LICK APF

2.4m TELESCOPE

ALIGNMENT PROCEDURE

ASP-13964-1

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1 INTRODUCTION

1.1 SCOPE

This procedure is for the opto-mechanical and optical alignment of the 2.4m Lick APF Telescope. It utilizes standard optical alignment equipment, as well as a Shack-Hartmann Wavefront Sensor (SHWS) for final optical alignment and verification.

1.2 CONFIGURATION STATUS

This document has been configured as ASP-13964-1 and is a designated controlled document under the EOST Quality System.

1.3 REFERENCES

- ASY-5760: M1 Mirror Support Assembly
- ASY-8809: Optical Support Assembly

2 EQUIPMENT AND GENERAL PROCEDURES

2.1 EQUIPMENT

- Spindle Mirror (flat mirror with a translatable tip/tilt stage) attached to M2 Dummy Mass
- Alignment Telescopes (2)
- Large Tubular Micrometer
- Rotary Table
- Dial Indicators
- HeNe Laser
- Shack-Hartmann Wavefront Sensor
- Crosshair String

3 OPTOMECHANICAL ALIGNMENT PROCEDURE - FACTORY

This is the procedure that was used for initial telescope alignment in the factory. Section 5 describes the procedure for realignment of optics on site when they are removed for coating.

3.1 PRELIMINARY MEASUREMENTS AND SETUP

1. Prior to installing M1 in telescope, measure/calculate
   a) Height of M1 vertex above mounting interface pads
   b) Height of M1 vertex above M3 tower interface
   c) Height of mirror edges above mounting interface pads

2. Estimate height of M3 center relative to the M3 tower interface, to check for any gross error in M3 height, with the adjusters on the M3 kinematic interface set to the center of travel.

3. Calculate thickness of shims required for M1 based on height and tip/tilt

4. Set spacing of M2 based on measurements of M1 height. Nominal M1 to M2 vertex spacing is 3066 mm. Measure between mechanical surfaces, e.g., M3 tower to M2 plate

3.2 ESTABLISH ALIGNMENT SCOPE ON THE AZIMUTH AXIS

1. Azimuth and elevation axes and mirror cover controls must be working at this point. Elevation axis must be roughly set to 90°.

2. Use two translatable crosshair targets in the base of the fork to align the alignment scope. Adjust the centration of each crosshair until it is stationary with rotation of the azimuth axis as viewed through the alignment scope. Then adjust the alignment scope to center both crosshairs.

3.3 ALIGN M1 AND M3 TOWER

1. Install M1 center target assembly

2. Adjust M1 centration to get the target crosshairs centered on the alignment scope

3. Set up an alignment scope off-telescope, aimed at the gap between the center section and LSF. Set the micrometers to 0,0.

4. Hold a ruler at the near edge of the primary (on the high point where the bevel starts, not the outside edge). Focus on the ruler with the AScope and read the height at the crosshairs. Try estimating to the nearest 0.25 mm or better. You can place the ruler directly on the mirror if you handle it carefully. Do not tape a huge amount of foam on the ruler, which would affect the measurement.

5. Rotate the telescope 180 degrees. Repeat (4).

6. Remove the ruler and adjust telescope elevation. Angle should be height difference divided by ~2340 mm (2350 - bevels). Try half way for starters. Iterate steps 4-6 until it's level.

7. Install M3 tower. String crosshairs on top

8. Adjust tower to center crosshairs on alignment scope

9. Define the final elevation position to be zenith (i.e., use the actual elevation numbers rather than 90° for the rest of this procedure)

3.4 ALIGN M2 QSTT AND M2 SPINDLE MIRROR

1. Set the elevation to zenith°. This must be accurately defined (previous section).

2. Adjust the M2 QSTT (Quasi-Static Tip Tilt mechanism) angle. Install crosshairs in two places on the QSTT, as far apart as possible. Using the spiders, adjust the QSTT until both crosshairs are centered on the alignment scope. Replace the M2 plate and check that the M1-M2 spacing is still correct. Adjust spacing and iterate QSTT alignment if necessary.

