs a specially designed telescope for alignment of its laser beamlines. There are two telescopes in the system, and since each telescope is a primary alignment reference, stringent boresight accuracy and stability over the focus range were required. Optical and mechanical designs, which meet this requirement as well as that of image quality over a wide wavelength band, are described. Special test techniques for initial assembly and alignment of the telescope are also presented.

The telescope, which has a 180-mm aperture FK51-KZF2 type glass doublet objective, requires a boresight accuracy of 2.8 μrad at two focal lengths, and object distances between 11 meters and infinity. Travel of a smaller secondary doublet provides focus from 11 m to infinity with approximately 7.8 m effective focal length. By flipping in a third doublet, the effective focal length is reduced to 2.5 m.

Telescope alignment was accomplished by using a rotary air bearing to establish an axis in front of the system and placing the focus of a Laser Unequal Path Interferometer (LUPI) at the image plane.

Introduction

The Antares CO_2 laser facility, constructed for inertial confinement fusion experiments, employs an alignment system which uses both visible and infrared wavelengths.[1] The telescope in conjunction with a TV camera views point light sources appropriately located down each of 12 beam paths. Two telescopes are required to align two beamlines, each beamline consisting of 12 beam paths. A beam expanded CO_2 alignment laser is also aligned by the telescope by viewing and aligning a tungsten illuminated pinhole in the beam expander.

Beam alignment is accomplished by determining the centroids of the imaged light sources and computer control of appropriate mirror positioners. Figure 1 is a schematic representation of the system showing the location of the telescope which provides the primary alignment reference for each beamline. The choice in making the telescope a primary reference eliminates the need for any other types of references in the beamline. Making this choice adds some stringent requirements to those already existing as a result of the laser's powered optics.

Several telescope optical designs were investigated and the design described here was selected, fabricated, and tested. The design provided the minimum number of optical elements, maximum mounting tolerances, and minimum travel of optical elements to provide the focus range. The design forced some new and innovative lens mounting, focusing, and testing techniques.

Telescope requirements

The basic requirement to provide beam path centering and angular alignment at critical points in the laser beam path resulted in the telescope requirements tabulated below.

Aperture	0.18 m diam unobscured
Length	2.1 m
Wavelength Band	0.5 to 1.1 μm
Focus Range	11.6 m to infinity (Stepper Motor Driver)
Focal Length	7.8 m or 2.5 m constant over focus range
Field of View	2.4 mr (7.8 m FL) 7.2 mr (2.5 m FL)
Resolution	50% theoretical limit MTF
Boresight	2.8 μrad max. radial deviation over focus range
Transmittance	0.7 over wavelength band
Temperature	70 ±2°F Operating 100°F to 40°F Storage and Shipping

The resolution was required over any 50-mm-diam area of the aperture for infinite objects and a 152-mm-diam area for nearer objects. This was because all critical light sources were viewed through a 26-mm-square aperture of the laser located about 18 m from the telescope.

Focusing and flip-ins are motor driven for control as part of an automatic system. Eyepieces were provided for eye viewing with a larger field of view for the purpose of trouble shooting and locating light sources.

The boresight requirement amounted to 0.02 mm at the vidicon faceplate or approximately one scan line. The camera was a silicon vidicon provided with special circuitry for scan raster position stability.

Optical design

The optical design is shown schematically in Figs. 2 and 3. The first doublet has 0.18-m aperture and 1.2-m focal length. The second doublet has a 38-mm aperture and a negative 152-mm focal length. These two doublets produce the desired 7.8 m effective focal length. A 152-mm travel of the small doublet provides focus over the object range.

To obtain the 2.5-m focal length, the small doublet is moved forward an additional 25 mm and then a 64-mm aperture, 305-mm focal length doublet is flipped in to refocus on the vidicon. A 152-mm travel of the second doublet once again provides focus over the required range. A fold mirror manually inserted after the third doublet turns the image to the side where four different eyepieces provide magnification up to 300x. The total length of the telescope is 2.0 m.

Figure 4 shows the finished optical assembly with the fixed first doublet followed by the second doublet on a focusing air bearing slide and the third doublet on its flip-in mechanism.

"Apochromatic" doublets consisting of FK51 and KZF2 type glass were used in all three cases. The matched partial dispersion of these glass types provided near diffraction limited performance over the broad wavelength band with less than 1/2 wave of primary and secondary color. The relatively low power elements are fairly insensitive to wavefront perturbations. The two major disadvantages of the design are the high thermal expansion and high cost of the FK51. This large thermal expansion requires special processing considerations and special mounting techniques which will be described in the following sections.

