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Alignment of vacuum feed stations on the Navy Prototype Optical Interferometer

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ABSTRACT

At the Navy Prototype Optical Interferometer (NPOI) we have developed a two-stage method for preparation and installation of the optical feed relay stations (elevators). This method reduces contamination, increases consistency, and allows greater management in testing and upgrades. In stage one, we prepare a pre-alignment facility in a laboratory. Using this facility we accurately position the feed stations, internal optics and detector optics relative to the NPOI array line-of-sight. The feed station is cleaned, assembled, internally aligned, tested and placed in its vacuum canister. It is stored under vacuum until transported to the array. In stage two, we align the station on the array by global five-axis adjustments of the vacuum canister. No further independent internal alignments are necessary. The canister is continuously under vacuum during global alignments. We describe the methodology and techniques for installing the optical feed stations.

Key Words: Optical interferometry, alignment

1. INTRODUCTION

The Navy Prototype Optical Interferometer (NPOI)[1], which comprises two distinct arrays, has been in operation at the Lowell Observatory site on Anderson Mesa, AZ, since 1996. The astrometric array consists of four siderostats in fixed locations forming a Y, with a maximum baseline length of 37 m. The imaging array consists of six siderostats that can be moved among 30 stations, also forming a Y, but with each arm being 250 m long. Up to three imaging siderostats can be placed on each arm. The current array configuration consists of the four astrometric siderostats, plus the first two imaging siderostats, and has a maximum baseline length of 67 m.

The light from each siderostat is conveyed into a vacuum tank (known as an “elevator can” for reasons that will become apparent) and proceeds through a vacuum feed system to the center of the array. It then is conveyed to the optics laboratory, where six periscopes rearrange and redirect the beams to the delay lines. Currently, the bottom mirrors of the periscopes direct the light into the fast delay lines (FDLs), which provide up to 35 m of continuously-variable delay. In the near future, the bottom mirrors will direct the light into the long delay lines (LDLs), which will provide delay in increments of 29 m (see Ref. 2 for a description). After two passes in each direction along the LDLs, the light beam will be directed by another mirror in the bottom of the periscope toward the FDLs.

Each of the three arms of the NPOI has three vacuum pipes arranged in a vertical plane, so the feed mirrors in each elevator can are mounted on a platform that can be raised or lowered to feed light to the desired pipe, or raised out of the beam line altogether to allow light from further out the arm to pass. Currently, all of the elevator cans have been assembled and installed, and we are proceeding with final alignment. The techniques we have developed to assemble these elevator cans in the laboratory, place them on the array, and align them to the feed system are the subject of this paper.

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14. ABSTRACT

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2. THE ELEVATOR CANS

The main function of the elevator cans is to redirect the 12.5 cm stellar light beam from the siderostat into the vacuum feed system that conveys the light into the optics laboratory. One of the major design constraints was that, regardless of the arm on which an elevator is located, the stellar beam must experience the same sequence of reflections in order to prevent polarization, polarization-dependent phase shift, and field rotation differences between the arms. (This constraint can be relaxed in only one way: successive reflections that all take place in one plane may be permuted.) For that reason, the elevator can design for each arm is unique.

Each elevator can includes three (for the west and north arms) or four mirrors (for the east arm) (see Fig. 1). The first mirror encountered by the stellar beam (the narrow-angle tracker, or NAT) is mounted in air on the top of the elevator can, and serves two purposes: directing the light straight down through a vacuum window into the can, and correcting tip and tilt variations caused by the atmosphere (the error signal is generated from a quad cell in the optics laboratory). The two or three mirrors on the elevator platform direct the light into the desired feed pipe. The NAT mirror and one internal mirror (two in the east arm cans) can be remotely adjusted with 12 V DC positioning screws. Because of the short light paths between mirrors on the elevator platform, one of those mirrors can be left without remote adjustment.

The elevator itself consists of an optical assembly standing inside the can. The assembly and the can are connected mechanically only at the base, in order to isolate the mechanism from the effects of wind buffeting the can. The assembly also includes two optical targets: an LED on a wand that can be moved into the light path, and a temporary pinhole that is used only during elevator installation. The elevator platform is raised and lowered using a lead screw powered by a 12 V DC motor [CHECK].

3. TWO-PHASE BUILD AND ALIGNMENT PROCEDURE

We have established a two-phase procedure to build and commission the elevator cans. We first build the optical assembly in the laboratory and place the vacuum elevator can around it. We then install the elevator can on the array and align the assembly as a whole. With the elevator can in its proper position and orientation, we adjust the mirror angles to center the light beam on each mirror in the optical train.

3.1. Laboratory build

The first step is building the assembly in the laboratory. Having an indoor assembly facility allows us to store and upgrade the elevator cans off the array, which avoids disrupting observations and allows us to work in clean conditions. The key concerns are:

- The mirrors must be maintained in a pristine state.
- Internal components that will be under vacuum must be clean and dust free.
- Alignments of internal components must be stable during storage and transport.
- Inspection and verification cannot reduce cleanliness.

