Magellan II
Telescope Cell
Manual

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1. Introduction

This manual provides information for the 6.5m mirror and telescope cell, and actuator test stand for the Magellan telescope. The various subsystems, their function, calibration, assembly / disassembly, and troubleshooting guide are provided to assist with the operation of the system.

In addition to this manual the entire mechanical and electrical drawings for the components and assemblies of the system are available at the Steward Observatory web site (www.as.arizoan.edu) in the Drawing Archive area.

2. Principles of Operation

2.1. System Description

The mirror cell system is a complete turnkey system that provides all the necessary hardware and software to support the mirror in the telescope system. The system requires the user to provide pressurized, clean air (nominally 130 psi), and two 20 amp, 115 Vac services to provide power to the air control box and to the computer system. Temperature controlled fluid is required for the thermal control system, but this is not part of the turnkey system.

The software required to run the system is supplied in PROMs installed in the main CPU. These PROMs contain all the software necessary to run the system, but provide nominal settings that allow safe, but not necessarily optimized, operation.

Communications with the system is provided through an Ethernet connection to the computer. Control of the cell as well as gathering information on the status and various parameters relating to the performance of the system is accomplished through the Ethernet connection.

The system supports the mirror by the use of 104 force servo controlled pneumatic actuators, and positions the mirror via six hardpoints configured in a Stewart platform arrangement (essentially three attachment points to the cell and six attachment points to the mirror). The six degrees of force (forces and moments acting in the three planes of space) are derived from loadcells mounted in line between the hardpoints and the mirror. The servo system treats the mirror as a free body mass and varies the forces commanded to the actuators to maintain near zero forces and moments acting on the mirror due to gravity, telescope accelerations and wind loading.

2.2. Subsystems Descriptions

2.2.1. Actuators

There are two basic types of actuators used in the system, single and dual axis. The single axis units provide force parallel to the optical axis of the mirror only. The dual axis units have a cylinder identical to a single and a cylinder providing force at a 45° angle. The force exerted by the dual unit is the combined vector force of the normal and 45° cylinders.

The actuators are comprised of a dual ported diaphragm air cylinder with an integral shaft, two voltage controlled pressure regulators and an S beam load cell for each cylinder and an electronics PC card.

The pressure regulators provide pressure to both sides of the cylinder in a differential manner to allow both compression and tension forces. A bias pressure is applied by both pressure regulators at all times, equal in both regulators for a zero force command.

The load cell provides a force feedback to the analog servo on the PC card. The force servo for each actuator is referred to as the inner loop. Each cylinder in a dual actuator is a separate independent servo loop. The overall force vector required is computed in the main CPU and distributed to each individual cylinder. The electronics card also provides DC-DC converters to supply logic voltage and precision excitation voltage for the load cell. Each card is supplied with 48 VDC and a command voltage for each cylinder on the actuator. The card provides a force feedback from the load cell to the main CPU. This allows the computer to verify the force command sent to each actuator.

The actuators are plumbed with a quick disconnect for servicing the unit. A 10 micron filter is also provided in the air supply line prior to the regulators to help prevent contamination entering the regulators.

Each actuator attaches to the mirror through a single puck or through two-puck or three-puck loadspreaders. All dual actuators attach to the mirror through a three-puck Loadspreader. On single actuators a pressure relief valve is attached to the actuator to prevent excessive force being applied to the mirror.

2.2.2. Hardpoints

There are six hardpoints in the cell to provide positioning of the mirror and the loadcell feedback to provide the forces and moments acting on the mirror to the outer servo loop. The hardpoints are designed to breakaway when the force in either tension or compression acting on the hardpoint exceeds a certain level. The exact breakaway force varies slightly between tension and compression and from one unit to the next, but is primarily determined by air pressure applied to the hardpoint.

The hardpoints have a roller screw with a gearbox and stepper motor drive attached to provide a means for changing the length of the hardpoint. The length feedback is provided to the computer by an LVDT. A loadcell is attached in line between the hardpoint and a glass wedge mounted to the mirror. This loadcell provides a force feedback to the main CPU that allows the computer to calculate the forces and moments acting on the mirror. The outer loop servo attempts to zero these forces and moments by applying force to the individual actuators.

A proximity switch is mounted to the hardpoint and interfaced to the stepper motor driver and the main computer to provide travel limits for each of the hardpoints.

The hardpoint is also equipped with a counterweight mechanism that negates the gravity effects of the weight of the hardpoint itself upon the loadcell reading. Effectively this system allows the hardpoint to appear to be weightless to the loadcell. The counterweighting system consists of two weights that apply varying loads to hardpoint as the elevation angle of the cell is changed.

2.2.3. Static Supports

The static supports interface to the mirror through bolts that are attached to the three-puck loadspreaders. The static support provides a limit to the range of motion of the mirror in all directions and provides a safe platform for the mirror to set down upon should the support system fail to support the mirror for any reason.

The unit is adjustable from beneath the cell top plate and is accurately positioned in each location to ensure that the static supports contact the bolts at as close to the same point in motion to provide equal loading on all bolts.

2.2.4. Thermocouples

There are 112 Type T thermocouples (TCs) located in the mirror and cell to provide temperature information for the thermal control system. In the mirror selected cells have three TCs mounted on the back of the faceplate, the sidewall and the top of the backplate. One TC is located in each of the separate bays inside the cell weldment. The remaining TCs are on the top plate of the cell below the mirror and around the perimeter of the top of the cell weldment to provide ambient temperature feedback.

The TCs in the mirror, on the plate, and reading ambient are fed through 50 pin D-subminiature connectors in the top plate of the cell. When installing or removing the mirror, the connectors attached to the TCs mounted in the mirror need to be connected / disconnected.

All TCs are fed to a common Isothermal Junction Block (IJB) where the conversion from TC wire to copper wire is made. The IJB temperature is measured via an AD590 current source. The TCs are multiplexed and input to the 16 bit ADC.

2.2.5. Support Air Control

The compressed air is divided into five separate feeds, four sectors to supply air to the support actuators and one feed to all six hardpoints. The air supply and 48 VDC Power supplies are separated into four sectors and then distributed to the actuators such that like color actuators are not clustered together. This is done so that if any one of the power supplies fails then the mirror will not be damaged, but will remain supported so that the mirror can be brought down in a controlled fashion.

Due to the color of the tubing used to plumb the air to the actuators the loops are referred to as the Red, Blue, Orange and Yellow loops. When the system is given a command to turn the air on, each of the loops is brought up one at a time, the actuators in that loop are commanded and evaluated for proper operation prior to the next loop being pressurized.

Each of the sector air supplies is controlled by the computer through a solenoid valve. The hardpoint supply is also regulated to provide the correct air pressure to the hardpoints for proper breakaway operation. When a condition is detected in the system that indicates a component failure or other dangerous loading to the glass the computer will immediately vent the air supply to the actuators through the Air Control solenoid valves.

The Air Control Box requires a separate 120 VAC supply for proper operation of the system.

2.2.6. Computer System

The computer box houses the main VME computer chassis, the four 48 VDC power supplies for the actuators, a triple supply that outputs +5 VDC and +/- 15 VDC logic supplies to the computer system, a +\- 12 VDC supply for the VME bus and hardpoint loadcells and LVDTs, and a +20 VDC supply for the hardpoint stepper motors.

An interface panel on the computer box and a similar one located on the side of the cell provide a means for interconnecting the computer to the cell.

The computer consists of a Motorola MVME-167 CPU, an Acromag 9330 16 bit ADC used to read the hardpoint loadcells and LVDTs and the TCs, and an IP carrier with DIGI-48 I/O modules and a 12 bit ADC for reading the actuator force monitors, a Steward Observatory built IP Translation board that handles the watchdog timer, control logic addressing, integrator lockout signals and line drivers, and eight Steward Observatory built DAC cards that provide the DC command signal to each of the actuators.

Located within the cell weldment are sector distribution cards that distribute power and the DAC output commands to each of the actuators, a cell distribution card, a set of sector distribution cards and a force monitor card that multiplexes the force monitor signals from each of the actuators. Mounted near each of the hardpoints are the amplifier for the loadcells, the demodulator card for the LVDTs and the driver for the stepper motor.

3. Cell Assembly Procedures

3.1. Mirror Installation and Removal

3.1.1. Vacuum Lifting Fixture

3.1.1.1. Preparation and Check-out

These are general guidelines to be used when setting up and checking out the 6.5m Vacuum Lifting Fixture. This procedure takes for granted that good plumbing techniques have been followed during initial set-up of the fixture.

1. Mechanical set-up.
2. All bolts must be torqued to their proper values during assembly.
3. All plumbing fittings should be doped, not taped, during assembly. Experience has shown that tape can clog the orifices in the vacuum pumps.
4. Apply anti-seize compound to the center pivots on the 6 substars (spherical bushings) before assembly.
5. Apply Anti-seize compound to the ball ends of the pad pivot bolts during assembly.

6. When installing the pads, run the nut down so bolt threads just show at the top of the nut.
7. During initial set-up, the pad mounting angles must be adjusted for a good fit (normal) to the mirror surface.
8. Plumbing.
9. Quality pipe thread sealant should be used for assembly rather than Teflon tape.
10. Baggies or some suitable substitute must protect all couplings during assembly, as dirt will prevent good connections and cause accelerated leak rates.
11. Plumb the pads in pairs, color coded to each vacuum sector. Each substar should have 3 colors of plumbing run to it, with same-color substars at 120 degrees to each other.
12. Cable ties should be used to secure loose hoses to the fixture.
13. Run the pumps individually to test for performance.
14. Electrical connections must be made following good, standardized practices.
15. Overnight testing of the system attached to the mirror is mandatory. Check for tools on the fixture before attaching it to the mirror.

3.1.1.2. Attachment to Mirror

1. Attach crane scale plus the 3-to-6 legged, color-coded sling to the crane. The order of assembly is as follows: hook, large 55 ton shackle, crane scale, small 55 ton (red and yellow) shackle, 3-to-6 legged color-coded sling. Shackles on the end of the 6 legs should be the large 12 tons followed by the small alloy 12.5 tons. These are what connect to the vacuum lifting fixture.
2. Attach the lifting fixture to the rigging and lift. Level fixture to within .25 inch with shot bags.
3. Clean the lifting fixture (usually with rags and compressed air outside).
4. Verify all connections from the mirror to the cell are disconnected.
5. Record the scale reading. It should be approximately 15,800 lbs.
6. Rotate substars so the Alpha designations are facing out and are centered on the 18-inch beam.
7. Tilt the substars 7 degrees and stabilize with bungee cords.
8. Record the scale reading. Again, it should be apx. 15,800 lbs.
9. Check the fixture for tools, etc.
10. Tare out the crane scale to read zero.
11. Check all 6 ball valves to insure that they are closed.
12. Close master bleed valve.
13. Perform final inspection of mirror surface for particles.
14. Set vacuum pump power switches to ‘on’ position.

15. Vacuum pump vacuum/release switches to release (this blows air out the pads).
16. Master power switch off.
17. Plug in the master power box to 3 independent circuits.
18. Master power switch 'on' (this stars the pumps).
19. Master bleed valve open (this clears all vacuum from the reserve tanks).
20. Master power switch off.
21. Center the fixture to the mirror (2mm) without contacting the mirror surface.
22. Master power switch 'on' (pads should be blowing air out).
23. Lower the lifting fixture until the ball bolt nuts (they attach the pads to the spider) have about .5 inch gap between them and the spider arm. Do not rest the fixture on the mirror. The crane will read approximately –1000 lbs.
24. Check to see that all the ball bolts are perpendicular to the mirror surface and centered in their holes. Minimum .25 inch clearance.
25. Master power switch off.
26. Adjust the ball bolt nuts so that they all have approximately 1.5-inch gap between them and the substar.
27. Record the crane scale reading.
28. Set the vacuum pump vacuum/release switches to vacuum.
29. Record all 6 vacuum readings.
30. Jog master switch for 5 seconds and check for contact at both the vacuum pad and the substar interface. No contact is allowed. Repeat until 15 inches of vacuum is achieved, checking contact and that the sectors are within 2 inches of vacuum to each other. Once 15 inches is achieved, more than 2 inches difference between sectors is allowed. Re-adjust crane if necessary to keep ball bolt nuts evenly spaced.
31. Check that all ball bolts are perpendicular and centered.
32. Turn the master switch on for 10 minutes.
33. Record all 6 vacuum readings.
34. Let sit for 10 minutes.
35. Raise crane to where the ball bolt nuts are about to contact substars.
36. Adjust ball bolt nuts by hand until all are evenly tight.
37. Record all 6 vacuum readings. If any have dropped appreciably, detach lifting fixture by procedure "Releasing From Mirror" and repair.
38. Turn the master switch on for 30 minutes.
39. Set master switch off.
40. Record all 6 vacuum readings.
41. Let sit for 4 to 16 hours. If any circuit has dropped more than .25 inch per hour, find and repair leak. Do not purposely release one sector. If release is necessary, accomplish using release procedure.
42. Record all 6 vacuum readings.
43. Set master switch on for 30 minutes.

44. Record all 6 vacuum readings. At this point, vacuum must exceed 24 inches.
45. Make sure of emergency set-down procedure.
46. Lift the mirror, stopping for frequent inspections for interference.
47. When the mirror is free of all supports, record crane scale.
48. Level mirror with shot bags and record final weight. Failure of one vacuum sector can be tolerated when the mirror is on the crane. If two sectors fail, the mirror must be set down on the foam pads with all deliberate haste. A vacuum sector is considered failed when it has less than 10 inches of vacuum on the gauge. The fixture should be detached by following "Releasing From Mirror" if two or more circuits have failed.

    Failure of individual or total circuit power does not mean the vacuum circuit is in immediate danger. The leak rate test will allow 24 hours before you must set the mirror down. The mirror should not be left unattended. Check the vacuum gauges and the pump operation every 30 minutes. Extended periods of hanging the mirror with pumps operating is quite safe. It is better, however, to run the pumps for 10 minutes every hour rather than to leave them running for extended periods, although running the pumps for days is safe. If one pump fails but the vacuum is intact, open the ball valve between the 2 sectors and turn on the active pump. **Do not open all 6 valves.**

3.1.1.3. Releasing From Mirror

1. Set the mirror down according to the appropriate procedure.
2. Lower the fixture until there is .5 inch of clearance under the ball bolt nuts. Do not allow the fixture to rest on the mirror. The crane scale should read 0 pounds.
3. Remove all of the mirror leveling shot bags. Leave the fixture leveling bags.
4. Set the mast power switch to off.
5. Open all 6 ball valves.
6. Open the master bleed valve.
7. Keep checking the clearance between the pads and the substars. Do not allow contact. Adjust crane height if required.
8. Once the system is down to 2 inches of vacuum, it is safe to leave the fixture hanging for extended periods unattended. If the fixture is to be lifted off, continue with the procedure.
9. Turn master power switch off.
10. Set all 6 vacuum/release switches to 'release'.
11. Return the master power switch to the 'on' position.
12. With the pumps still running, lift the fixture away from the mirror.
13. Turn the master switch off.

3.1.2. Transport Box

3.1.2.1. Installing Mirror

Personnel required: 1 crane operator, 1 inside spotter and 6 mirror spotters. Set-up vacuum lifting fixture attached according to procedure "Attachment to Mirror".

1. Place the 6 mirror spotters around the mirror. Place spotter on ladder in center hole.
2. Place 6 PVC tubes between mirror and cell walls, spread evenly around the circumference.
3. Read the crane scale. This should be 0 or some small negative number.
4. Set the master power switch on.
5. Take up load with crane (it should lift around 20,000 lbs).
6. Lift the mirror slowly from the cell, checking for any dangling items that may catch. Crane operator should watch for any sudden changes in crane scale reading.
7. Lift mirror clear of cell and transport box.
8. Place cell on appropriate supports.
9. Install transport box onto aircraft using required supports.
10. Inspect all interfaces, box and mirror for interference.
11. Center transport box under mirror.
12. Lower mirror to 1 inch above interfaces. Adjust in X, Y and rotation until good fit is achieved.
13. Loosen interface bolts and raise them to meet the mirror.
14. Install 2 bolts in each interface and tighten.
15. Unload crane onto the box, watching for any interference.
16. Remove lifting fixture by following procedure "Releasing From Mirror".

3.1.2.2. Removing Mirror

Set-up: The vacuum lifting fixture is attached according to procedure "Attachment to Mirror". All aft and side covers, and the box lid, must be removed before starting.

1. Place the spotters around the mirror at the 6 substars. These spotters should be looking at the blue interface arms during the lift.
2. Place the inside spotter where they can see the mirror surface and all 6 substars. This spotter is looking for any problems with the substars or the vacuum pads on the mirror.
3. Crane scale should be set to zero or, if using a hydraset, not the starting value. The Magellan I primary mirror weighs 21,400 lbs.
4. Remove all the 3/8-inch bolts holding the blue transport box arms to the mirror loadspreaders.
5. Double check that all bolts have been removed.
6. Take up mirror load on the crane in slow speed. Crane operator must watch the scale or hydraset for any sudden load changes.