The basic resolution requirement was converted to $\lambda/4$ asymmetric and $\lambda/2$ symmetric wavefront irregularity. The tighter specification placed on the asymmetry was done to keep the image centroid centered. In order to meet the 2.8-μrad boresight tolerance, group decenter tolerances of 1.3 μm for all group motions and element decenter stability within groups of 0.3 μm were required. The tolerance on the initial element-to-element decenter stability within groups is 0.3 μm required. The tolerance on the initial element-to-element alignment within the doublets is less than 100 μm. The 0.3 μm is the required stability after alignment to maintain the boresight. The required fringe stability in the boresight alignment test, which is described later, is 1.3 fringes double pass.

Mechanical design

The boresight requirement of 2.8 μrad and the required centration stability of 1/4 μm between doublet elements and less than 2 μm between doublets had to be held for long periods of operation over a temperature range of ±2°F. Also, the non-operating temperature range was specified to be 40° to 100°F. These stringent requirements necessitated innovative mechanical designs for lens mounts and mechanisms.

A 35 cm by 206 cm by 30.5 cm thick Newport Research Corporation, steel faced honeycomb optical table was selected as a support for the telescope elements. This table was mounted on steel differential jack screws providing vertical and lateral adjustment to 1.3 μm resolution so that the entire telescope assembly could be aligned when installed in the Antares alignment system. Upon this table were mounted the three doublet lens assemblies.

The first (objective) doublet lens assembly was mounted in a unique thin-walled lens barrel which was especially designed to hold the relatively large, thermally sensitive doublet elements. Traditional lens mount designs were determined to be unacceptable because initial preload could not be well determined, thus exposing the delicate FK-51 doublet element to unknown stresses over the wide non-operating temperature range. Figure 5 is a photograph of this assembly and Figure 6 is a sketch showing its key features. The bezels are designed as "long cylinders" which uncouple the effects at one end from the other. The doublet elements are preloaded using a "force fit" into the bezels. The preload desired was calculated to be 8.62 kg to assure specified performance over the operating and storage temperature ranges. No problems have been found with this design.

The second (focusing) doublet lens assembly was mounted on a stepper motor driven linear air-bearing to achieve the total 180-mm travel necessary to change focus. Air-bearing alignment was achieved by adjusting wedges and a flexure joint. Figure 7 is a photograph of this assembly. The error budget for this assembly was determined to be approximately 1.3 μm, divided between centration of the lens in its mount, adjustment of the slide, and straightness of the air-bearing track.

The third (flip-in) doublet was mounted on an AC servo-motor-controlled "flip" mechanism, using preloaded bearings to move the doublet in and out of the optical path as required. Figures 8 and 9 show this assembly in both the "in" and "out" positions, respectively. This mechanism met its centration tolerance of 1.3 μm with no difficulty.

Finally, the entire telescope assembly was fit with a protective cover. "Chimneys" were installed to allow any heat buildup in the motors to escape and a shutter was provided to protect the objective lens assembly (telescope aperture) when not in use.

Optical assembly and test

Testing the individual doublets was the first step. Null tests were set up with a laser unequal path interferometer (LUPI) in the manner shown in Fig. 10. For the large objective a flat could be used with the LUPI focus at the focal point of the doublet. However, for the smaller doublets test plates were used as mirrors to simulate the conjugates at which spherical aberration was minimum in order to get a better test for the more critical wedge and decentration tolerances.

The system assembly and test was set up as shown in Fig. 11 with all components mounted on a Newport isolation table. A rotary air bearing tilt table with different reference spheres placed on it was used to establish an optical axis. A fold mirror above the rotary table turns the axis horizontal and a LUPI is positioned at the far end of the telescope.

The alignment required several steps. First, the LUPI is moved to the center of curvature of a 2.6-m concave sphere which is on the air bearing table. The telescope structure less optics is positioned so that its eventual image plane coincides with the LUPI. When the air bearing is rotated, the return image at the LUPI moves in a circle, until the sphere is adjusted on the air bearing such that the center of curvature of the sphere coincides with the axis of rotation. A final motion of the LUPI is made to obtain a null fringe pattern so that the LUPI is on the bearing axis. This is actually a two-step process in which the image motion is first observed visually and then final adjustments are made while observing the motion of the fringe pattern in the LUPI. The LUPI position is fixed for the remainder of the test after a null fringe has been obtained which no longer moves with rotation of the bearing. At this point an optical axis has been defined.