3. Set the M2 kinematic interface (tip/tilt) adjusters and M2 support decenter adjusters to their center of travel. Set the QSTT settings to 0.

4. Install the spindle mirror. Adjust the tip/tilt, using the spindle mirror adjusters for large changes and the QSTT for fine adjustment, until the retro-reflection is centered on the alignment

scope. Then adjust the spindle mirror centration, using the spindle mirror adjusters, until the crosshairs are centered on the alignment scope. The spindle mirror is now aligned to the azimuth axis and will be used as a reference for future alignments. The alignment scope may be removed if needed for other alignments.

3.5 ESTABLISH ALIGNMENT SCOPES ON THE ELEVATION AXIS

1. Use translatable crosshair targets mounted on the elevation bearings

2. Adjust the centration of each crosshair until it is stationary with rotation of the elevation axis as viewed through an alignment scope. Then adjust each alignment scope to center both crosshairs. This should be done as carefully as possible

Both alignment scopes will be used to align M3. The alignment scope in the non-drive (instrument) side will also be used to align M2. The alignment scope in the drive side will also be used to align the autoguider breadboard and possibly the customer's instrument.

3.6 ALIGN M3 AND ROTATOR

1. Install M3 rotator with laser mount

2. Adjust tip/tilt of rotator until laser stays at the same level on the center section as the mirror is rotated. This may be done with the telescope pointing to horizon. Temporary paper targets should be attached to the center section, to enable marking and measuring of the beam height.

3. Install M3

4. Adjust rotator tip/tilt to get the retro-reflection (off the M2 spindle mirror) centered on one alignment scope

5. Check the retro-reflection on the other alignment scope

6. Iterate tip/tilt of the rotator and M3 until the retro-reflection is centered on both alignment scopes

7. Adjust the height of the M3 to get its crosshairs centered (in the elevation direction) on one of the alignment scopes. Adjust M3 tip/tilt to keep the retro-reflection centered

8. Adjust decenter of the M3 tower to get the M3 crosshairs centered on the alignment scope in the cross-elevation direction

9. Fine adjust the height of M3 to get the M2 spindle mirror crosshairs at the same distance from the alignment scope crosshairs on both alignment scopes. (Note that the M3 crosshairs will no longer be centered.) Adjust M3 tip/tilt to keep the retro-reflection centered

10. Adjust decenter of the M3 tower along the elevation axis to center the M2 spindle mirror crosshairs on one of the alignment scopes. Check that they are centered on the other alignment scope.

11. Steps 9 and 10 may be reversed and/or iterated as needed

12. Check retro-reflection and fine adjust M3 tip/tilt if necessary

If any error is not totally correctable, optimize using the alignment scope on the non-drive (instrument) side.

3.7 ALIGN M2

Use the non-drive (instrument) side alignment scope.

1. Remove the spindle mirror and install M2

2. Adjust the QSTT tip/tilt to center the retro-reflection on the alignment scope

3. Fine adjust M2 using the lateral stages (set screw adjustments) to center its crosshairs on the alignment scope

4. Check retro-reflection and fine adjust QSTT tip/tilt if necessary. Set tip/tilt values as defaults (zero position) in the software configuration file

3.8 ALIGN AUTOGUIDER BREADBOARD

This may be done after Optical Alignment if necessary.

1. Use alignment scope mounted on drive side tine, aligned to elevation axis as accurately as possible (from earlier procedure)

2. Install breadboard

3. Install camera and lens mount on-axis. A target may be useful for the lens.

4. Set breadboard height and angle to get them centered on the alignment scope. A level may be useful for setting the angle

5. Install camera and lens mounts at correct location

6. Install fold mirror

7. Adjust fold mirror tip/tilt and location to get camera and lens centered on the alignment scope

8. Pin the breadboard to the brackets

4 OPTICAL ALIGNMENT PROCEDURE

4.1 ALIGN SHACK-HARTMANN WAVEFRONT SENSOR

1. Install the SHWFS and mount on the elevation bearing. Set the image plane (field stop) distance to 619 mm.

2. If feasible, use the alignment scope on the opposite (drive) tine to center the field stop. Use the linear stage(s) on the SHWFS mount. Change telescope elevation to rotate the SHWFS.