7. The mirror should clear the supports when the scale reads the above noted weight.
8. Remove and store with the box hardware the special aluminum interfaces attached to 4 mirror loadspreaders. These stay with the box.
9. Once clear of all blue box interfaces, lift the mirror clear of the box extension arms located at the 4 corners of the box frame before translating the mirror in X or Y.

   Keep all box hardware together. After the mirror is clear of the box, remove all 3/8-inch hex bolts from both the 3-puck and 2-puck loadspreaders. These are for transport only and are not used in the telescope. Include this hardware when the box is returned to the Mirror Lab. Re-install the box lid and aft and side covers as soon as possible to keep the box clean.

3.1.3. Mirror Installation Procedure

The purpose of this section is to describe the standard installation procedure for the 6.5m primary mirror into the Magellan I telescope cell.

The procedure assumes that the vacuum fixture has been installed and checked out following the appropriate procedure. The cell has been checked for any obstructions such as tools, etc. on the cell faceplate. Any bent ventilation nozzles have been removed as they can be caught by loadspreaders as the mirror is lowered into position. Tuck the thermocouple wires up inside the mirror to keep them from dangling in the way.

Personnel: 1 crane operator, 1 inside spotter, 1 procedure person and 6 mirror spotters

1. Locate the 6 spotters around the cell so they have access to the top of the cell and can see down into it.
2. Position the inside spotter in the center hole of the cell.
3. Have the mirror spotters install the lightweight PVC bumpers down the side of the cell. These will protect the mirror from contacting the cell.
4. Remove the mirror from the transport box using procedure "Removing Mirror".
5. Remove all 3/8-16 hex bolts from the loadspreaders. These were installed for shipping only.
6. Check all of the mirror interfaces to be sure they are clear of any obstructions.
7. Center the mirror over the cell by eye.
8. Clock the mirror to the cell using hardpoint locations as reference.
9. Lower the mirror to 12 inches above the cell.
10. Install 3 plumb bobs at 3 single-axis actuator locations, using the interface on the mirror as the center for the bob. These bobs will center the mirror more precisely. Allow 3 feet of line between the bobs and the mirror.

11. Adjust X-Y of the mirror for centering of the plumb bobs in the cell faceplate perforation.
12. Lower the mirror slowly to 6 inches above the static supports, watching the crane scale or hydraset value at all times.
13. Remove the thermocouple connectors from their respective holes and lay them on the cell faceplate so they are out of the way of the descending mirror.
14. Have the inside spotter perform a thorough visual inspection to assure there is no interference.
15. Lower the mirror to 1mm above the static supports, watching the crane scale or hydraset value at all times.
16. Install 3 guide rods into 3 loadspreader puck locations 120 degrees apart around the outer edge of the mirror. Small adjustments in X, Y and clocking may be needed.
17. Using the slowest crane speed, lower the mirror to contact the static supports.
18. Watching the value of the crane scale or hydraset, unload the mirror weight plus 1000 lbs. onto the cell. This should be done with the 6 mirror spotters now watching the vacuum lifting fixture substars.
19. Remove the vacuum lifting fixture from the mirror using procedure "Releasing From Mirror".
20. Clear lifting apparatus from the mirror before proceeding.
21. Remove the PVC bumpers from the cell.
22. Install static support bolts. This should be done in a systematic way. Torque the bolts to 15 ft/lbs.
23. Install all remaining ventilation nozzles.
24. Install the 6 hardpoints by following procedure "Hardpoints Installation".
25. Install the actuators using procedure "Actuators".
26. Connect thermocouple connectors.

The Mirror systems are now ready for checkout using the appropriate procedures.

3.1.4. Mirror Removal Procedure

The purpose of this section is to describe the standard removal procedure for the 6.5m primary mirror from the Magellan I telescope cell. The procedure is essentially the reverse of the installation procedure, with some of the mirror guiding and alignment steps removed.

The procedure assumes the vacuum fixture has been attached to the mirror and checked out following the appropriate procedure. It is also suggested to weigh the fixture and note the value prior to removing the mirror.

Personnel: 1 crane operator, 1 inside spotter, 1 procedure person and 6 mirror spotters.

1. Remove all the bent air nozzles from the cell
2. Disconnect the thermocouple connectors attached to the mirror thermocouples.

3. Remove the static support bolts. This must be done in a systematic way to ensure that no bolts remain in the cell. This should be double and triple checked by various individuals. A single or a few bolts remaining attached to the mirror could cause severe damage to the mirror when lifting with the crane.
4. Disconnect and remove the six hardpoints following the reverse of the "Hardpoints Installation" procedure.
5. Remove all actuators from the cell following the reverse of the procedure in the following section "Component Installation Procedures-Actuators"
6. Install the PVC bumpers between the cell and mirror to protect the mirror from contacting the cell when removing it.
7. Attach the lifting fixture to the mirror using the procedure "Attachment to the Mirror" in the Vacuum Lifting Fixture" section 3.1.1.2.
8. Watching the crane scale or hydraset, load the crane to the weight of the lifting fixture.
9. With the spotters in place around the perimeter of the mirror/cell slowly increase the crane load until it has been loaded to the weight of the fixture plus mirror. As the weight is increased the static supports should deflect up as the mirror weight loading them is reduced.
10. Once the crane has been loaded to the fixture plus mirror weight, using the slowest possible crane speed, slowly lift the mirror until it can be verified that the mirror is free of all static supports.
11. After it is verified the mirror is completely free of the static supports the lifting fixture / mirror can be lifted out of the cell. Once clear of the cell remove the PVC bumpers and tuck the thermocouple wire / connectors into the mirror to prevent damage.

3.2. Component Installation Procedures

3.2.1 Actuators

These procedures cover the installation procedures for all 6.5m telescope cell actuators. It is assumed that the person performing this operating has some working knowledge of the cell. A more experienced person must supervise anyone performing this operation for the first time.

3.2.1.1. Dual-axis and Cross-lateral Actuators

1. Loosen actuator electronics board screws (4) and let the board dangle to the side of the assembly.
2. Install the actuator onto the installation jack on the proper interface.
3. Position actuator under the location to be installed.
4. Orient the actuator by checking which way the actuator should face (top or bottom horizon pointing) or sideways for the 4 cross-laterals.
5. Carefully raise actuator with the jack, watching for interference with cables, hoses, pipes or the cell itself.

6. When close enough, engage the locating pins by pushing the actuator into position by hand. This prevents bent pins and is **very** important.
7. Install the 4 hold-down bolts.
8. Torque the bolts to 15 ft/lbs.
9. Make the interface connection by pushing up on the ends of the 2 cylinder rods until you feel the pins engage the interface.
10. Install two (2) 3/8-16 s.s.s.h.c.s. and torque to 15 ft/lbs.
11. Tuck the loose load cell cables into the cavity in the actuator and install the electronics board.
12. Install the proper airline connection by reading the connector i.d. number and matching it to the actuator being installed. Do the same for the electronics connector.
13. Do a visual check to make sure no wires or airlines are pinched.
14. Actuator installation is now complete.

3.2.1.2. Single-axis Actuators

1. Verify that the correct actuator is being installed.
2. Check that a trantorque is installed on the end of the actuator interface stud.
3. Locate the actuator to the interface pins by hand, watching that the trantorque fits up into the mirror interface.
4. Install three (3) 3/8-16 s.s.s.h.c.s. and torque to 15 ft/lbs.
5. By hand, push the rod of the air cylinder up until it bottoms out.
6. While holding the rod up, reach up above actuator and tighten the trantorque.
7. Install the proper airline connection by reading the connector i.d. number and matching it to the actuator being installed. Do the same for the electronics connector.
8. Do a visual check to make sure no wires or airlines are pinched.
9. Actuator installation is now complete.

Removal of actuators is performed by simply reversing the appropriate procedure given above.

3.2.2. Hardpoints

The purpose of this procedure is to describe the hardpoint installation and adjustment procedure for the 6.5m telescope cells. This document assumes a working knowledge of the cell by the person performing the operations. A more experienced person **must** supervise anyone performing this operation for the first time.

3.2.2.1. Installation

1. Identify the correct hardpoint for the location to be installed.
2. Check that the correct flexure is installed on the upper and lower hardpoint interfaces. These are numbers to correspond to the hardpoint they go with.
3. Install protective shims in the lower fixture. These protect the flexure from being bent. This is very important.
4. Install the hardpoint onto the jacking fixture with the motor up.
5. Verify that the upper and lower clamps match the hardpoint to be installed.
6. Verify that the zenith and horizon counterweight arms are ready to be connected. They should be close to the position in which they normally rest.
7. Check that the horizon weight is free to move. The zenith weight arm should be clamped in such a way that it is in the center of it's range-of-motion.
8. Position the hardpoint under the location to be installed.
9. Raise the hardpoint slowly, watching for any interference that might occur.
10. Maneuver the hardpoint over the lower flexure. Done properly, the lower connection should drop down onto the seat of the lower flexure while the upper connection is in line with the upper flexure.
11. Adjust tilt until upper connection is aligned, but do not make the connection.
12. Install the lower clamp, but do not tighten at this point.
13. Attach the horizon and zenith counterweight connections.
14. Remove the safety strap on the transmission jack.
15. Check that the hardpoint is now floating on the zenith counterweight.
16. Adjust the clocking of the hardpoint to approximately 90 degrees on the side of the counterweight connection plate.
17. Snug up the lower clamp.
18. Remove the transmission jack.
19. Make the upper connection by pushing out the end of the hardpoint (breakaway) until it seats on the upper flexure.
20. Install the upper clamp, but do not tighten.
21. Adjust the clocking again to 90 degrees on the side of the counterweight connection plate.
22. Tighten the upper and lower clamps.
23. Remove the protective shims from the lower flexure.
24. Connect the breakaway air supply. It is the clear airline.
25. Connect the load cell and the hardpoint electronics.
26. Hardpoint is now installed.

3.2.2.2. Hardpoint Counterweight Balance Adjustment

1. Install hardpoint following the above procedure thru step #18.
2. Install the counterweight balance adjustment weight. Note: This is a weight that is clamped to the hardpoint at a specific point to represent the weight of the upper flexure assembly, which needs to be accounted for in the counterweight trim weight assembly.
3. Install enough trim weights to make the hardpoint float.
4. Remove the protective shims from the lower flexure.
5. Check the balance again and adjust if needed.
6. Make the upper connection by pushing out the end of the hardpoint (breakaway) until it sits on the upper flexure.
7. Install the upper clamp, but do not tighten.
8. Remove the counterweight balance adjustment weight.
9. Adjust the clocking again to 90 degrees on the side of the counterweight connection plate.
10. Tighten the upper and lower clamps.
11. Remove the protective shims from the lower flexure.
12. Connect the breakaway air supply. It is the clear airline.
13. Connect the load cell and the hardpoint electronics.
14. Hardpoint is now installed.

3.2.2.3. Load Cell Calibration

The hardpoint loadcells are mounted in a housing that provides the mechanical interface to the mirror and hardpoint. This housing, however, imparts a force on the loadcell that is measured at all times and would appear as an offset in the outer loop servo. In addition the weight of the load cell and housing hanging off the mirror is also measured by the loadcell. It is therefore necessary to null this offset so that the outer loop servos to a true zero load acting on the mirror.

1. Attach the six loadcells assembled in the flexure housing assembly to the primary mirror.
2. Connect the hardpoint loadcell cable from the loadcell to the preamplifier.
3. The loadcells should not be connected to the hardpoints, but be free hanging with the computer system powered up and running.
4. After logging into the cell computer at the prompt type in the command show_hplc.
5. A list of six rows of numbers will be displayed beginning with ch0 and ending with ch5. The value associated with each channel should be recorded.
6. In the cell_setup.c file and array called "hppreload[]" should be modified to reflect the numbers previously recorded. This will be the new offsets for the hardpoint loadcells.

7. After making and saving the changes the software should be rebuilt using the "make" command.
8. Any time that a hardpoint loadcell is changed or has to be disassembled from its housing this procedure must be repeated to prevent a bias occurring in the outer loops.

3.2.3 Thermocouples

The only issue regarding installation of the thermocouples is to connect the mirror thermocouple D-subminiature connectors to the mating connector on the interface plate of the cell top plate when the mirror is installed or disconnecting them prior to mirror removal from the cell. All other thermocouples are already installed in the system when it is delivered. There are six interface plates with 12 D-sub connectors in the top plate. Most of these connectors are for mirror thermocouples and the remaining connectors are for ambient and upper plenum thermocouples.

3.2.3. Computer System

The computer system box must be mounted to the side of the cell with the hardware supplied and mounted on the cell. The set of cabling that runs from the computer box to the cell interface plate is labeled at each end and also keyed such that there is only one configuration allowable. The keying prevents the cable ends from being swapped and also from installing the wrong cable to the connectors on the interface plates. Care should be taken, however, to avoid forcing the connectors into a mating connector that is not keyed properly and to avoid dropping the connector housing which could result in damage to the connector preventing it from mating.

3.2.5. Static Support Adjustments

This section covers the installation and adjustment of static supports in the 6.5m telescope cells. Current assembly drawings must be in hand to use this procedure. The endnotes are specific to the Magellan I installation at the site and should be used only for that application.

3.2.5.1. Installation

1. Install 3 static supports around the 3-puck loadspreader location. Leave the ¼-28 screws loose.
2. Place actuator locating jigs in the location being installed and the location adjacent it.
3. Insert the 2-inch pipe locators. These are part of the jig assemblies.
4. Install the static support jig onto the 2 pots. The jig should slide down over the posts.
5. Move the static supports around until they line up with the 3 holes in the jig plate.

6. Insert locating pins through the jigs and into the static supports.
7. Tighten the hold-down screws of the static supports.
    9. Remove the jigs and repeat until the entire cell is populated.

3.2.5.2. Height Adjustment

1. The cell must be level with respect to gravity to perform this adjustment.
2. Install the auto-level (or some other like instrument) in the center hole of the cell.
3. Take and record the heights of the reference pads located around the outside of the cell faceplate.
4. Install height gauge onto a static support.
5. Using the drawing and known offset, adjust the interface bolt up or down to achieve the appropriate height.
6. Lock the adjustment in place using the 2 brass nuts.

Note: For the adjustment to be made for Magellan I when it arrives at the site, the height needed is 2.77mm above the current set plane. This will position the mirror vertex to the value set forth in the Technical Specifications, Document #95PR0014, page 3, para. 1.2.

4. Operating Procedures

4.1. Initial Start-up Procedure

The recommended start up sequence for the mirror support system is to energize the two 120 VAC power feeds, allowing the computer to fully boot and then apply the 130 psi pressurized air to the system. It is not absolutely necessary to follow this sequence, but in the event of a problem with the computer no air, and therefore no force, can be applied to the mirror.

4.2. General Operating Procedures

All mirror control functions, system status, parameter values and bias values to the nominal force set can be interfaced to the system via the Ethernet connection and the two ports described in the following section. In general the cell is provided with a pre-established operating position that effectively centers the mirror in the cell. The raise command will raise the mirror to this operating point and close the outer loop servos automatically. Other inputs allow the mirror to be lowered in a control fashion, or provide a panic command that sets the mirror down on the static supports rapidly by venting the pressurized air to the system.

Other functions in the command set allow for various parameters in the system to be monitored, gathering of data while the system is operating to gauge the performance of various aspects of the system, and to set various user adjustable parameters in the system.

4.3. Computer Interface

4.3.1. Operational Commands

In order for external systems to communicate with the mirror cell, a set of network interfaces have been implemented in the control software. These interfaces monitor two TCP/IP ports, awaiting commands from the external system, and responding to them as appropriate. The ports defined for these purposes are: 5800 for "normal" requests and 5801 to request various error data.

Commands are passed to the mirror cell by using defined symbolic constants to represent the commands. The commands recognized by the mirror cell and the symbolic constants associated with them are defined in the file cell_net.h and summarized below. The table below also details any arguments that are passed along with the command and the responses that are returned by the mirror cell system.

4.3.1.1. Port 5800 Command Summary

CMD _ RAISE – Raise the mirror into operating position. No arguments
CMD _ PARK – Lower the mirror back to it's "parked" position. No arguments
CMD _ PANIC – Cause a "panic stop". The mirror is parked and all control loops are terminated. No arguments.
DO _ FADC – Perform a single ADC time series. Single parameter is the number of seconds to run the series. Return values are the number of data points collected.
DO _ TRAN – Parameter are the number of seconds and the amount of bump to apply. Returns the number of data points collected.
DO _ VTRAN – Perform a more verbose version of the DO_TRAN command. Parameters are the number of seconds, followed by the amount of bump to apply. Returns the number of data points collected.
DO _ FAST – Execute a faster version of the DO_TRAN command.
SET _ FAST _ HZ – Set the number of samples per second to be taken when the DO_FAST command is executed.
DO _ STIFF – Perform a hardpoint stiffness test. No arguments
GET _ STATUS – Request mirror cell to return current system status. No arguments. Returns a structure with all available status information.
SET _ MON _ AVG – Set the averaging value for force monitors.
GET _ ACTLOC – Get an actuator location number.
GET _ TIME – Takes no arguments and causes the mirror cell to return the time stamp of the last time it was rebooted, along with the current time from it's internal clock.
GET _ MON – Get force monitor data.
GET _ SNAP – Get the last set of force monitor data.