Next, the first doublet is placed on the telescope. A convex sphere is placed on the air bearing and adjusted in height to produce a return image at the LUPI. The sphere is positioned on the axis of rotation so that the return image stops moving. Since there are no centration adjustments on the first group, the entire telescope is moved horizontally and vertically using differential adjustments on the legs to obtain a few concentric fringes. The concentric fringes come from the spherical aberration due to using the first doublet at close conjugates. This positions the first group on the reference axis.

Next, the second group with its focusing slide is mounted on the structure. A 1.2-m convex sphere is put on the air bearing and displaced until the image stops moving. The lens mount and track are focused and centered at this position. A flat mirror is then placed on the bearing and the process is repeated at the opposite end of the focus travel. A few iterations are required to get both ends of the focus travel aligned. A 23-m convex sphere is used to check the middle of the focus slide to verify straightness.

The third doublet is mounted with the same iteration procedure. At this point the optics are aligned with the air bearing axis. The 2.8-μrad tolerance allows only 1.3 fringe departure from symmetry for all of these adjustments.

Once the LUPI, fold mirror, and air bearing have been removed, the TV camera placed at the image plane. A point source in front of the telescope is moved until its images in both the 2.5 and 7.8-m focal length modes coincide. This point on the TV is now on the previously defined optical axis.

Reference

1. Q. Appert, T. Swann, W. Sweatt, A. Saxman, "Antares Automatic Beam Alignment System", SPIE 24th Annual Technical Symposium, San Diego, California, July 28-August 1, 1980.

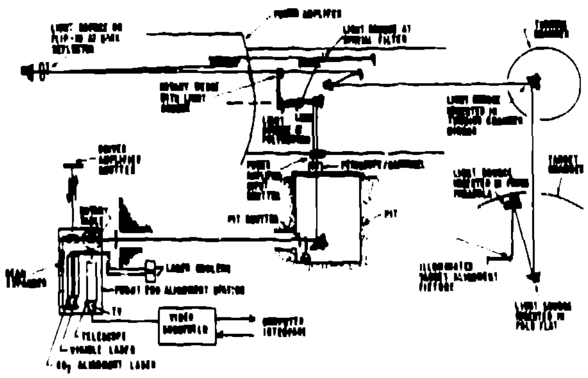

Fig. 1. Antares automatic alignment system schematic.

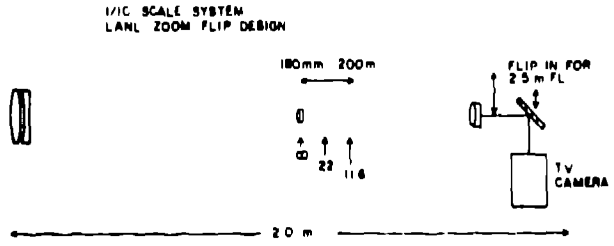

Fig. 2. Optical schematic of telescope.

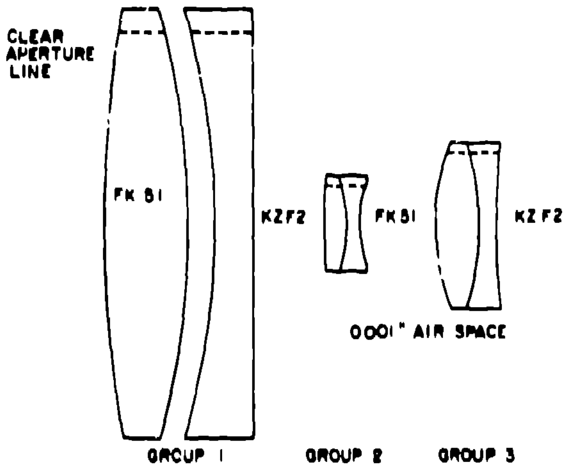

Fig. 3. Optical elements.

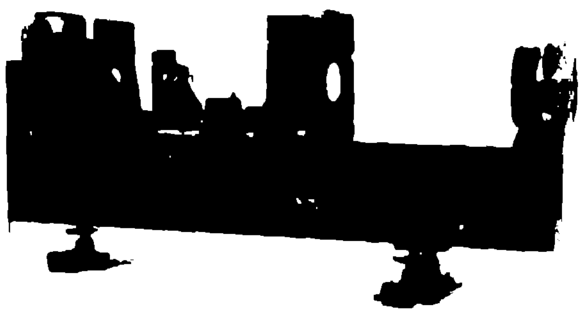

Fig. 4. Photo of finished telescope less enclosure.

