TITLE

LARGE OPTICS SUSPENSION BALANCING

APPROVALS:	DATE	REV	DCN NO	BY	CHK	DCC	DATE
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1 INTRODUCTION

1.1. Objectives and Scope

The scope of this document is to specify how to clean and assemble a Large Optic Suspension. It also details how to prepare an optic for installation into the suspension structure and how to hang and balance that optic.

1.2. Version History

8/21/98: Rev A by J. Hazel Romie.

6/28/99: Rev B first draft by M. Barton - near-complete rewrite.

7/13/99: Rev B second draft. Extensive revision of procedure for installing the wire.More detailed description of autocollimator usage.

1.3. Applicable Documents

LIGO-D960132: Large Optic Suspension Assembly, LOS1a
LIGO-D970560: Large Optic Suspension Assembly, LOS1b
LIGO-D970564: Large Optic Suspension Assembly, LOS1c
LIGO-D970572: Large Optic Suspension Assembly, LOS1d
LIGO-D970577: Large Optic Suspension Assembly, LOS1e
LIGO-D970561: Large Optic Suspension Assembly, MMT3, 4k
LIGO-D970578: Large Optic Suspension Assembly, MMT3, 2k
LIGO-D970505: Large Optic Suspension Assembly, LOS2a
LIGO-D970539: Large Optic Suspension Assembly, LOS2b
LIGO-D970507: Large Optic Suspension Assembly, LOS3

LIGO-D960133: LOS Structure Assembly, LOS1
LIGO-D970551: Recycling Mirror Structure Assembly
LIGO-D970506: LOS Structure Assembly, Beamsplitter
LIGO-D970508: LOS Structure Assembly, Folding Mirror

LIGO-D960145: LOS Height Adapter Assembly
LIGO-D970571: LOS1c Height Adapter, Recycling Mirror 4k
LIGO-D970579: LOS1e Height Adapter, Recycling Mirror 2k
LIGO-D970554: LOS2a Height Adapter, Beamsplitter 4k

LIGO-D970555: LOS2b Height Adapter, Beamsplitter 2k
LIGO-D970569: LOS3 Height Adapter, Folding Mirror

LIGO-E960022: LIGO Vacuum Compatibility, Cleaning Methods and Qualifications Procedures
LIGO-M990034: LIGO Hanford Observatory Contamination Control Plan
LIGO-E970153: Large Optics Suspension Quality Conformance Worksheet
LIGO-E990196: Magnet/Standoff Assembly Preparation Specification
LIGO-E990197: Magnet/Standoff Assembly Quality Control Worksheet
LIGO-T960074: Suspension Preliminary Design
LIGO-T950011: Suspension Design Requirements
LIGO-T970158: Large Optics Suspension Final Design (Mechanical System)
LIGO-L970196: Part Numbers and Serialization of Detector Hardware

2 VACUUM COMPATIBILITY REQUIREMENTS

2.1. General Handling

All procedures listed under this specification for assembly and balancing must be performed in a clean room environment while suited up in clean room clothing including, but not limited to: coat, booties, bonnet, latex gloves, facial mask. This applies to anyone handling or near clean pieces or pieces being cleaned.

For further detailed handling requirements see M990034, LIGO Hanford Observatory Contamination Control Plan. In the terminology of that document, the optic, suspension structure and associated parts are Class A hardware (i.e., destined to be installed in vacuum) and once cleaned and baked should not come into contact with anything but Class A and B hardware.

2.2. Preparation of the Suspension Structure

2.2.1. Cleaning and Baking

The structure assembly is to be cleaned and baked in preparation for installation according to LIGO-E960022, LIGO Vacuum Compatibility, Cleaning Methods and Qualifications.

During cleaning, all personnel in the cleaning area must wear complete clean room garb, including a lab coat, face mask, bouffant cap, shoe covers and clean room gloves. (This applies to anyone handling or near clean pieces or pieces being cleaned.)

Cleaning is to be performed in a “clean manufacturing area” separated from all other operations. This space should have non-shedding floors, walls and ceiling. In addition, the atmosphere for this “clean manufacturing area” must not exchange directly with the shop floor area; the air must be carbon and HEPA filtered and monitored with a hydrocarbon meter.