GET _ PANIC – Request information regarding latest cell "Panic". No arguments. Return a string, explaining the cause of the panic.
GET _ RAPID – Retrieve a rapid data sample.
GET _ PSI – Get sector air pressure monitor readings.
GET _ HPSI – Get hardpoint air pressure monitor readings.
START_SLEW – Begin collecting slew data. Takes no parameters and returns no values.
STOP _ SLEW – Stop collecting slew data. No parameters and no return values.
DO _ SLEW – Perform "slew". Single-parameter is the number of seconds the slew is to last. Returns data similar to DO_TRAN command.
CLR_ADJ – Discard soft force adjustment values.
ZAP_ADJ – Discard both soft and hard force adjustment values.
PUT_AADJ – Change actuator Z force adjustment value for a single actuator.
PUT_ZADJ – Change global actuator Z force adjustment value.
GET_POS – Get mirror position.
GET_HPLVABS – Get absolute hardpoint LVDT readings.
GET_MAGIC – Get LVDT "magic point" values.
SET_MAGIC – Change LVDT "magic point" values.
GET_HPLV – Get hardpoint relative LVDT readings.
GET_HPLC – Get raw load cell readings from hardpoints.
GET_FORCE – Get resolved load cell readings from hardpoints.
GET_OLCMD – Get outer loop command vector.
GET_ANGLE – Get mirror elevation angle information.
GET_STUFF – Get VMON and other system status information. No parameters
GET_VTEMP – Get raw voltage readings from thermal system.
GET_MTEMP – Get measured temperatures from thermal system.
GET_TTEMP – Get filtered temperatures from thermal system.
GET_ACTU – TBD
GET_ACTA – TBD

4.3.1.2. Port 5801 Command Summary

GET_ECOUNT – Get current error count.
GET_ERRORS – Get current error count and error details.

5. Troubleshooting

5.1. Actuators

Improper functioning actuators are indicated by the software and are recorded in the error log. This error log entry indicates the actuator location number and the problem that has been detected. After diagnosing and repairing the problem a bump test should be performed on the actuator to verify that it is operating correctly. In extreme cases it may be necessary to recalibrate the unit on the test stand.

1. Actuator will not respond
    - At the servo card verify the 48VDC supply voltage is present. If not check the fuse at the sector distribution box and replace if open.
    - Verify the DC / DC converter is outputting +/- 15VDC. If the voltage is not present then verify that the output is not shorted and if not it would indicate the converter has failed.
    - At the servo card verify that a command is present. If not check the output at the DAC card in the computer and/or verify continuity in the cabling.
    - At the servo card verify that the loadcell feedback is present. If not check the loadcell connections and verify that U6 and/or U12 is functioning properly on the card.
    - Verify that the integrator lockout signal is present. If not verify the output at the computer.
    - Verify the operation of the air pressure regulators.
2. Actuator slow to respond
    - Verify that the integrator lockout signal is present on the servo card.
    - Verify the operation of the air pressure regulators
3. Actuator out of control
    - Verify that the +/- 15 VDC is present on U6 and U12.
    - Verify the operation of U6 and U12.
    - Verify the proper excitation voltage for the loadcell.
    - Verify the load cell connections at JP4 and JP5 (not used on singles).
    - Verify that the DAC command is present at the servo card. If not check the DAC output in the computer chassis.

5.2. Hardpoints

The hardpoints provide a force feedback to the outer loop through the hardpoint loadcell. The units also position the mirror in the cell by changing length. The length of the unit is changed by a stepper motor and drive and the length information is fed back to the computer system by an LVDT.

1. Hardpoint will not extend or retract.
    - Verify the presence of the +5 VDC and +20 VDC power supplies are present at the motor driver.
    - Verify the proper operation of the proximity limit switches and limit circuit relays. Replace if required.
    - Verify that step pulses are present at the driver on JP1-3. If not present check the cabling and the IP-Translation board.
    - Verify the presence of the enable bit signal on the driver at JP1-6. If not present check the cabling and the IP-Translation board.
    - Verify the operation of the opto U1 on the PC board at the driver and replace if necessary.
    - Verify that the motor and coupling are positively engaged.
    - If all previous checks are verified, replace the motor driver.
2. No LVDT position feedback.
    - Verify the presence of the +/- 15 VDC supplies at the LVDT demodulator board.
    - Verify the continuity of the demodulator board cabling from the LVDT.

- Verify the continuity of the cabling from the demodulator to the computer.
- Verify the Acromag 9330 ADC operation.
- If all previous checks verified replace demodulator board.

5.3. Thermocouples

The thermocouple monitoring system consists of 112 Type T thermocouples, an isothermal junction block (IJB) with integral multiplexer board and an AD590 current source temperature transducer for measuring the IJB temperature.

1. No temperature readings.
- Verify that all cables are properly connected to the IJB.
- Verify the presence of +5 VDC and +/- 15 VDC supplies are present on the Mux board.
- Verify the presence of the address and control signals to the Mux board.
- Verify the operation of the instrumentation amplifier on the Mux board.
- Verify the AD590 operation.
2. Thermocouples read –999
- This is an indication of an open thermocouple or an invalid AD590 output. Verify the connections at all locations (i.e. the Mux board, top plate D-sub connectors, miniature TC connectors, etc.) and the operation of the AD590.

5.4. Computer System

The computer enclosure houses the main computer, and all of the power supplies for the cell. The power supplies are monitored by the computer via the voltage monitor card and will indicate when there is a problem with any of the power supplies. The supply outputs should also be verified by a voltmeter if problems are indicted to verify the out of range condition of the power supply.

For diagnosing problems with the VME bus based boards refer to the operations manual for the respective card. For the Steward Observatory built cards refer to the appropriate schematic to assist in diagnosing problems.

5.5. Air Control

The air control system consists of five pressure transducers, a control board and four AC operated air solenoid valves.

1. Air is not provided to the cell
- Verify that all interface cables are connected properly and that the green LED is lit on the control board.
- Verify the presence of 120 VAC at the air control box.
- Verify that air is being supplied to the main manifold.
- Verify that the cell computer has not caused the air system to shut down due to an error somewhere else in the cell.
- Verify the operation of all pressure transducers and / or the hardpoint pressure regulator.
- Refer to schematic gcar411a.sch to assist in diagnosing problems with the air control board.

6. Recommended Spare Parts List

The mirror support system is designed to provide failsafe operation in the event of a component failure. Should a device fail the system will no longer be fully functional and, depending on the nature of the failure, may prevent use of the system in the telescope. Due to this fact it is recommended to have at least on spare unit of the following parts on hand to allow timely repair of the system and minimal down time of the telescope. The list is divided into two broad categories, commercially available parts and those manufactured exclusively by Steward Observatory.

Commercially available parts:

- Motorola MVME-167 CPU
- Acromag 9330 16 bit ADC
- Greenspring VIPC-610 IP Carrier board
- Greenspring IP-Digital48 Digital I/O module
- Greenspring IP-Unidig24 Digital I/O module
- Greenspring IP-Precision 12 bit ADC
- Vicor VI-PA22-EWW +/- 15 VDC Power Supply
- Acopian USC-150-401 +5 VDC, +/- 12 VDC Power Supply
- Acopian BFS-200-20 +20 VDC Power Supply
- American Precision CMD-40 Stepper Motor Driver
- Lucas-Schaevitz LVM-110 LVDT Demodulator
- Swagelock EB-45XF8-53BD Air Solenoid
- Belofram 962-312-00 I/P500 Air Regulator (Hardpoint Air)
- Belofram 962-312-000 T1000 (I/P500) Air Regulator (Actuators)
- Speedaire (Granger part # 1A483) filter
- Controlair DE-L-XX-UM Mod#178 Air Cylinder
- Aurora MW-3T-C3 and MM-3T-C3 Rod Ends (Hardpoint Breakaway)
- INA GT-21 Ball Decoupler Bearings

Steward Observatory manufactured parts

- DAC card
- IP Translation Board
- Sector Distribution Card
- Cell Distribution Card
- Force Monitor Card
- Temperature Mux Card
- Single Axis Actuator Servo Card
- Dual Axis Actuator Servo Card
- Hardpoint Stepper Motor Interface Card
- Ball Decoupler Flexure MAG0160, MAG0165

7. Test Stand

7.1. General Description

The test stand provides a means for calibrating the single and dual axis force servo actuators. The unit consists of a steel structure with six integral loadcells mounted to the structure in such a manner that the three forces and three moments that the actuator can produce are measured. The stand allows for mechanical adjustment of the actuators to minimize the non-controlled stray forces that can be potentially generated as well as for verifying the accuracy of the servo-controlled forces. It also provides a volts per pound gain for each actuator that is used in the cell control software.

7.1.1. Test Stand Sign Conventions

1. +X is toward you.
2. +Y is to your right.
3. +Z is down.
4. +Mx is right hand rule about +X.
5. +My is left hand rule about +Y.
6. +Mz is left hand rule about +Z.

7.1.2. Criteria

1. Force measurement accuracy is 1 part in 1200.
2. Axial force accuracy is 0.2 lbs at zenith.
3. Uncontrolled lateral forces must not exceed 1.3 lbs at zenith and 2.6 lbs when horizon pointing.
4. Moments, Mx, My and Mz must not exceed 177 in-lbs over +/-0.12 inches of travel.
5. Single-axis/single-puck limits are 106 in-lbs. After subtracting out the position effect (0.12*300 lbs = 36 in-lbs) we are left with 70 in-lbs as the single-axis actuator allocation and 141 in-lbs for duals (test limits are 50 and 75 in-lbs, respectively).
7. Dual-axis cross coupling (Fz, Fy) is 1.3 lbs at zenith and 2.6 lbs at horizon.

7.1.2.1. Rejection Criteria Implementation

Rejection of an actuator against the criteria cited above can occur at the following steps of the calibration procedure:

7.1.2.1.1. Single-axis Actuators

1. Reject if [Fx], [Fy] > 0.5 lbs when Fz is 0 or 100 lbs or [Fx], [Fy] > 0.75 lbs when Fz is +400 lbs.
2. Reject if [Mx], [My]. [Mz] > 50 in-lbs when Fz = 100, 0 or +400 lbs.

7.1.2.1.2. Dual-axis Actuators

1. Reject if [Fx], [Fy] > 0.5 lbs when Fz is 0 or [Fx], [Fy] > 0.75 lbs when Fz is +400 lbs.
2. Reject if [Fx], [Fy] > 0.5 lbs when Fy is 0 or [Fx], [Fy] > 1.5 lbs when Fy is +400 lbs.
3. Reject if [Mx], [My]. [Mz] > 75 in-lbs when Fz = +400 lbs.

7.1.2.1.3. Calibration Test

1. Reject if Fz error exceeds 61.0 lbs at Fz = 300 lbs after calibration.
2. Reject if Fz error exceeds 61.0 lbs at Fz = 300 lbs after calibration.

7.2. Software

7.2.1. Description

Two separate programs are provided for the test stand. Both programs are loaded into system memory at the time the stand is powered up and are available from command line.

The first is called calib, and is used to calibrate the test stand. It provides a set of commands that are useful for getting load cell data from the test stand in a couple of useful forms. The calibration procedure is usually done only once, when the stand is first built, to determine the gain factors for the load cells mounted on the stand and to insure that the stand is functioning properly.

The second program is the actual program for testing actuators. It is available in two different forms, depending on whether you are accessing the test stand from an X-terminal in an X-windows session or some form of VT100 terminal or terminal emulator. If using an X-terminal, the test is started with the x_test command. If a VT100 is being used, then the command is v_test.

7.2.2. Calibration

The object of the test stand calibration is to obtain the load cell values produced from a calibrated loading of the test stand and to use these values to derive the matrix used in the actuator calibration software. This matrix converts the test stand load cell values into X, Y, Z forces and moments.

The calibration of the test stand is accomplished by applying a series of known forces and moments to the interface plate. Each load vector produces a set of load cell voltages which are converted to forces. Given a minimum of six loads and corresponding force vectors, a matrix is determined that will convert an arbitrary force vector into a load vector. In this way, the telescope actuator can be mounted to the stand and its action can be precisely converted to forces and moments.

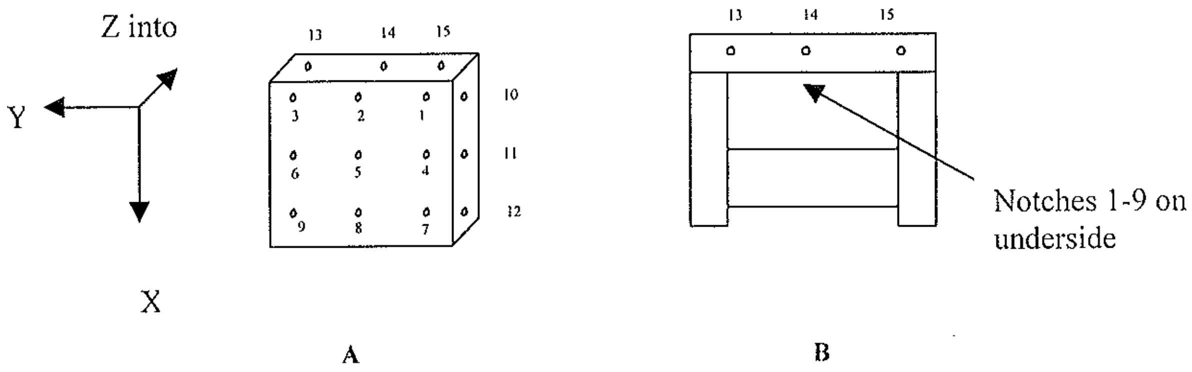


Figure 1
A. Notch designations on notch plate of reference block
B. Side view of reference block

7.2.2.1 Definitions

Mathcad Program file- tstand.mcd. The program that derives the matrix requires Mathcad 2000 software.

Mathcad input files- Two files, tstand.prn and notches.prn. If using the same reference block then notches.prn remains unchanged. The tstand.prn file contains the load cell data taken at each of the reference block notches during the calibration. The tstand.mcd reads these 2 files in order to derive the matrix.

Reference block- the 6" x 8" x 9" block made out of plates screwed together containing the notches for load points in calibration. Notches 1-9 are on the underside of the main plate, notches 10-12 on one edge of the same plate and notches 13-15 on another edge of the same plate.

C-pendulum- The hook that seats into a notch on one end and attaches to the weight, chain and shackles at the other end.

Load cell and axes convention:

Matrix column	1	2	3	4	5	6
Load cell channel	0	1	2	3	4	5
Load cell number	3	4	5	6	7	8
Axis (matrix)	Z	Z	X	X	Y	Y
Axis (actuator)	Z	Z	Y	Y	X	X

Note: The matrix axes are the axes used when performing the test stand calibration. This is the axes convention that the Mathcad program uses. After the matrix is derived, and the matrix is then entered into the actuator calibration software, the Fx and Fy rows must be swapped, and the Mx and My rows must be swapped. This is the axes convention the actuator calibration software uses. For the remainder of this section the axes convention referred to is the matrix derivation axes convention.

Loading of all notches puts the corresponding load cells into tension. Refer to the figures showing the three orientations of the test stand during calibration.

Loading notches 1-9 results in +Z force.
Loading notches 10-12 results in +Y force.
Loading notches 13-15 results in a +X force.

Case	Notches used					
Case 1	1	3	8	10	12	14
Case 2	2	7	9	11	13	15
Case 3	2	6	7	11	13	15
Case 4	3	4	9	11	12	13
Forces	f1	f2	f3	f4	f5	f6

7.2.2.2 Calibration Procedure

1. Hook up computer, monitor and test stand
2. Load software –readV and –setZero
3. With unloaded test stand plate, command readV
4. Check each load cell with a voltmeter. Verify the voltmeter agrees with the readV values.
5. Load test stand plate and repeat step 4, verifying that the voltmeter agrees with the readV values.
6. If the voltmeter does not agree with the readV values check the load cell amplifiers and verify that the unused inputs in the ADC inputs to the computer are grounded.
7. Apply tension and compression to each loadcell and verify that the voltage reads positive in compression and negative in tension.
8. With a precise scale weigh the calibrated weight, shackles, chain and C-pendulum.
9. Measure the notch placement relative to the test stand / actuator '0'. This means measuring all the piece parts and adding up the X, Y and Z distances from the '0' point. The '0' point is the center of the top of the test stand interface plate.
10. Attach reference block to the test stand interface plate using four long screws and an open ended wrench.
11. Use eyebolts and crane to lift and rotate test stand to desired orientation (see figures 2-4).
12. Set test stand on three metal stands and shim between the stand legs and the floor to prevent wobble in the stand.
13. Use a precision 6" long level to level the test stand, placing the level on the reference block notch plate.
14. Use wooden door shims and a mallet to achieve leveling.