The assembly facility accurately simulates the NPOI array geometry, allowing us to orient the assembly as it will be on the array. It consists of a concrete pier of the same size and shape as the pier at the array station, a set of precisions lines marked on the lab floor to indicate the feed beam direction and oriented to the elevator jack screw locations, and an alignment telescope stand 14 m from the pier. The alignment telescope is leveled to within 2 arcsec

We install target mirrors, which have integrated alignment marks, in the mirror mounts of the optical assembly. These target mirrors are the same size, shape, and mass as the final mirrors that will be used in actual operations. As each component is aligned, its target mirror is replaced by a final mirror. A removable template with a pinhole is left in the elevator assembly to serve as a final target for aligning the elevator can when it is placed on the array, after which it is removed. After assembly, the completed elevator can is stored under vacuum until the array station is ready for it.

A detailed list of the laboratory alignment procedure follows:

- Place elevator assembly on laboratory pier
- Precision level the elevator assembly fiducial plane to within 2 arcsec
- Install target mirror in first mount
- Focus alignment telescope on target mirror
- Adjust elevator platform height to alignment telescope
- Adjust yaw angle of alignment telescope V-block to target mirror
- Keep telescope level
- Activate LED target and focus on it
- Translate LED target to match telescope cross-hairs
- Replace target mirror with actual mirror
- Install target mirror in second mount
- Adjust first mount to align target mirror on cross-hairs, using manual adjustment screws in azimuth and elevation
- Replace target mirror with actual mirror
- Continue repeating these steps for each mirror in the chain
- Illuminate upper target pinhole using a flashlight resting on top of pinhole
- Align final mirror to target pinhole
    - Hand align mount such that illuminated target template is as close to cross-hairs as feasible
    - Use motorized adjustment screws on mount until alignment is within tolerance
- Clean and inspect all mirror surfaces and mechanical components per NPOI specifications
- Prepare and inspect vacuum shell components per NPOI specifications
- Leave upper target template installed
- Park elevator platform against internal lower cushion-stop
- Install top seal lid
- Connect internal cable harness to vacuum feed-throughs
- Install all port plugs
- Install vacuum shell per NPOI specifications
- Remove from pier, stow assembly, and vacuum test
- Maintain vacuum until installation on array occurs.

3.2. Installation and alignment on the array

The second step is the installation of the elevator can on the array. The key concerns for this step are:

- The mirrors, internal components, and alignment must be maintained in pristine condition throughout the process.
- Only gross alignments are allowed during installation: three rotations and two translations of the can as a whole (translation along the feed beam direction is not critical).
- The alignment telescope must be calibrated for each array station.
- The alignment telescope and centroiding software must be accurate to 0.1 mm.

The feed system and the elevator can are brought to atmospheric pressure. We transport the elevator can to its pier, connect it to the feed system, and pump down to vacuum (to the milliTorr level). We connect the elevator controller and raise the platform to the stow position (above all three beam lines). We then set up the alignment telescope in the optics laboratory, sight out through the feed system, and adjust the feed mirrors to bring a fiducial mark at the end of the array onto the alignment telescope crosshairs. This procedure establishes a fiducial line down the array arm to which the elevator will be aligned.

We level the elevator assembly (2 arcsec accuracy), bring the elevator can target LED into the beam line, and translate the elevator assembly transversely and vertically to center the LED target on the alignment telescope crosshairs (1.5 mm accuracy). The assembly is leveled after each translation.

We then move the LED target out of the beam and illuminate the pinhole template. The position of the pinhole image in the alignment telescope field of view with respect to the crosshairs (i.e., the position the LED occupied) indicates which combination of rotations may be needed to bring it to within tolerance (1.5 mm). If the internal alignment has not changed since assembly, only an azimuthal rotation is needed. The rotation point is directly below the LED target. Rotations of < 2 arcsec around the two horizontal axes to bring the pinhole image to the desired position are also permitted (see Fig. 2).

After any rotation, the LED target must be brought back into the beam and the elevator assembly must be adjusted in translation to re-establish its position along the fiducial beam line. We alternate between translations and rotations until we achieve satisfactory alignment. At that point, we tighten the hardware connecting the elevator to its pier to established specifications and re-check the alignment.

3. CONCLUSION

To date (mid-2004), we have installed a total of six stations and aligned them to the array. An additional 25 elevator can assemblies have been aligned in the laboratory and have been installed (but not aligned) on the array for storage. We anticipate no further design changes to the assemblies or alignment procedures.