3. Use a star image to center pupil on SBIG camera (using SHWFS tip/tilt adjustment). Iterate with step 2 if necessary.

4.2 SET FOCUS COMPENSATION WITH TEMPERATURE

1. Initially use an estimate of the CTEs along the effective path length between the M1 and M2 vertices

2. Fine tune the compensation value during SHWFS measurements, over the rest of this procedure, by comparing required focus settings to the temperature logs. Note that the SHWFS must remain installed in order to tie focus settings together, since the SHWFS mount is not kinematic and the M2 position will have to be adjusted if the SHWFS is removed and reinstalled.

4.3 ALIGN TELESCOPE

1. Adjust M2 focus to zero focus Zernike term. Initially, take wavefront measurements at two different focus settings and use difference in Zernikes to establish the correct scale factor.

2. Adjust M2 tip/tilt to zero coma Zernike terms. Initially, take wavefront measurements at two different tip or tilt settings and use difference in Zernikes to establish the correct scale factors.

3. Adjust M2 decenter to minimize astigmatism Zernike terms. Use intuition and/or ZEMAX for guidance. Move M2 using the M2 decenter adjusters (if possible) or the spiders. If spider adjustment is necessary, remove the M2 and replace with the spindle mirror, and use an AScope to assess the amount of decenter and monitor/maintain tip/tilt as the spiders are moved. Repeat measurements and iterate as needed.

4.4 SET TIP/TILT/FOCUS COMPENSATION WITH ELEVATION

1. Take SHWFS measurements while tracking a star over a wide range of elevations.

2. Calculate required tip/tilt/focus correction as a function of elevation and enter into telescope configuration file.

3. Repeat SHWFS measurements over a wide range of elevations.

4. Iterate as needed.

5 ON SITE REALIGNMENT PROCEDURE

This is the procedure for realigning the optics, e.g. before/after recoating.

For all measurements of a retro-reflection, the AScope micrometers should be set to 0,0.

5.1 M1 RECOATING

The only special precaution required when removing the M1 for recoating is to mark the shims to ensure that they are reinstalled at the same locations and with the same orientations.

The M1 has a diamond mark scribed on it, corresponding to the position of the diamond pin on the mirror support, to ensure that the M1 is clocked correctly when reinstalled on its support. (Otherwise, the mirror could be clocked ±120° from its correct position.)

The M1 support is pinned to the LSF, and the LSF pinned to the center section, so both will relocate to the same position. No position adjustment is necessary (or possible, without removing the pins).

5.2 M2 RECOATING

The M2 position is repeatable if kept on its support. If the mirror must be removed from the support for coating, the position may shift slightly and the procedure below should be followed to maintain its alignment. Make sure that the clocking of the mirror on the support is not changed.

This is most easily done with an AScope having an attached video camera. The target locations can be marked on a video monitor. Otherwise, the AScope lateral position may have to be adjusted to get the targets within the limited range (typically ±0.052”) of the micrometers.

1. Set up an AScope on the drive side tine, if possible on the elevation axis of the telescope using e.g. a target in the instrument or better yet crosshairs on the elevation bearings, if available. It may be necessary/convenient to manually rotate the M3 by 90° during this step, to enable viewing of objects on the opposite (instrument) tine.

2. Focus AScope on the retro-reflection from M2. Adjust the AScope tip/tilt and/or fine adjust the QSTT (noting the change in tip/tilt values so that they may be undone later) to get the retro-reflection centered on the AScope (with the micrometers set to 0, 0).