15. Connect the C-pendulum to the weight using the small chain and shackles. Make sure the weight is on a small rolling jack.
16. Make sure the level and any other miscellaneous hardware has been removed from the test stand.
17. Make sure the electronics have been powered up for at least 10 minutes before taking measurements to minimize any drift in the electronics.
18. Command setZero to zero out the test stand
19. Us the small rolling jack to maneuver the weight into place.
20. Attach C-pendulum into the notch of choice for the test. Make sure that the extra chain length is piled up on top of the weight. Also make sure that the weight is not touching the metal stand legs.
21. Pull out the jack and steady the weight.
22. Re-level using the precision level, mallet and shims.
23. Steady weight.
24. Command readV. Record the displayed voltages (not the forces). Take three readings for each notch and average. Each sample also averages 20 readings.
25. Roll jack back in, lift the weight and take the C-pendulum off the test stand completely.
26. Command setZero. Make sure no hardware is till on the stand.
27. Repeat steps 20 – 26 for each notch required for the current orientation.
28. Reorient the stand in the next configuration and repeat the measurement procedure.

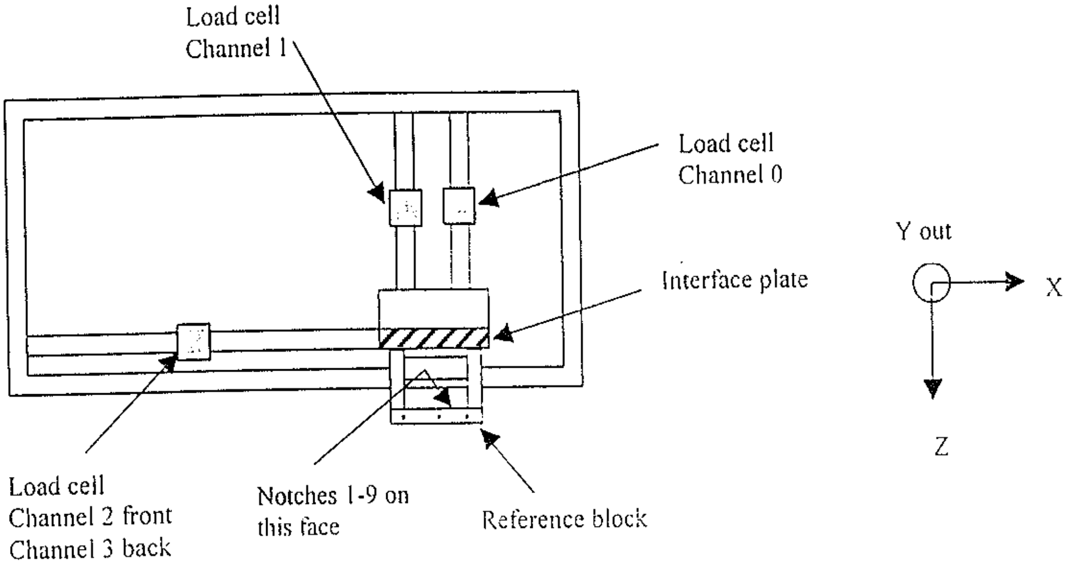


Figure 2 (above)
Orientation 1: Notches 1-9, loading +Z direction

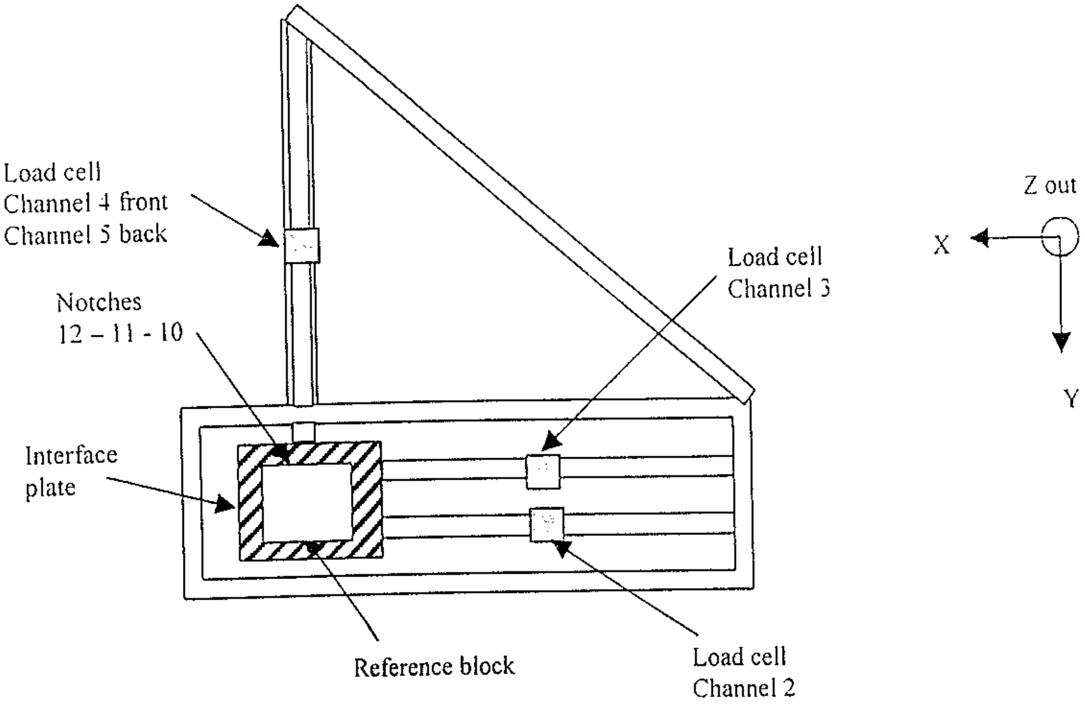


Figure 3 (above)
Orientation 2: Notches 10-12, loading +Y direction

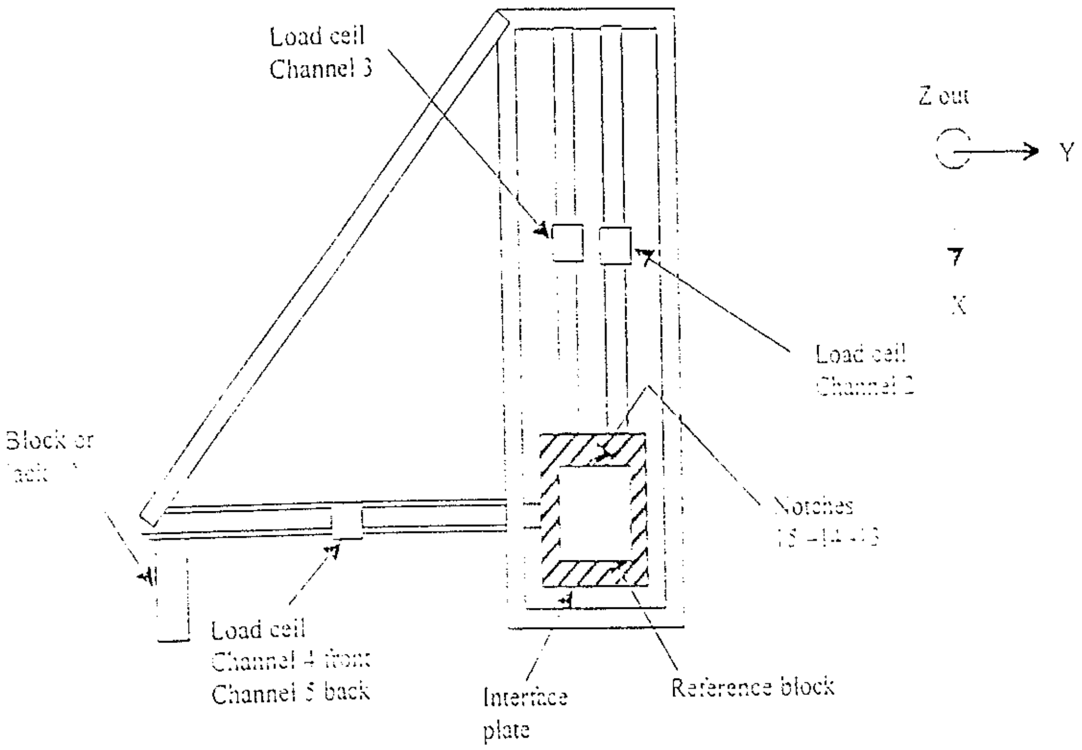


Figure 4 (above)
Orientation 3: Notches 13-15, loading +X direction

7.2.2.3 Matrix derivation procedure

1. Obtain the latest of the following Mathcad files:
    - tstand.mcd
    - tstand2.mcd
    - tstand3.mcd
    - tstand4.mcd
    - tstand.prn
    - notches.prn

   Note: Mathcad cannot open the .prn files, use a text editor
   If the .prn file is rename, then the tstand.mcd file that reads the .prn file must be edited to correspond to the change in the file name.
2. Revise the tstand.prn file to reflect the values obtained during the calibration for each notch location.
3. Revise the tstand.mcd file as follows:
    - revise the name of the .prn file being read if necessary
    - Revise the weight value if required
    - Revise xoff, yoff and zoff if required
    - If changing the set of notches being read in, revise the $F_{1,i}$ = force $_{1,i}$, etc. and the $L_{1,i}$ = L1 $_{1,i}$, etc. and rename file.
4. After having created the four tstand.mcd files corresponding to the four notch set cases, print out pages 8-9 (containing the matrix and the residual error matrix) for each file.
5. Compare the 'Resid ^{T} =' matrix of each of the four notch set cases. Highlight all values above 0.2. Note the number of values above 0.2 in each error matrix. Note the overall highest value in each error matrix.
6. Choose the best matrix based on residual error.

7.2.2.4. Matrix calculations.

- What does the Mathcad file do? It creates a matrix, that when multiplied by the 6 test stand load cell readings, gives a product that is the X, Y and Z forces and moments.
- The solver works by taking the load cell readings from 6 notch locations,

(load cell readings of notches 1, 3, 8, 10, 12, 14)
$L^3{}_2 = L^{\text{notch loc.}}{}_{\text{load cell}}$

(conversion matrix that program solves for)
$dF_Y/dL_2 = dF_{x,y,z\ \text{axis}}/dL_{\text{load cell}}$

$$\begin{bmatrix} L^1{}_1 & L^1{}_2 & L^1{}_3 & L^1{}_4 & L^1{}_5 & L^1{}_6 \\ L^3{}_1 & L^3{}_2 & L^3{}_3 & L^3{}_4 & L^3{}_5 & L^3{}_6 \\ L^8{}_1 & L^8{}_2 & L^8{}_3 & L^8{}_4 & L^8{}_5 & L^8{}_6 \\ L^{10}{}_1 & L^{10}{}_2 & L^{10}{}_3 & L^{10}{}_4 & L^{10}{}_5 & L^{10}{}_6 \\ L^{12}{}_1 & L^{12}{}_2 & L^{12}{}_3 & L^{12}{}_4 & L^{12}{}_5 & L^{12}{}_6 \\ L^{14}{}_1 & L^{14}{}_2 & L^{14}{}_3 & L^{14}{}_4 & L^{14}{}_5 & L^{14}{}_6 \end{bmatrix} \text{X} \begin{bmatrix} dF_X/dL_1 & dF_Y/dL_1 & dF_Z/dL_1 & dM_X/dL_1 & dM_Y/dL_1 & dM_Z/dL_1 \\ dF_X/dL_2 & dF_Y/dL_2 & dF_Z/dL_2 & dM_X/dL_2 & dM_Y/dL_2 & dM_Z/dL_2 \\ dF_X/dL_3 & dF_Y/dL_3 & dF_Z/dL_3 & dM_X/dL_3 & dM_Y/dL_3 & dM_Z/dL_3 \\ dF_X/dL_4 & dF_Y/dL_4 & dF_Z/dL_4 & dM_X/dL_4 & dM_Y/dL_4 & dM_Z/dL_4 \\ dF_X/dL_5 & dF_Y/dL_5 & dF_Z/dL_5 & dM_X/dL_5 & dM_Y/dL_5 & dM_Z/dL_5 \\ dF_X/dL_6 & dF_Y/dL_6 & dF_Z/dL_6 & dM_X/dL_6 & dM_Y/dL_6 & dM_Z/dL_6 \end{bmatrix}$$

(known forces and moments)
$F^1{}_X = F^{\text{notch loc.}}{}_{x,y,z\ \text{axis}}$

$$= \begin{bmatrix} F^1{}_X & F^1{}_Y & F^1{}_Z & M^1{}_X & M^1{}_Y & M^1{}_Z \\ F^3{}_X & F^3{}_Y & F^1{}_Z & M^3{}_X & M^3{}_Y & M^3{}_Z \\ F^8{}_X & F^8{}_Y & F^8{}_Z & M^8{}_X & M^8{}_Y & M^8{}_Z \\ F^{10}{}_X & F^{10}{}_Y & F^{10}{}_Z & M^{10}{}_X & M^{10}{}_Y & M^{10}{}_Z \\ F^{12}{}_X & F^{12}{}_Y & F^{12}{}_Z & M^{12}{}_X & M^{12}{}_Y & M^{12}{}_Z \\ F^{14}{}_X & F^{14}{}_Y & F^{14}{}_Z & M^{14}{}_X & M^{14}{}_Y & M^{14}{}_Z \end{bmatrix}$$

- And by knowing what the force / moment matrix should look like (due to calibrated weights and known distances from '0' being used),
- And solves for the conversion matrix.
- Note – The matrix that the program creates has the forces and moments horizontal and load cells vertical (produces a matrix with columns/rows swapped from what is shown above). This swapped style is what the V_test software uses, but remember to additionally swap the F_X and F_Y rows, and the M_X and M_Y rows.

7.2.2.5. Revising V_test software

1. Choose the best four matrices based on residual error.
2. Create a text file with the new matrix
3. Swap the Fx and Fy rows and the Mx and My rows.
4. Input the V_test software
5. Print out and double check the matrix
6. Check the volts to pounds (force) conversion factor in the V_test software. Note: the value is positive in this software, and negative in the Mathcad program, so that Fz is positive when the load cell is in compression.

7.2.2.6. Testing matrix prior to actuator calibration

1. Remove test stand from metal stands and rotate upright.
2. Re-install leveling feet
3. Remove reference block
4. Level stand using precision level on interface plate.
5. Remove level and any hardware from stand.
6. Allow electronics to be powered up for at least 10 minutes.
7. Command setZero
8. Load top of interface plate, in the center, with two 50 lb. weights.
9. Command readV
10. Record the 6 load cell readings and multiply them by the matrix to produce the forces and moments. The results should be similar to: 0.01 -0.03 100.2 3.1 -4.2 0.3.
11. If values are not similar a problem occurred in the calibration, otherwise proceed.
12. Remove weights.
13. Load V_test software.
14. Command 'z' to zero the test stand.
15. Check to verify that the real time forces and moments are reading near zero.
16. Re-load the two 50 lb. Weights in the center of the interface plate.
17. Check the real time forces and moments to verify that they agree with the values obtained from multiplying the load cell values by the matrix. The results should be similar to: -0.05 0.01 100.17 -2.8 -1.1 -0.8.

7.2.3. Testing

The test program is started by entering the command x_test (or v_ test, depending on the interface being used) at the command line of the terminal or window being used. After a slight delay, the program will put the terminal in a "full-screen" mode, with dynamically updating data fields, showing several pieces of information about the current status of the test stand and any actuator attached to it.

7.2.4. Test Data

The software to analyze the test data consists of a set of gnuplot functions to process the raw data and produce plots of forces and moments, either on the screen or to a postscript file that can be printed.

YwavePlot - process the y-Wave test data and produces two graphs: y-error and z-error values over time and moments in x, y and z over time.

ZwavePlot - produces the same types of plots as described for YwavePlot, but uses z-Wave test data as input.

TMagPlot – uses the transient test data as input and produces a graph of forces in the z and y axis over time.

7.3. Test Procedures

7.3.1 Single-axis Actuator Test Procedures

7.3.1.1. Overview

1. Zero out test stand (z)
2. Install actuator
3. Perform bump test (sz load)
4. Perform initial auto-calibration test (c)
5. Perform initial wave test (w)
6. 8 minute burn-out
7. During burn-in, adjust the actuator air cylinder
8. Auto-calibrate (c)
9. Perform wave test (w)
10. Perform transient test (t)

7.3.1.2. Detailed Procedures

1. Turn on power strip. AC power, +30V, +/=15V for LC Rs, terminal and crate power (crate should be switched on).
2. After the crate boots, enter v_test.
3. Type as (for single-axis actuator).
4. Set air pressure to 130psi (125 to 150psi).
5. Install the single-axis actuator interface hardware, the actuator mounting plate and the load cell interface member.
6. Type z to zero out the test stand (remove the trans torque before zeroing). When testing multiple single-axis actuators, this step is the starting point for all subsequent actuators.
7. Install the actuator using the appropriate adapter plug.
8. Hook up air.
9. Check "test stand" forces.
   - Mx, My and Mz must be less than 100 in-lbs.
   - Fx and Fy must be less than 5 lbs.
   - Fz must be –100 to +100 lbs.
10. Type J to enable the integrator (close the force loop). Check forces – they should be somewhere close to zero.