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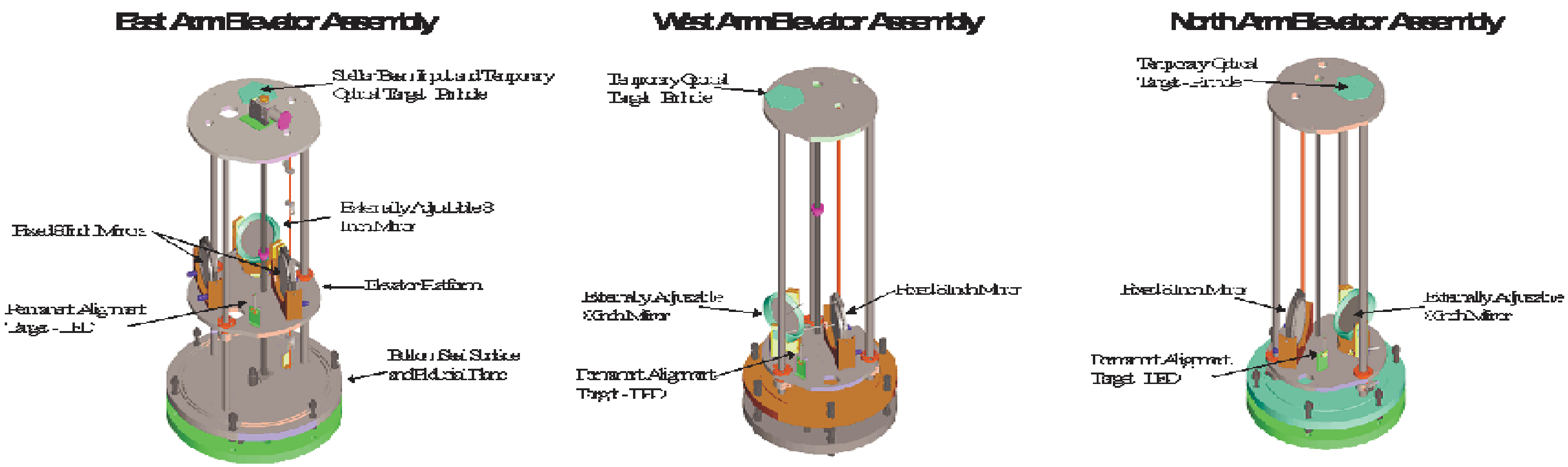

Fig. 1: Vertical and horizontal pointing drift measurements, and LDL temperature measurements, for LDL station 6 west mirror. The pointing drift was primarily vertical, and closely correlated with the temperature. The total excursion is within the pointing compensation capabilities of the NPOI tip/tilt compensation.

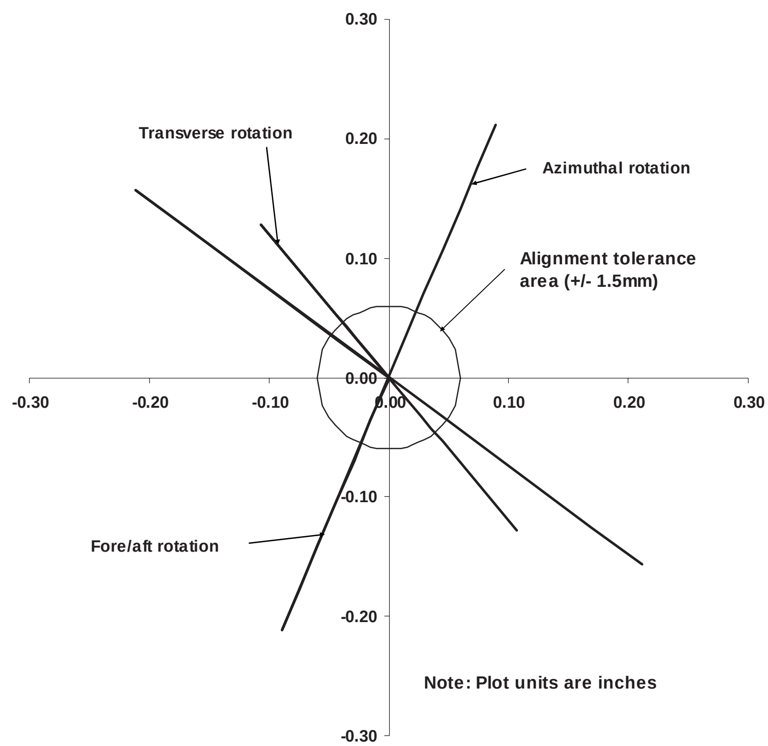

Fig. 2: Pinhole position in the alignment telescope field of view. The intersection of the axes indicates the position occupied by the LED target when it is raised into the beam line. The image of the pinhole is brought into the 1.5 mm alignment tolerance by rotations about three axes. "Transverse rotation" refers to rotation about a horizontal axis parallel to the array arm. "Azimuthal rotation" refers to rotation about a vertical axis through the LED target position. "Fore/aft rotation" refers to rotation about a horizontal axis perpendicular to the array arm. Transverse and fore/aft rotations less than 2 arcsec are permitted.