3. Focus AScope on the M2 fiducial. Mark the location on the video monitor, or measure the offset using the micrometers on a non-video AScope. (The latter may require decenter of the AScope to get within the limited range of the micrometers.)

4. Mark the M2 so that it will be clocked correctly when reinstalled.

5. Remove the M2 from the support, recoat, and reinstall. Do not allow any personnel near the telescope during this time, as disturbing the AScope will destroy the alignment reference.

6. Focus AScope on the retro-reflection. Use the QSTT (or manual tip/tilt adjusters if the change is significant) to center the retro-reflection on the AScope/monitor.

7. Focus AScope on the M2 fiducial. Using the adjusters, adjust M2 centration to put the fiducial at the correct location on the video monitor or centered on the AScope crosshairs with the crosshairs at the previously measured position.

8. Undo any QSTT adjustment that was made in (2).

5.3 M3 RECOATING

Removing M3 may have a slight effect on mirror centration, but this will only shift the beam footprint on the mirror and will have no effect on telescope alignment.

Removing M3 may have a minor effect on mirror tip/tilt but this should have a negligible effect on telescope alignment. If there is any concern about this, the alignment can be adjusted using the procedure below.

This is most easily done with an AScope having an attached video camera. The target location can be marked on a video monitor. Otherwise, the AScope lateral position may have to be adjusted to get the target within the limited range (typically ±0.052”) of the micrometers.

1. Set up an AScope on the drive side tine, if possible on the elevation axis of the telescope using e.g. a target in the instrument or better yet crosshairs on the elevation bearings, if available. It may be necessary/convenient to manually rotate the M3 by 90° during this step, to enable viewing of objects on the opposite (instrument) tine.

2. Focus AScope on the retro-reflection from M2. Adjust the AScope tip/tilt and/or fine adjust the QSTT (noting the change in tip/tilt values so that they may be undone later) to get the retro-reflection centered on the AScope (with the micrometers to 0, 0).

3. Remove the M3 from the support, recoat, and reinstall. Do not allow any personnel near the telescope during this time, as disturbing the AScope will destroy the alignment reference.

4. Focus AScope on the retro-reflection from M2. Using the manual adjusters, adjust the M3 tip/tilt to get the retro-reflection centered on the AScope.

5. Undo any QSTT adjustment that was made in (2).

5.4 SPIDER ADJUSTMENT

Under normal operation, adjustment of the spiders will not be necessary. These comments are provided for general guidance in case a significant change to the telescope is made (e.g., if a different M2 is installed).

If the spiders must be adjusted, remove M2 and replace it with a Spindle Mirror on the dummy weight for all spider adjustments.

The separation of M1 and M2 must be maintained (unless the focus needs to be changed, e.g., when installing a different M2). This is best done using a tubular micrometer held between two mechanical surfaces. The most convenient surfaces may not be between M1 and M2, e.g., the back surface of the QSTT and a beam on the dome may be used, if the predicted change in the separation due to expected temperature fluctuation is not significant.

Align an AScope on the elevation axis (as discussed in the previous sections) and record or measure the location of the Spindle Mirror fiducial and retro-reflection. Move the spiders the desired amount with respect to the fiducial reference. After each decenter adjustment, adjust the tip/tilt with the spiders to get the retro-reflection back to the same location. This will prevent introduction of a significant angle to the QSTT.

6 CUSTOMER INSTRUMENT

This is a possible procedure for the customer to use after Site Acceptance Testing, before the alignment scope, mount, and alignment targets are removed from site.

1. Use alignment scope mounted on drive side tine, aligned to elevation axis as accurately as possible (from earlier procedure)

2. Install atmospheric dispersion correctors (ADCs). Set ADCs spacing appropriately, to give desired beam shift during alignment (e.g., middle of range or middle of typical range). ADCs must be installed *after* alignment scope.

3. Translate instrument to center target/slit on the alignment scope.