11. Check “test stand” forces.
    - Mx, My and Mz must be less than 100 in-lbs.
    - Fx and Fy must be less than 5 lbs.
    - Fz must be –5 to +5 lbs.
12. Bump test both directions.

sz 400	Fz = 395 to 405	test stand = 350 to 450
sz 0	Fz = -5 to 5	test stand = -5 to 5
sz –400	Fz = -405 to –395	test stand = - 450 to –350
sz 0	Fz = -5 to 5	test stand = -5 to 5

13. Type c to perform an initial auto-calibration test.
14. When prompted, enter Filename = pcmag1-sna where ‘sn’ is the actuator serial number and ‘a’ is a test sequence number. (If this actuator is retested, use b, etc.). Example: pcmag1-03a
15. When prompted for serial number, enter the actuator’s serial number.
16. Type ‘w’ to perform a wave test (z direction).
17. When prompted for wave test direction, enter ‘z’.
18. Using a convention similar to the one for Filename given above, enter the Filename in the format: wmag1-z-sna, where ‘sn’ again is the actuator serial number and ‘a’ is the test sequence. Example: wmag1-z-003a
19. Type ‘t’ to perform the transient test.
20. For the direction, enter ‘z’ when prompted.
21. Enter a testing time of 4.
22. Enter 20 for starting force.
23. For ending force, enter –20.
24. Set the Other axis force to 0.
25. Enter the Filename as tmag1-z-sna, using the conventions discussed for filenames earlier. Example: tmag-z-032a
26. Pull off the airline and remove the actuator.
27. Test complete.

7.3.2. Dual-axis Actuator Test Procedure

7.3.2.1. Overview

1. Zero out test stand (z)
2. Install actuator
3. Perform bump test (sz load)
4. Perform initial auto-calibration test (c)
5. Perform initial wave test, z axis (w)
6. Perform initial wave test, y axis (w)
7. 8 minute burn-in
8. During burn-in, adjust the actuator air cylinder
9. Auto-calibrate (c)
10. Perform wave test, z axis (w)

11. Perform wave test, y axis (w)
12. Perform transient test, z axis (t)
13. Perform transient test, y axis (t)

7.3.2.2. Detailed Procedure

1. Turn on power strip. AC power, +30V, +/-15V for LC Rs, terminal and crate power (crate should be switched on).
2. After the crate boots, enter v_test.
3. Type 'ad' (for dual-axis actuator).
4. Set air pressure to 130psi (125 to 150psi).
5. Install the dual-axis actuator interface hardware, the actuator mounting plate and the load cell interface member.
6. Type 'k' to disable the integrator.
7. Type 'z' to zero out the test stand.
8. Install the actuator.
9. Hook up air.
10. Check 'test stand" forces.
    - Mx, My and Mz must be less than 100 in-lbs.
    - Fx and Fy must be less than 5 lbs.
    - Fz must be –100 to +100 lbs.
11. Type 'J' to enable the integrator (close the force loop). Check forces. They should be somewhere close to zero.
12. Check "test stand" forces.
    - Mx, My and Mz must be less than 100 in-lbs.
    - Fx and Fy must be less than 5 lbs.
    - Fz must be –5 to 5 lbs.
13. Bump test both directions:

sz 400	Fz = 395 to 405	Fy = -5 to 5
test stand:	Fz = 350 to 450	Fy = -5 to 5
sz –400	Fz - 0405 to –395	Fy = -5 to 5
test stand:	Fz = -450 to –350	Fy = -5 to 5
sz 0	Fz = -5 to 5	Fy = -5 to 5
test stand:	Fz = -5 to 5	Fy = -5 to 5
sy 400	Fz = -5 to 5	Fy = 395 to 450
test stand:	Fz = -5 to 5	Fy = 395 to 450
sy –400	Fz = -5 to 5	Fy = -405 to -395
test stand:	Fz = -5 to 5	Fy = -405 to -395
sy 0	Fz = -5 to 5	Fy = -5 to 5
test stand:	Fz = -5 to 5	Fy = -5 to 5

Notes:
S1 400 is the same as 'sz' 400.
S2 400 exercises only the diagonal cylinder, 'sy' 400 commands a 'y' force of 400.

14. Type 'c' to perform an initial auto-calibration test.
    - Filename = pc-mag1-sna
    - Serial # = the serial number of the actuator being tested
15. Type 'w' to perform the wave test (z direction).
    - Direction = z
    - Filename = pz-wmag1-sna, where 'sn' is the actuator serial number and 'a' is a test sequence letter (if this actuator is re-tested, use 'b', etc.)
16. Type 'w' to perform
    - Direction = y Note: 2 results in only diagonal cylinder being exercised
    - Filename = py-wmag1-sna, where 'sn' is the actuator serial number and 'a' is a test sequence letter. (If this actuator is re-tested, use 'b', etc.). Examples: py-wmag1-103a for the first test of actuator 103, py-wmag1-103b if this actuator is reworked and re-tested. Note that the test program will not allow a file to be overwritten.
17. Type 'w' to perform the wave test (y direction).
    - Direction = y Note: 2 results in only diagonal cylinder being exercised.
    - Filename = py-wmag1-sna, where 'sn' is the actuator serial number and 'a' is a test sequence letter. (If this actuator is re-tested, use 'b', etc.). Examples: py-wmag1-103a for the first test of actuator 103, py-wmag1-103b if this actuator is reworked or re-tested. Note that the test program will not allow a file to be overwritten.
18. Burn-in and adjustment (at least 8 minutes of operation including adjustment time). Note that 2 minutes of the required 10-minute burn-in are taken up by the wave test.
19. Air Cylinder Adjustment
    1. Apply a 400 lb axial load sz 400.
    2. Adjust the tilt of the axial air cylinder to reduce Fx and Fy to less than 0.5 lbs (-0.5 to 0.5).
    3. Apply a –100 lb axial load sz –100.
    4. Verify that the magnitude of Fx and Fy are less than 0.75 lbs.
    5. Zero out the axial load (sz 0) and verify that Fx and Fy are less than 0.5 lbs.
    6. If the above requirements are not satisified, adjust until the magnitude of Fx and Fy are less than +/-0.5 lbs under zero and less than +/-0.75 for +/-400 lbs axial. Fail the actuator if this cannot be achieved.
    7. Zero out the axial force (sz 0) and apply a –400 lb commanded lateral load to actuators 54 to 86 or a 400 lb commanded lateral load to actuators 87 to 105 (sy –400 or sy 400).
    8. Adjust the tilt of the diagonal air cylinder to reduce Fx and Fz to less than 0.5 lbs (-0.5 to +0.5)
    9. Zero out the lateral load (sy 0) and verify that Fx and Fz are less than 0.5 lbs.

10. If these requirements are not satisified, adjust until the magnitude of Fx and Fz are less than +/-0.5 lbs under zero and less than +/=1.5 for +/-400 lbs lateral. Fail the actuator if this cannot be achieved.
11. Check Mx, My and Mz at –100, 0 and +400 lbs axial load. None of these forces can be permitted to exceed +/-70 in-lbs. Reject the actuator if this condition is not satisifed.
12. Check Mx, My and Mz at –400 or +400 lbs axial load. None of these forces can be permitted to exceed +/-70 in-lbs. Reject the actuator if this condition is not satisfied.

Note: When changing from axial to lateral loading, or vice versa, zero out the initial load before applying the new load. For example, to go from an axial load of 600 lbs to a 400-lb lateral load, type 'sz 0' then 'sy 400'.

7.4. Troubleshooting the Test Stand

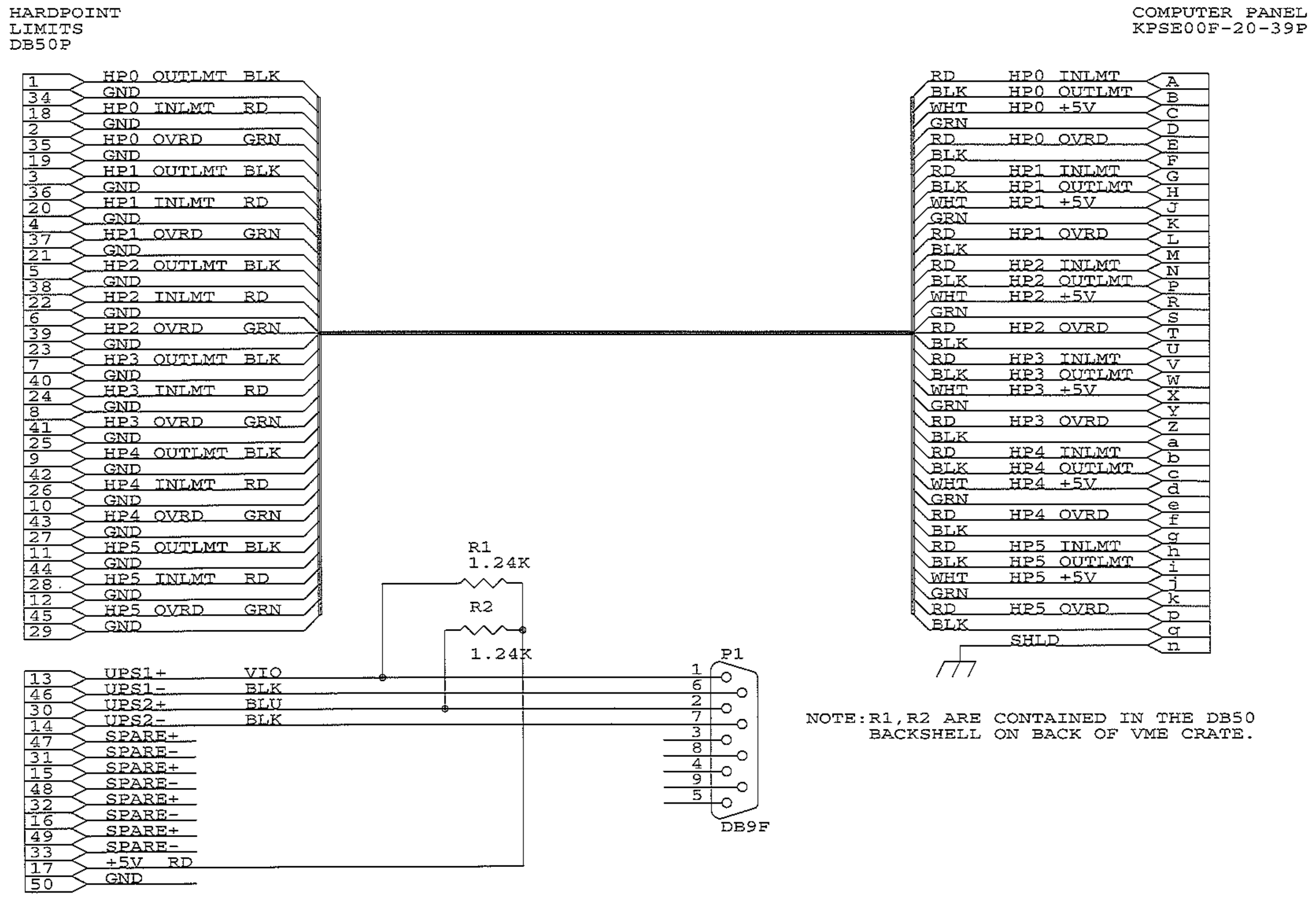
The software for the test stand, unless modified, should perform as described in this section. If anomalous results occur it is probably due to a hardware failure with the test stand electronics or computer system, or with the actuator being tested. The following areas should be investigated when problems do occur.

- If an actuator does not respond to a commanded force, check the "Readback" field of the test stand interface. If it is reasonable for the force commanded, the commanded voltage may not be getting to the actuator. This can be checked with a voltmeter on the test stand. If the expected voltage is present at the connector, then the actuator or its associated control card will need to be diagnosed.
- If a loadcell seems to be reading abnormally low, given the commanded force, this should also be checked with a voltmeter at the output of the preamplifier.
- Strange readings on the actuator may be the result of the stand being set for a dual actuator when it is testing a single actuator or vice versa.
- Whenever problems are encountered when testing an actuator always verify that the actuator is working correctly before investigating the test stand.

Appendix A

Revised Electronic Schematic Drawings and Mechanical Drawings.

NOTE: Only drawings modified after Magellan I Telescope Cell are included.

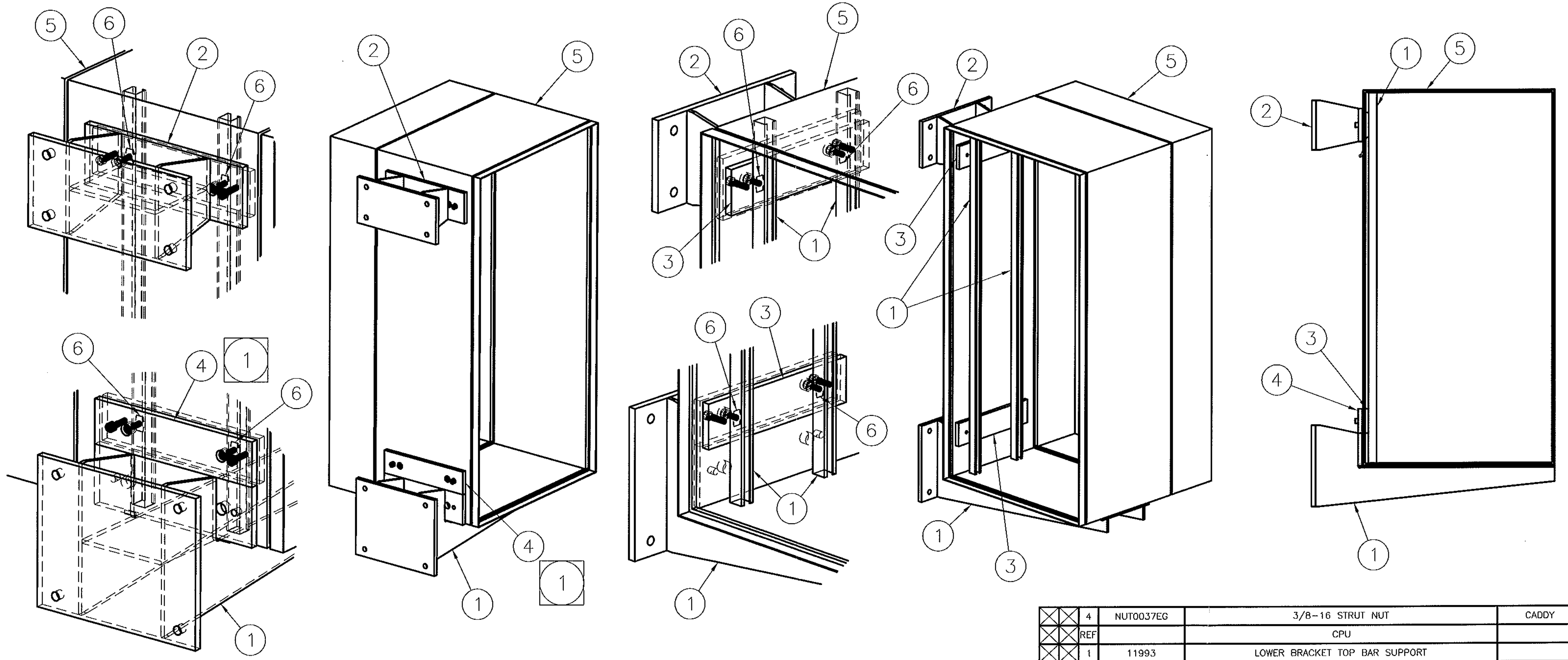


NOTE: R1, R2 ARE CONTAINED IN THE DB50
BACKSHELL ON BACK OF VME CRATE.

STEWARD OBSERVATORY
UNIVERSITY OF ARIZONA
TUCSON AZ 85721

Size A	Document Number MAG2UPSTAT.SCH	REV A
Date: June 22, 2001	Sheet 1 of 1	

REVISIONS				
LTR	DESCRIPTION	DATE	REVISED BY	APPROVED
A	INITAL RELEASE	04/09/01	T. HOPPER	G. LANDIS



NOTES:

1 ITEM 4 IS A NEW PART,

ALL OTHER PARTS ARE PRE-EXISTING.