Fig. 5. Objective Lens Assembly.

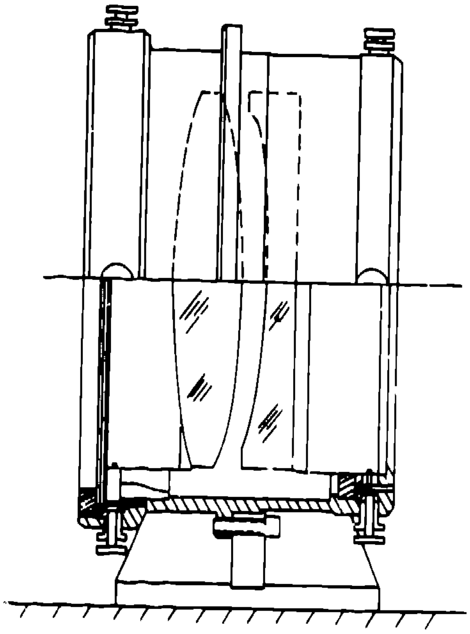

Fig. 6. Lens Assembly.

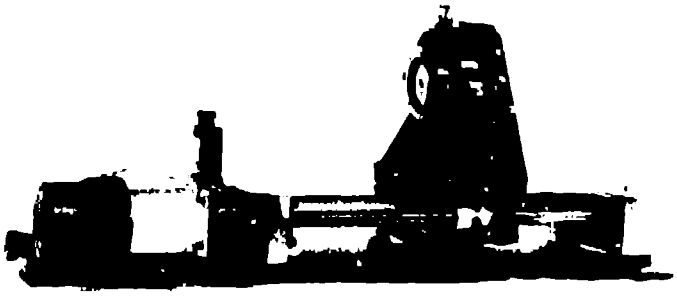

Fig. 7. Secondary Lens Assembly.

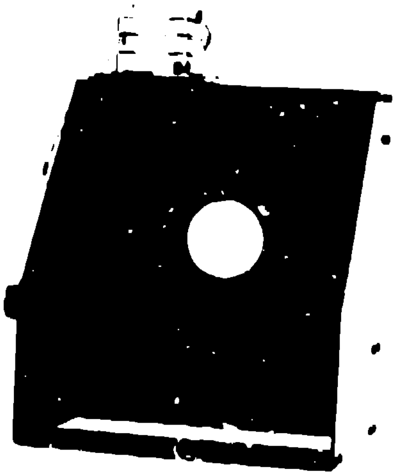

Fig. 8. "Flip-in" Lens Assembly -- IN.

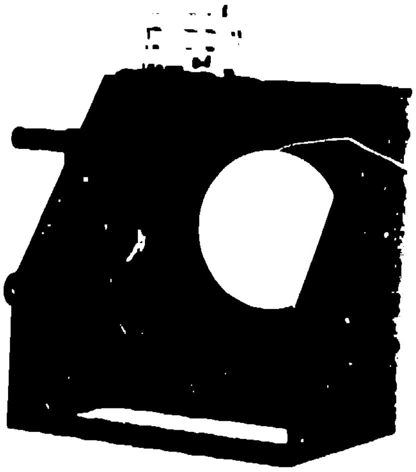

Fig. 9. "Flip-in" Lens Assembly -- OUT.

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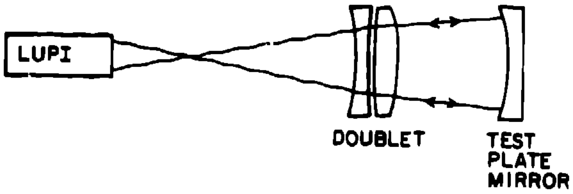

Fig. 10. Individual Doublets Test Setup.

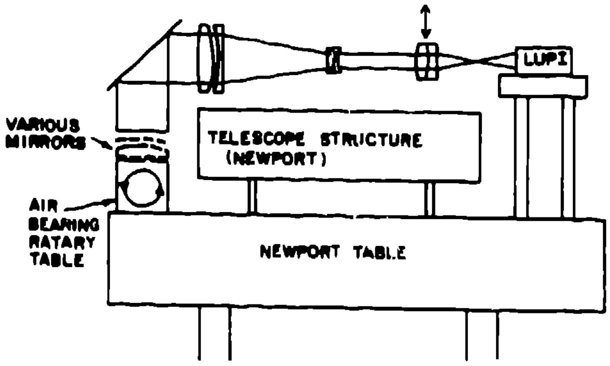

Fig. 11. System Test Setup.