QTY PER ASSY -3	-2	-1	PART NUMBER	PART DESCRIPTION	MANUFACTURER or MAT'L SPEC	ITEM NO.
		4	NUT0037EG	3/8-16 STRUT NUT	CADDY	6
		REF		CPU		5
		1	11993	LOWER BRACKET TOP BAR SUPPORT		4
		REF	10521	ADAPTER PLATE		3
		REF	10528	UPPER BRACKET		2
		REF	10527	LOWER BRACKET		1

LIST OF MATERIALS

DO NOT SCALE DRAWING
INTERPRET DIMENSIONS AND TOLERANCES IN ACCORDANCE WITH ASME Y14.5M-94
TOLERANCES UNLESS OTHERWISE SPECIFIED
LINEAR ANGULAR
.X =
.XX =
.XXX =
DIAMETRICAL
SEE SPEC S-002
DIMENSIONS ARE IN INCHES / DIMENSIONS IN ( ) ARE METRIC
MATERIAL
FINISH

THIS DRAWING CREATED IN:
ACAD ☐ MECH ☒ IDEAS ☐
NEXT ASSY USED ON
ASSEMBLY APPLICATION

Steward Observatory, University of Arizona
933 N. Cherry Avenue, Tucson, AZ 85721 (520)621-7659

DESIGNED BY: B. CUERDEN	DATE: 03/30/01	CATEGORY: MAGELLAN TELESCOPE CELL
DRAWN BY: T. HOPPER	03/30/01	PROJECT: MAGELLAN COMPUTER
CHECKED BY: G. LANDIS	04/09/01	TITLE: COMPUTER MOUNT INSTALLATION MODIFICATIONS
APPROVED: B. CUERDEN	04/09/01	
APPROVED: S. WARNER	04/09/01	
APPROVED:		PLOT SIZE: D · SCALE: 1 : 6 · DRAWING NUMBER: 11992 · REVISION: A
APPROVED:		

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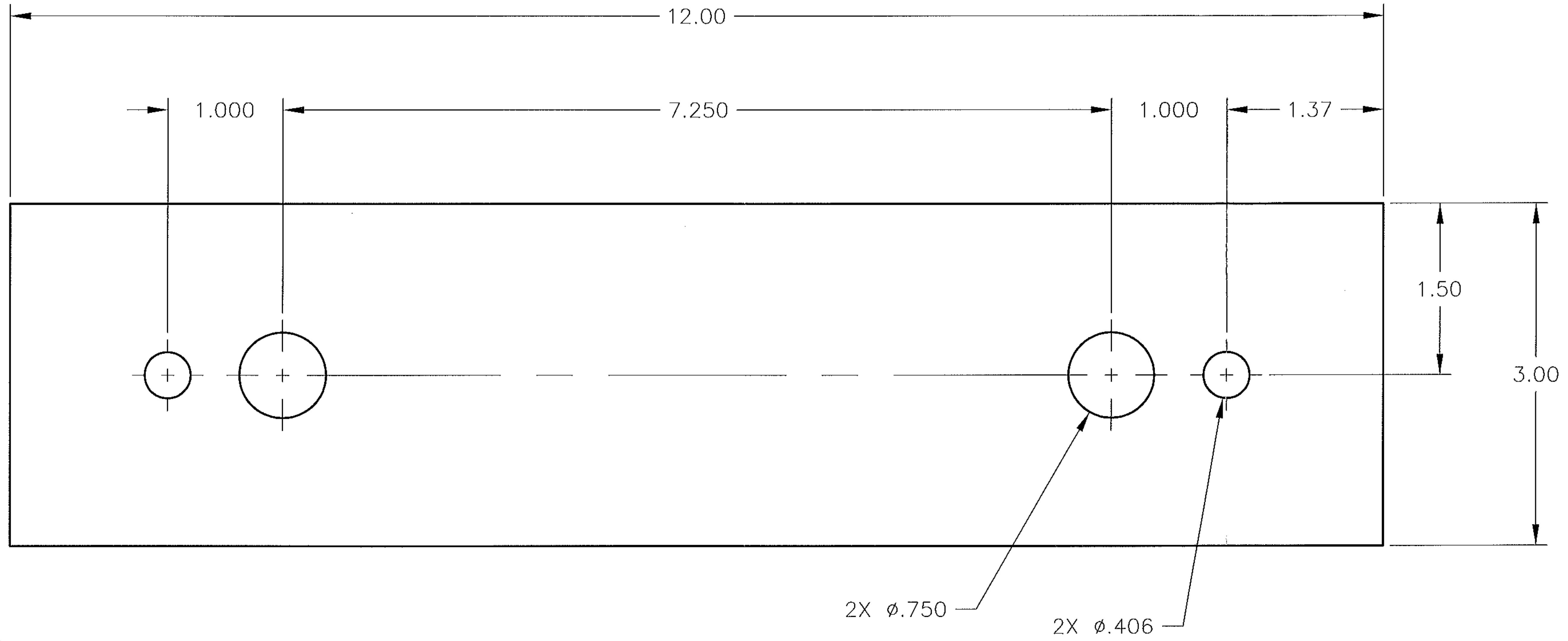
SHEET 1 OF 1

REVISIONS

LTR	DESCRIPTION	DATE	REVISED BY	APPROVED
A	INITAL RELEASE	04/09/01	T. HOPPER	G. LANDIS



NOTES:

1) BREAK SHARP EDGES & DEBURR.

2) ALL MACHINING FILLETS TO BE R .015 MAX

DO NOT SCALE DRAWING

INTERPRET DIMENSIONS AND TOLERANCES IN ACCORDANCE WITH ASME Y14.5M-94

TOLERANCES
UNLESS OTHERWISE SPECIFIED
LINEAR ANGULAR
.X =
.XX = ±.06
.XXX = ±.010
DIAMETRICAL
SEE SPEC S-002

DIMENSIONS ARE IN INCHES / DIMENSIONS IN [ ] ARE METRIC

MATERIAL
1018 OR A36 STEEL
.50 PLATE

FINISH

THIS DRAWING CREATED IN:
ACAD ☐ MECH ☒ IDEAS ☐

NEXT ASSY	USED ON

ASSEMBLY APPLICATION

Steward Observatory, University of Arizona
933 N. Cherry Avenue, Tucson, AZ 85721 (520)621-7659

DESIGNED BY: B. CUERDEN	DATE: 03/30/01	CATEGORY: MAGELLAN TELESCOPE CELL
DRAWN BY: T. HOPPER	03/03/01	PROJECT: COMPUTER MOUNT
CHECKED BY: G. LANDIS	04/09/01	TITLE: LOWER BRACKET COMPONENT PART TOP BAR SUPPORT
APPROVED: B. CUERDEN	04/09/01	
APPROVED: S. WARNER	04/09/01	
APPROVED:		
APPROVED:		

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SHEET 1 OF 1

Results of Magellan 2 primary mirror integration

Steward Observatory Mirror Lab
June 26, 2001

1. Summary

We optimized the support forces for the second Magellan primary mirror in late May and early June, 2001. We chose to control 26 bending modes, and were able to do that with modest correction forces in the range $-31 < \Delta F < 23$ N. The resulting mirror figure is better than we obtained with the mirror on the polishing support. The rms surface error is 22 nm, reducing to 14 nm when astigmatism is subtracted. The image quality is also better than that on the polishing support, with 80% of the light at 500 nm contained in a $0.07''$ diameter. Three sets of repeatability measurements demonstrated that this excellent image quality is maintained over several days.

2. Optimization of support forces

The mirror support system was installed in the cell and tested, the 6.5 m mirror was installed, and the system was made available for optical testing and force optimization beginning May 21, 2001. Initial results were limited by seeing (temperature gradients and turbulence in the air) that appeared worse than we had experienced while polishing the mirror. Temperature measurements revealed a thermal instability in the tower, the air handlers making the air at the top colder than the air in the main volume of the lab. The set point for the tower's air handler was adjusted on June 5, and this made a dramatic improvement in seeing. From this point, a single iteration of force adjustment gave the optimized figure presented here, obtained on June 6.

The optimization is done using the mirror's natural bending modes, calculated by BCV using finite-element analysis. Each orthogonal bending mode has a corresponding pattern of actuator forces. Working with Steve Shectman and Paul Schechter, we verified that the force patterns applied by the active support system produce the desired bending modes to high accuracy. We applied force patterns for 5 of the 20 softest modes, and mode 29. Results are given in Table 1 and Figure 1.

In all cases the amplitude of the desired mode is within 20% of the prediction, and within 8% for modes 1, 10, 12 and 13, which have better signal:noise. Leakage into astigmatism is as much as 22% in deflection for the modes with good signal:noise. When one takes into account the stiffness of the modes, this corresponds to less than 1% leakage in force. Even mode 29's 73% leakage in deflection corresponds to less than 0.5% leakage in force. There is negligible crosstalk between complementary modes (the pair of modes with even and odd symmetry about the y axis).

We used 26 modes for the final optimization. The correction forces are all in the range $-31 < \Delta F < 23$ N.

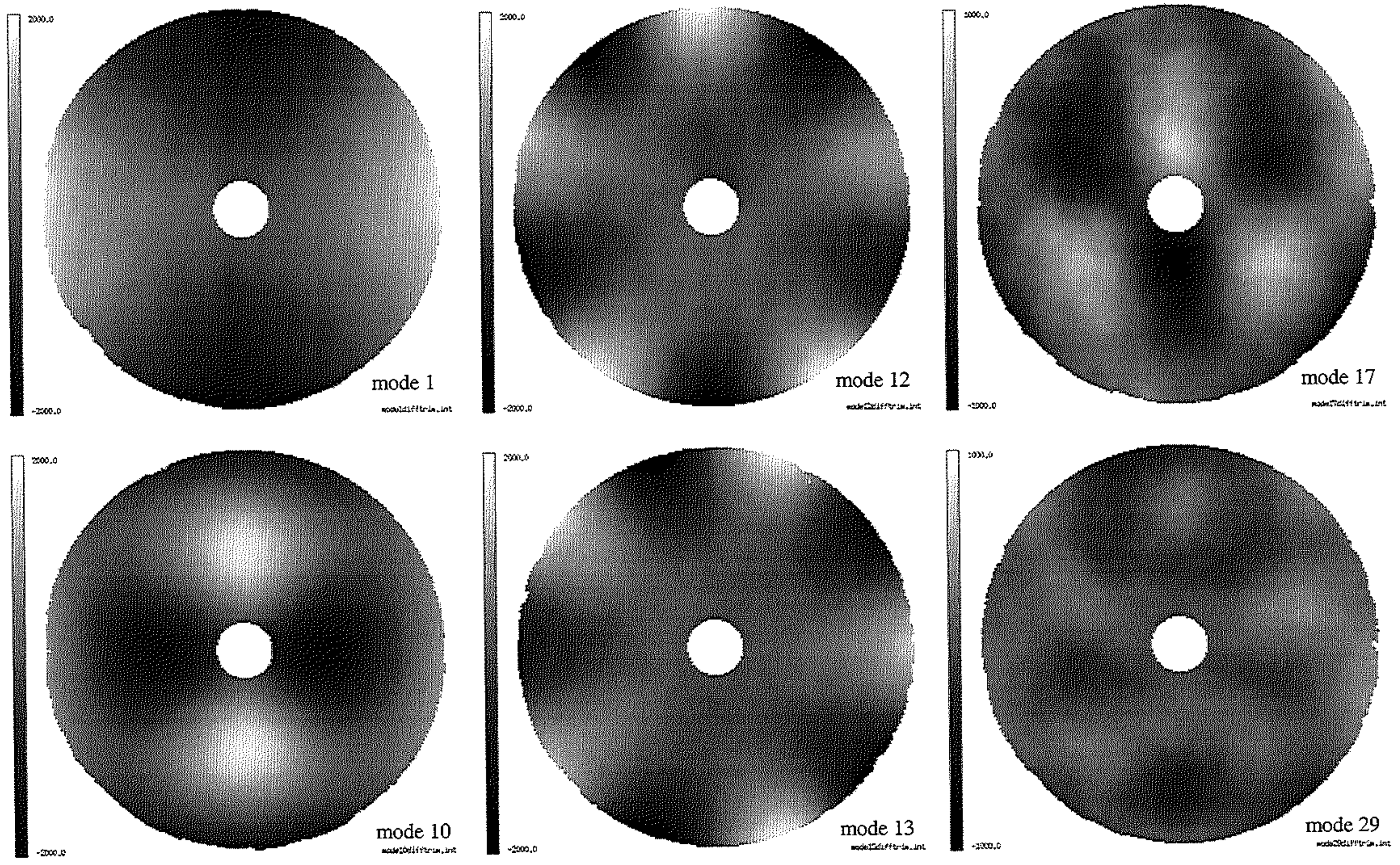


Figure 1. Measured bending modes obtained by applying calculated force sets. Gray-level bars are labelled in nm of wavefront (not surface). Modes 1, 10, 12 and 13 have similar signal:noise. Stiffer modes 17 and especially 29 have less signal but similar noise.

Table 1: Measured modal influence functions

mode	radial zero-crossings	azimuthal symmetry	rms force (N)	predicted rms deflection (nm)	measured rms deflection (nm)	rms in complementary mode (nm)	rms in astigmatism (nm)
1	0	2	2	336	349	11	
10	1	2	60	338	335	0	75
12	0	5	60	296	274	1	27
13	0	5	60	272	267	8	36
17	1	3	60	158	138	4	28
29	1	5	60	64	52	<6	47

3. Figure measurements

Figures 2 and 3 are surface maps and synthetic interference patterns from the measurements made with the optimized forces. All measurements have been corrected for errors in the null lens as determined by the hologram, and for image distortion as determined by the fiducials. A small amount of spherical aberration was subtracted (Zernike coefficient of 9 nm surface, corresponding to 17 parts per million in conic). While spherical aberration is well fit by the bending modes used, we chose not to correct it because the equilibrium value in the telescope will be determined by spacings. The interference patterns are calculated for a wavelength of 633 nm and contain 10 waves of tilt.

The rms surface error is 22 nm including astigmatism, and 14 nm after subtracting astigmatism. Results for the mirror on the polishing support were 150 nm including astigmatism (we made little effort to control it), 20 nm after subtracting astigmatism, and 16 nm after subtracting an additional 3 pairs of Zernike polynomials similar to flexible bending modes. The figure is significantly better on the active support with optimized forces. The figure error on the polishing support was dominated by a high-order astigmatism (mode 10, shown in Figure 1, and its complement) and a high-order spherical aberration. These aberrations were not present consistently over the last few measurements on the polishing support, and may have been due to temperature gradients. The high-order spherical aberration was not present when we optimized the support forces, and the high-order astigmatism, if it was present, was eliminated in the optimization.

4. Encircled energy

We calculated the encircled energy from the map shown in Figure 2. The diffraction calculation covers a 3.6 arcsecond field with 7.2 mas resolution, at a wavelength of 500 nm. Figure 4 shows encircled energy diagrams for the actual mirror and a perfect mirror, in perfect seeing and 0.25 arcsecond seeing. (Seeing is included by convolving the mirror's PSF with that of the atmosphere.) For comparison, Figure 5 shows the same quantities for the mirror on the passive polish-

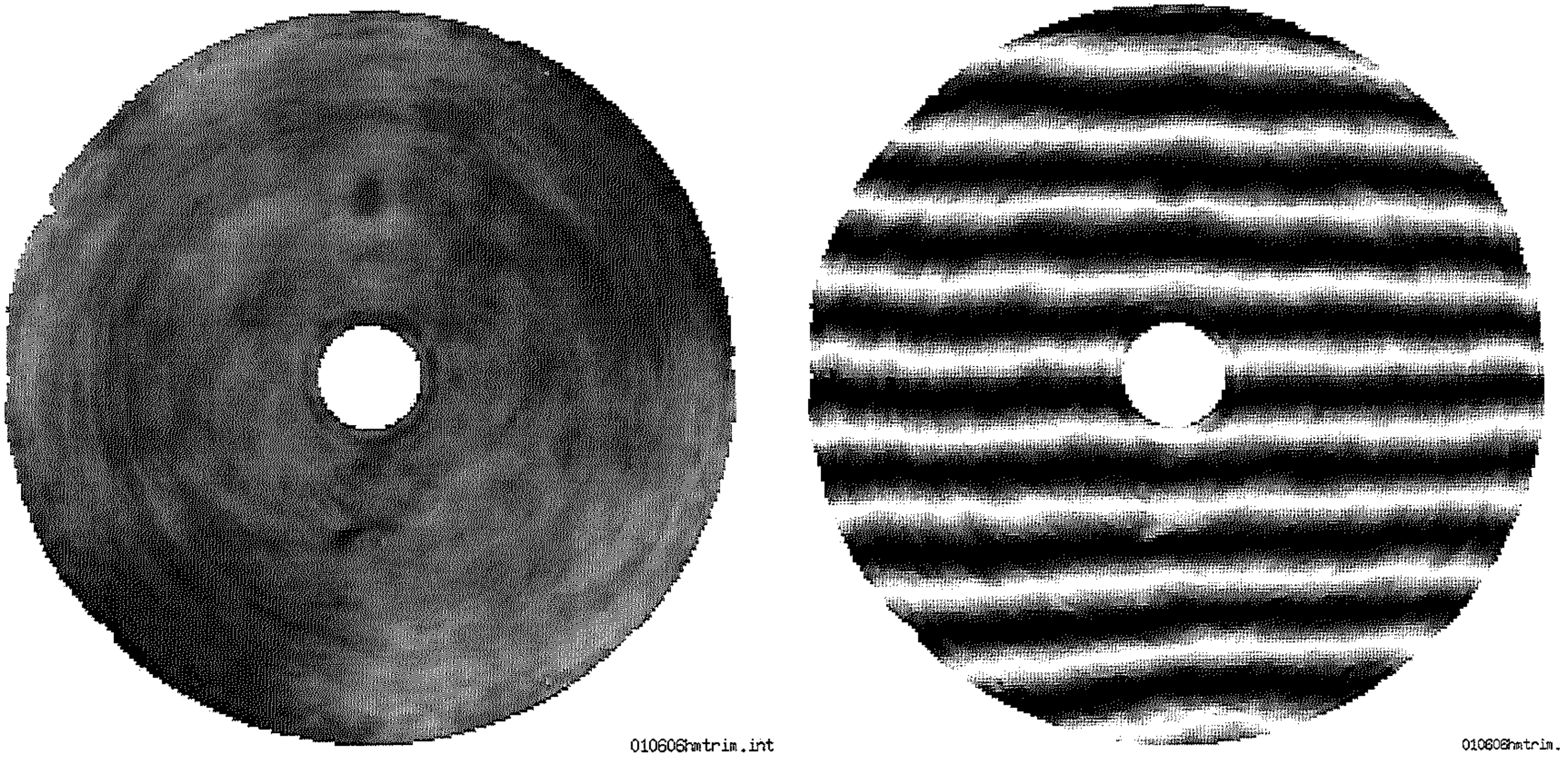


Figure 2. Gray-scale surface map and synthetic interference pattern for the optimized support forces. The gray scale covers ±100 nm of surface. The rms surface error is 22 nm.

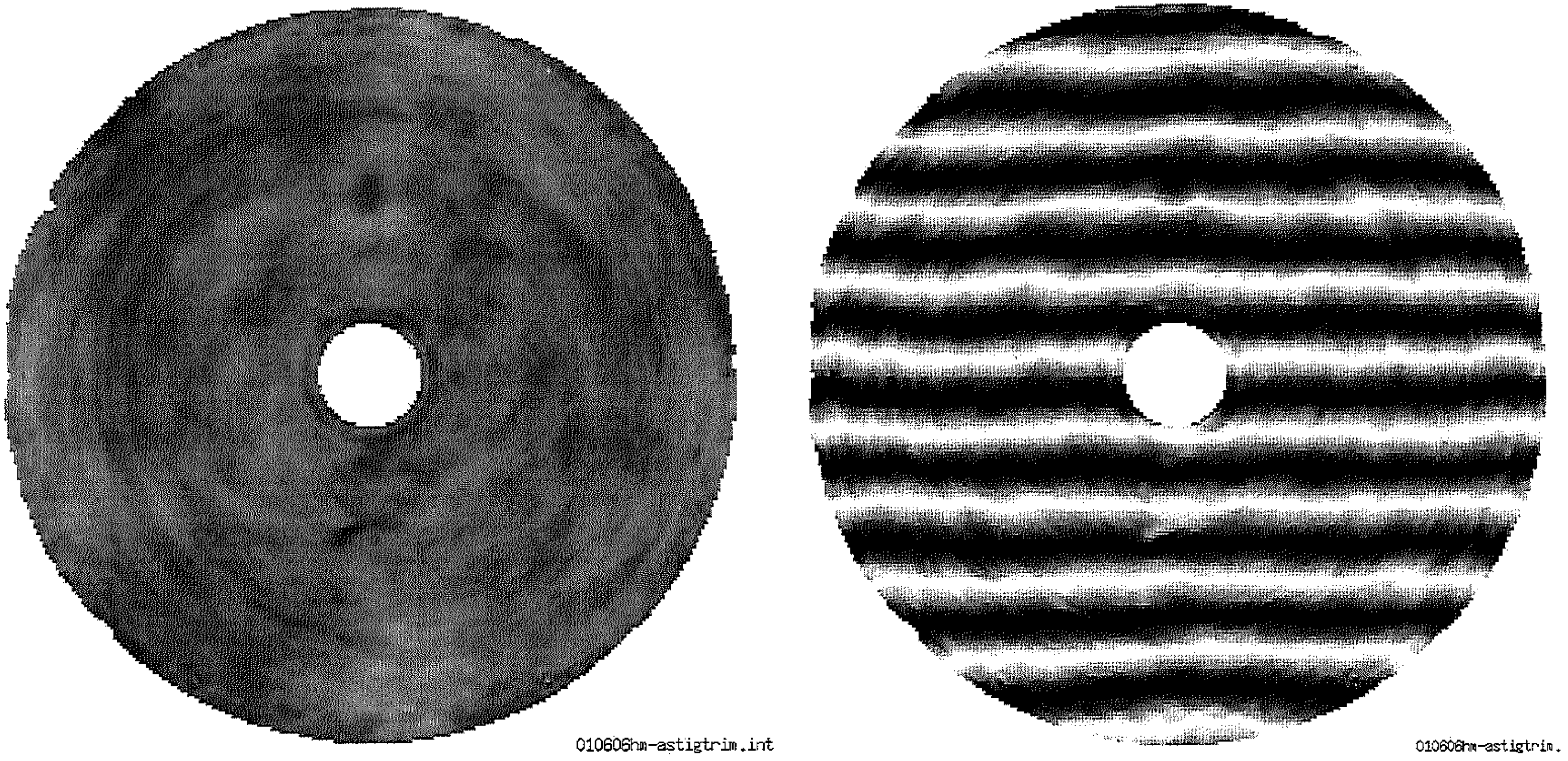


Figure 3. Gray-scale surface map and synthetic interference pattern for the optimized support forces, with astigmatism subtracted. The gray scale covers ±100 nm of surface. The rms surface error is 14 nm.

ing supports, after subtraction of astigmatism. Table 2 gives the diameter containing 80% of the energy for all cases. The mirror on optimized support forces performs better than the mirror on the polishing support.

Table 2: Image diameter containing 80% of the energy at 500 nm

	no seeing	0.25″ seeing
polishing support	0.08″	0.52″
telescope support	0.07″	0.52″
perfect mirror	0.04″	0.49″

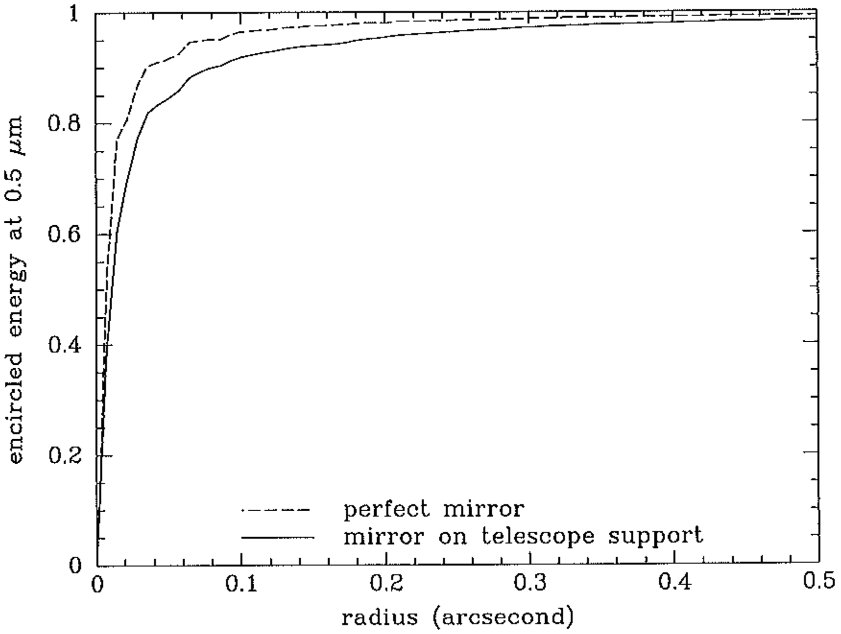
5. Figure repeatability

We made three sets of measurements following the optimized results of June 6. In each case the forces were reoptimized, using successively fewer modes. The goal of this exercise was to see how well the lower modes such as astigmatism and trefoil could be controlled when we did not adjust the higher modes. As it turned out, we never improved on the June 6 results, although the final measurement on June 10 was slightly better on small scales and nearly as good on large scales.

Although we applied slightly different forces for the last three measurements, they illustrate the repeatability of the system. If it were perfectly repeatable, the small changes in force would have eliminated the residual astigmatism and other low bending modes obtained on June 6. The presence of these modes in the last three measurements represents non-repeatability, caused by variations in temperature gradients, support forces, or other factors. These measurements therefore give an upper limit on figure changes due to non-repeating forces.

Table 3 gives the surface error obtained in the final four measurements, starting with the best optimized figure of June 6. We also list the number of modes corrected in the current iteration, and the maximum force change in the current iteration. For the June 6 measurement, forces were optimized based on the previous measurement of June 5. For all later measurements, forces were optimized based on the June 6 measurement. (We always used the best measurement to date as the starting point for each iteration.) We give the rms surface error without any synthetic correction, and after subtracting several polynomials similar to the lowest bending modes.

Figure 6 contains encircled energy plots for the final four measurements, starting with June 6 (which is also shown in Figure 4). Table 4 gives the Strehl ratio (central intensity of the point-spread function relative to a perfect mirror) and the diameter θ_{80} containing 80% of the energy, both calculated at 500 nm. The encircled-energy diameters are nearly identical because the figure changes are on such large scales (primarily astigmatism and trefoil) that most of the light



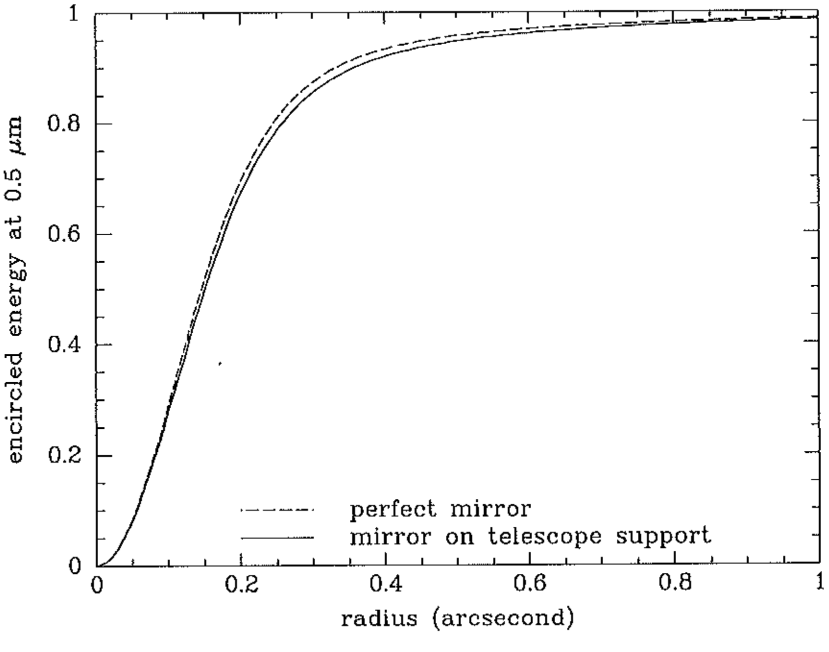
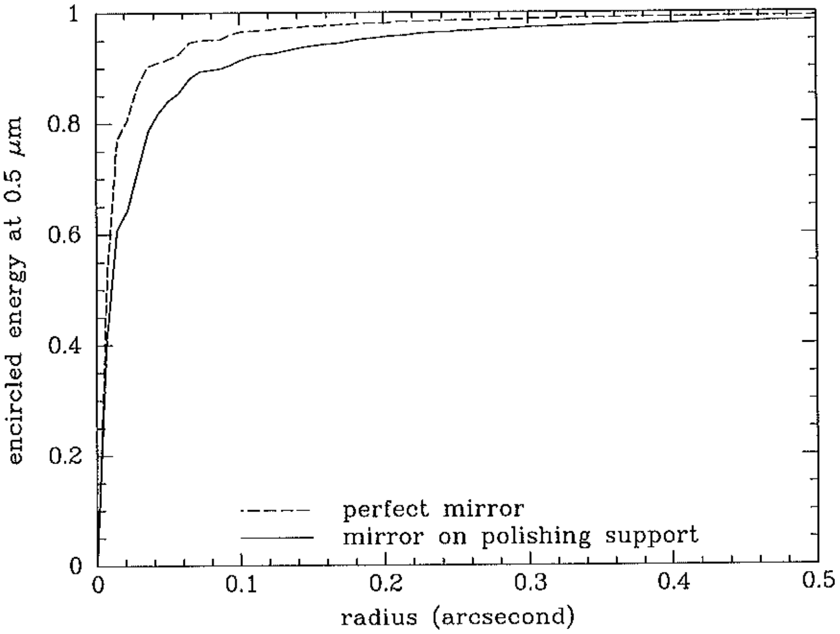


Figure 4. Encircled energy diagram for the mirror of Figure 2 and a perfect mirror. Top: in perfect seeing. Bottom: in 0.25 arcsecond (FWHM) seeing.



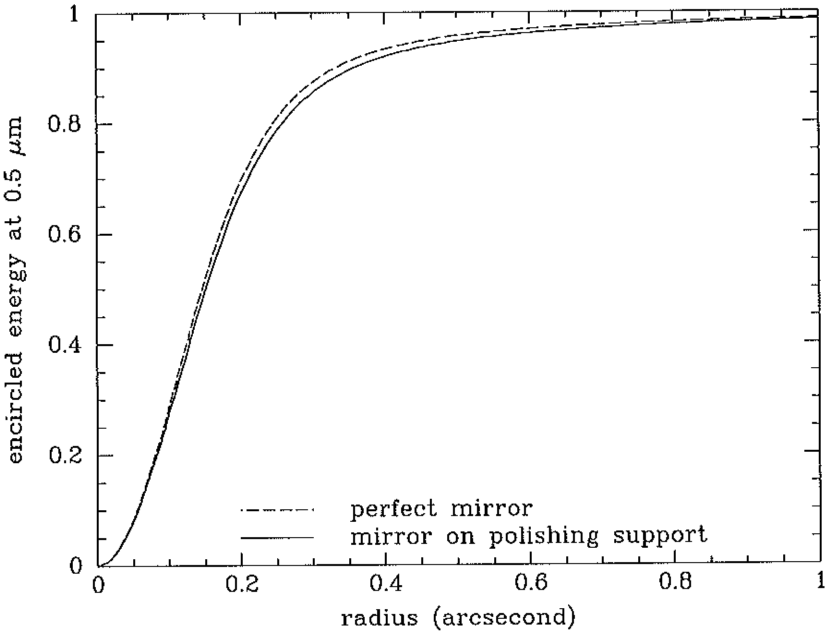


Figure 5. Encircled energy diagram for the mirror on the polishing support, with astigmatism subtracted, and a perfect mirror. Top: in perfect seeing. Bottom: in 0.25 arcsecond (FWHM) seeing.

Table 3: Figure repeatability

date	# modes corrected	max force change (N)	uncorrected rms surface error (nm)	astigmatism subtracted (nm)	+ trefoil subtracted (nm)	+ quatrefoil subtracted (nm)
June 6	26	13	22	14	13	12
June 7	20	6	26	15	15	13
June 8	14	5	28	24	16	16
June 10	9	2	24	16	15	13

remains inside a 0.07″ diameter circle. Thus there is very little degradation in image quality due to non-repeatability.

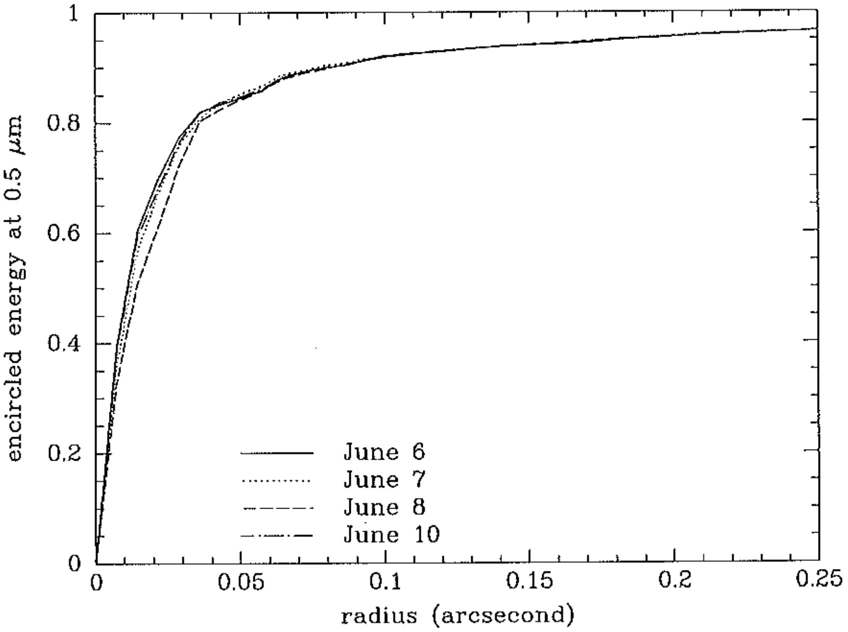


Figure 6. Encircled energy plots for the final four measurements, June 6-10.

6. Optimized forces

The optimized forces, used for the June 6 measurement, are listed in Table 5. These forces are added to the nominal forces from the BCV calculation. The optimized forces will also be transmitted electronically to Magellan staff.

Table 4: Image quality repeatability

date	Strehl ratio	θ_{80}
June 6	0.73	0.07″
June 7	0.64	0.07″
June 8	0.60	0.07″
June 10	0.70	0.07″

Table 5: Optimized forces

actuator ID	force (N)
1	10.4
2	19.9
3	11.8
4	10.2
5	14.1
6	-8.3
7	-1.4
8	3.6
9	0.5
10	-14.3
11	-9.3
12	-2.6
13	-6.0
14	-18.3
15	-14.1
16	-6.2
17	3.2
18	-3.2
19	-13.0
20	-1.8
21	9.1
22	5.0
23	-3.7
24	-3.8
25	16.3
26	7.0
27	-2.9
28	-0.1
29	11.4

Table 5: Optimized forces

actuator ID	force (N)
30	7.0
31	-7.3
32	-3.7
33	7.2
34	1.4
35	3.9
36	-8.7
37	-12.6
38	-0.4
39	3.5
40	-1.2
41	-13.2
42	-13.7
43	1.7
44	9.6
45	2.5
46	-11.9
47	7.6
48	17.7
49	-3.0
50	1.8
51	23.4
52	17.6
101	-2.2
102	1.7
103	6.5
104	-1.5
105	4.1
106	0.1
107	-1.6
108	7.5
109	9.9
110	-7.2
111	3.3
112	14.5
113	0.0
114	-25.3
115	-8.3
116	8.4
117	7.7

Table 5: Optimized forces

actuator ID	force (N)
118	-9.2
119	-17.7
120	-5.2
121	4.5
122	3.5
123	3.4
124	13.9
125	-7.3
126	1.3
127	7.8
128	15.5
129	-9.1
130	-5.4
131	-1.8
132	-3.2
133	3.7
134	-2.8
135	-2.1
136	-0.7
137	-15.2
138	-31.2
139	1.5
140	8.9
141	-0.6
142	-29.3
143	-2.7
144	4.0
145	13.6
146	-1.5
147	-9.7
148	3.5
149	10.4
150	-14.6
151	0.8
152	12.9

STEWARD OBSERVATORY TECHNICAL DIVISION

MEMORANDUM

TO: **Matt Johns**

FROM: **Steve Warner**

RE: **Magellan 2 Scope of Work Compliance**

DATE: **June 22, 2001**

ATTACHMENTS: **B. Cuerden memo**

CC: **S. Miller, S. DeRigne**

The purpose of this memo is to demonstrate compliance with the "Scope of Work" document 96PR0114, Paragraph 4.1, deliverables, "A report with.....tests and measurements of the loadspreader and hardpoint attachments....". With this memo I have attached the specifications and test methods for lateral and shear proof testing of the loadspreader attachments called out by Brian Cuerden, Mechanical Engineer, Steward Observatory Technical Division and agreed upon by Dr. John Hill, Casting Director of Steward Observatory Mirror Lab.

Position

After the initial loadspreader bonding, a series of point-to-point measurements were made using 2 single-axis to triple loadspreader interfaces and a set of calibrated inside micrometers. Data was then sent to Brian Cuerden for analysis and with this analysis, several loadspreaders (#'s 101, 106 and 405) were shown to be out of tolerance. These were removed and re-bonded. Total RMS of the point-to-point measurements is reported as .006" with no point-to-point value over .020". A height gauge was then used to measure the loadspreader to glass dimensions at 4 points; the 3 static support lands and the center interface. This was a go/no-go system with .007" as the upper limit. All loadspreaders passed.

Proof Testing

Axial load testing was performed after the required cure time for the bonds. The procedure was to load test using a bar that spanned 3 triple loadspreaders, attaching a loadcell to the interface of the loadspreader in the middle. Jacking screws at either end of the bar were then torqued to give the appropriate load (950 lbs.) at the loadcell. The unit was left loaded for the prescribed period (1 minute) and the process repeated for all triple loadspreaders, with the exception of the 2 special triples. These have historically been ignored, as a failure would jeopardize the glass. All loadspreaders passed.

Lateral load testing was performed using a jig made up of 2 bars that attach to triple loadspreaders, a captivated belville washer stack and a turnbuckle. This system was calibrated on the puck pull-testing station and then used on the mirror. This unit was used for MMT, Magellan 1 and 2, and most recently, LBT 1. The specified load (450 lbs) was applied and left for the prescribed period (1 minute) and the process repeated for all triple loadspreaders. Singles, duals and the special triples were not tested, as a failure would jeopardize the glass. All loadpsreaders passed.

Hardpoint Wedge Bonding

The glass wedges were bonded to the mirror using Norland 61 Optical Adhesive. The wedges were scribed along the major axes during fabrication. The mirror was marked for these scribes during the layout procedure on the LOG. An autocollimator was mounted in the center of the mirror, the mirror was then leveled to 2 arc minutes and a zero point established using 2 sets of loadspreaders 180° apart. A thin (.003") layer of adhesive was applied and the wedge was aligned to the marks on the glass. The autocollimator was then used to set the proper angle of the wedge using a jig mounted with 2 optical flats installed onto the wedge and rotated to proper alignment with the autocollimator. UV light was then applied for the manufacturers specified time to bond the wedge in place. This process was repeated for all 6 glass wedges.

The University of
ARIZONA®
Tucson Arizona

STEWARD OBSERVATORY
TUCSON, ARIZONA 85721

June 27, 2001

MEMORANDUM

d:\bc\

To:

cc:

FROM: Brian Cuerden
Technical Services

SUBJECT: 6.5 M Loadspreader Bond Proof Testing

History of Proof Testing

First Gluing	7/94	Triples	450 lbs bidirectional 2x30 minutes 38 mm above back of mirror
	8/94		950 lbs > 2 hours (axial?)
2nd Gluing	10/94	950 lbs overnight (axial?)	
3rd Gluing	11/94	340 lbs for 30 sec (shear?) 1020 lbs for 30 sec (axial?)	
B. Martin	8/16/94	Increased force from 650 lb (200 psi tensile) both directions (N&S), 4 cycles of 5 min separated by relaxation.	
P. Gray	8/17/94	450 lb proof test in shear, 2" off back plane of mirror 15 to 30 min with some tests over the weekend.	
J. Hill	8/18/94	Proof test loads:	Single 270 lbs Dual 540 lbs Triple 809 lbs
P. Gray	8/24/94	650 lb Lateral on triples, 450 lb lateral on special triples	

P. Gray 11/1194 Axial loading of 300 lbs/puck for a few seconds.
Sample 25 triples at 900 lbs axial overnight.

Acceptable Loads

UA-95-02 2.3.5 1350 N shear on a triple (for 100 psi?) = 303 lbs

Glass Stress (per BCV Rep. # 147 rev 0)

300 lb tensile load = 143 psi glass stress

Per UA-95-02 we can apply 150 psi for short durations (5 minutes) and 100 psi indefinitely (ref para. 9.1).

Proof Testing for Magellan I

450 lbs shear on every triple loadspreader for 1 minute

950 lbs axial on 9 triples for 1 minute

Proof Testing for Magellan II.

Tensile proof load:

950 lbs tensile on every standard triple (150 psi glass stress) for 1 minute.

No axial tests on special triples.

Shear Load Test

450 lbs for 1 minute on every standard triple loadspreader

All standard triples that can be loaded (no shear test on special triples).

Repair of the Piece of Glass that Broke off Magellan 2

Randy Lutz

June 28, 2001

During disassembly of the mold after casting the Magellan 2 blank, it was notice that a piece of the blank at the outer side wall-backplate interface had broken away. The piece was about 12" wide and extended in to an outer backplate hole. The piece also extended up the outer side wall about 4". No other damage was detected associated with this fracture and no definitive proof was found for its occurrence. The bolt in the backplate hole did have some glass leak around it during casting, which could have caused some localized stress during the cool-down of the blank, resulting in the fracture.

The piece of glass was removed and set aside while the blank was washed out and prepared for generating and polishing. During this time a plan was made to glue the piece back in prior to generating the backplate. It was decided to use Norland 61, a UV curing cement, to reattach the piece. Norland 61 will give a joint strength equal to or exceeding the bulk strength of the glass. The piece was successfully reattached while the blank was hanging vertical in the washout stand.

Since this was a potential problem during the generating and polishing of the surface and outer edge of the backplate, we paid close attention to this feature. No problems occurred while working these surfaces, and no degradation of the glue joint was seen after the blank was generated and polished.

We feel that the repair will not hinder the Magellan 2 mirror in any way and should give no long-term problems during the lifetime of the blank.

Final Inspection of Magellan 2 Mirror

Randy Lutz
June 28, 2001

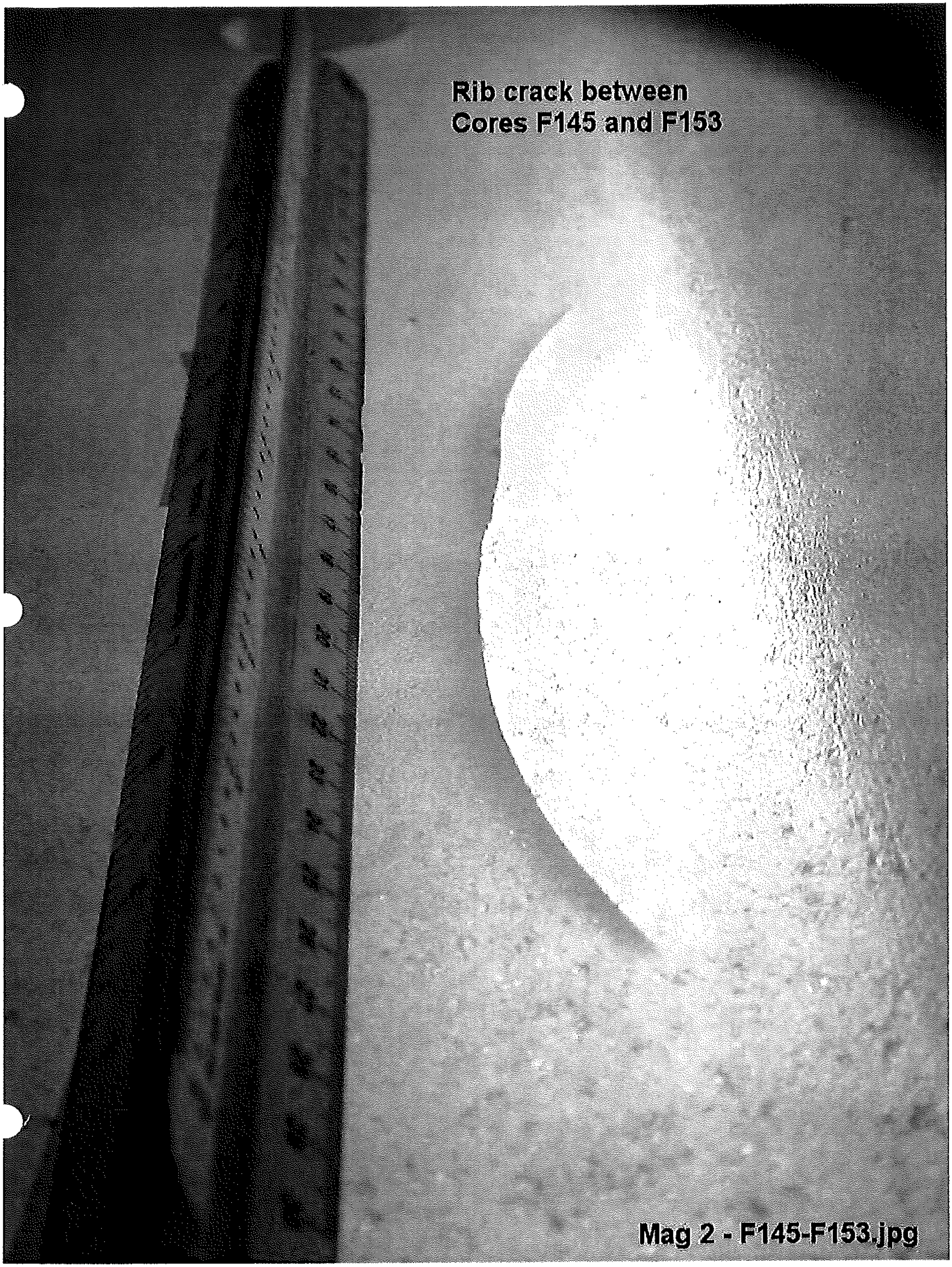
The Magellan 2 mirror was inspected for any damage that may have occurred since it was inspected in May 1999. The damage previously repaired was also inspected to insure no further action was necessary. The mirror was inspected while in the transport box, so approximately 10% of the cells could not be thoroughly inspected due to interference of the support structure.

The mirror was inspected by three people and took approximately 5 hours to complete. Each cell wall and the backplate were inspected for fractures. The procedure used was to insert a fluorescent lamp into a cell and to inspect its cell walls by peering through the neighboring backplate holes. An inspection mirror was used to view those areas not readily visible. By this method, each cell wall was inspected on each side. The backplate was inspected while it was illuminated by the lamp inside the cell.

As a result of the inspection, a single, new fracture was observed. The fracture was detected in the rib between core F145 and F153. The fracture is about 17 centimeters long and runs roughly vertical from about 10 centimeters up from the inside surface of the backplate. No readily apparent impact location was noted around the fracture and its source is unknown.

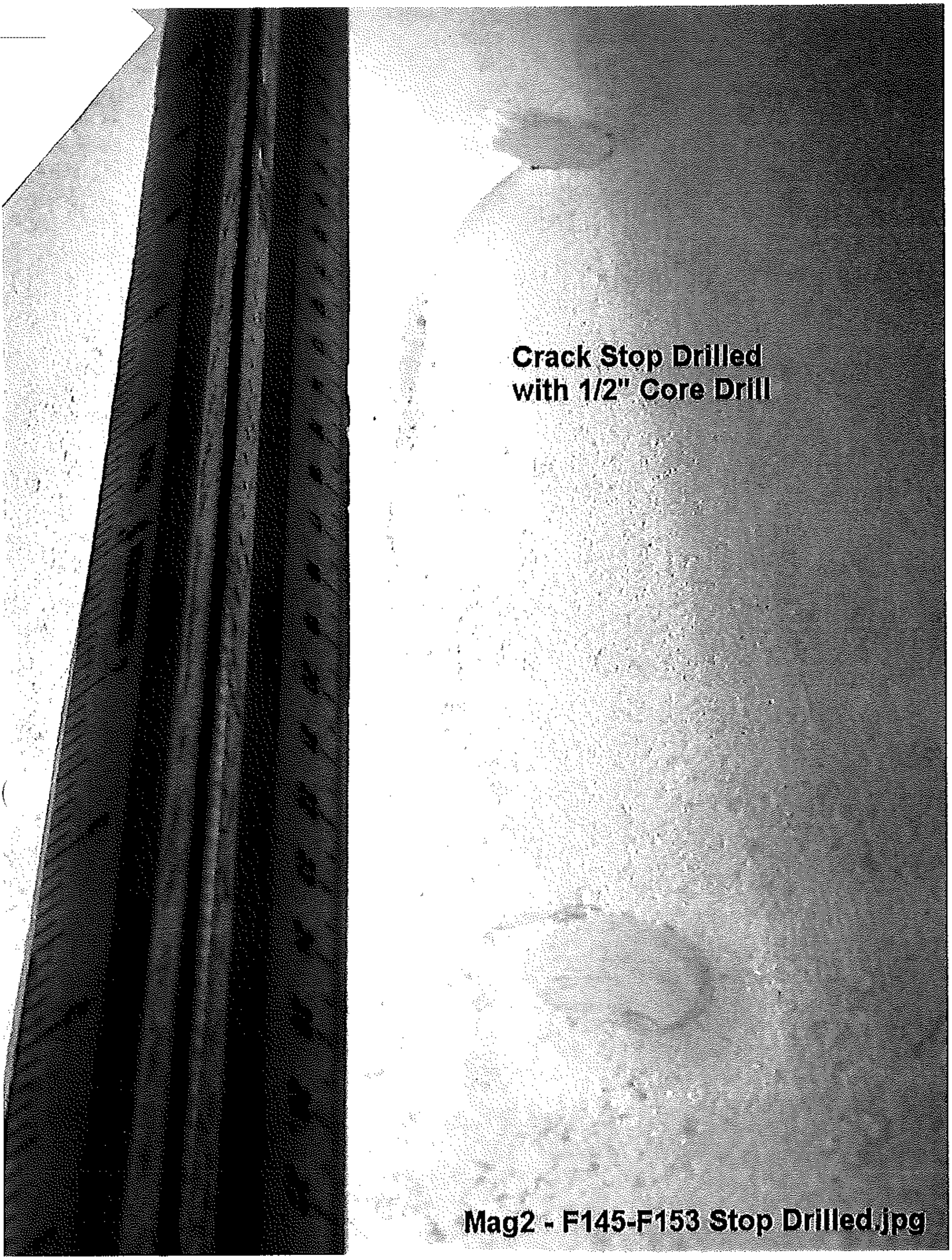
The fracture was treated by terminating both ends of the fracture with a 1/2" hole. The fracture was then re-inspected to make sure the tips of the fracture were captured by the holes. As the holes looked clean and no other damage was noted, that was the extent of the treatment required. Photographs were taken before and after crack termination for documentation purposes.

We noticed some loose dirt and refractory material on the inside surface of the backplate during inspection, so a final washdown was done to wash it away.



Rib crack between
Cores F145 and F153

Mag 2 - F145-F153.jpg



Crack Stop Drilled
with 1/2" Core Drill

Mag2 - F145-F153 Stop Drilled.jpg