Use latex gloves (see Appendix 1) for handling cleaned parts.

After cleaning and baking, suspension component surfaces shall not be touched by skin or other contaminants. Only C.P. Stat plastic sheet, UHV Al foil and latex gloves are acceptable. All suspension parts shall be double bagged (C.P.Stat plastic) or protected by a Class 100 cleanroom atmosphere. Small components can be bagged together with other small pieces. See Appendix 1 for information about the plastic, foil and gloves.

2.2.2. Cleaning Inspection and Testing

Sample check the cleanliness of blind tapped and through tapped holes with a clean Q-tip dampened with alcohol for a minimum of 10% of the holes. If any discoloration of the Q-tip is evident, then the part must go through at least one more wash before repeating a check of the cleanliness. If any machining chips are found:
(a) a HEPA filtered vacuum cleaner may be used to remove the chips from the holes, and
(b) the holes must be cleaned with a solvent dampened Q-tip wipe.

After inspection and testing, double bag the component in C.P. Stat plastic film. Tie or band the inner bag(s) closed. Do not use tape or heat sealing on the inner bag. Purge the bag with dry nitrogen (class 5 or better) before closing. The outer bag should be heat sealed, after purging with dry nitrogen.

A log of the cleaning procedure shall be kept and form part of the component traveler.

2.2.3. Baking Inspection

Sample check the cleanliness of blind tapped and through tapped holes with a clean Q-tip dampened with alcohol for a minimum of 10% of the holes. If any discoloration of the Q-tip is evident, then the part must go through at least one more wash before repeating a check of the cleanliness. If any machining chips are found:
(a) a HEPA filtered vacuum cleaner may be used to remove the chips from the holes, and
(b) the holes must be cleaned with a solvent dampened Q-tip wipe.

Use isopropanol to spot clean any fingerprints.

After inspection, double bag the component in C.P.Stat plastic film. Purge the bag with dry nitrogen (Grade 5 or better) before closing. Tie or band the inner bag(s) shut. Do not use tape or heat sealing. The outer bag should be heat sealed, after purging with dry nitrogen.

A log of the baking procedure shall be kept and form part of the component traveler.

3 QUALITY ASSURANCE/CONTROL

3.1. Quality Assurance Provisions

Measure the strength of the coils in the sensor/actuator head assemblies using an F. W. Bell Model 9200 Portable Gaussmeter with a Gaussmeter Probe, P/N HTB92-0608 and the Coil Strength Fixture, P/N D970616 for sensor/actuator head assembly testing. Collect six sensor/actuator head assemblies (five needed and one spare) that have comparable strengths, to within +/- 1%, record serial numbers and strengths of each assembly and set

them aside for one suspension. Use the Large Optic Suspension Assembly Quality Conformance Worksheet to record this data.

???Move measurement of photodiode output voltage here?

To ensure Quality Conformance for the assembly, complete and file the Large Optic Suspension Assembly Quality Conformance Worksheet, E970132, and keep it with the traveler record for the assembly.

4 FIXTURES

4.1. Drawing Numbers

D961412: Set Screw Tool

D990159: Magnet/Standoff Assembly Fixture
D990186: “Ears” for use with ETM, MMT3, FM, Dummy Mass
D990187: “Ears” for use with ITM4k
D990189: “Ears” for use with ITM2k
D990188: “Ears” for use with RM

D990190: LOS2 Magnet/Standoff Assembly Fixture (for use with BS)

D960147: Base Plate of Guide Rod Fixture Assembly and blocks for use with ETM, MMT3, FM and Dummy Mass
D970574: Guide rod blocks for use with ITM4k
D970573: Guide rod blocks for use with ITM2k
D970568: Guide rod blocks for use with RM
D970550: LOS2 Guide Rod Fixture for use with BS-4k, BS-2k

D960763: Fixture, Test Mass (a.k.a. the Dummy Mass)
D970553: LOS2 Test Mass Fixture (an Al blank the size of the BS)

38427: Edmund Scientific, Pocket Measuring Microscope
D960016: Microscope Bushing
PZT Buzzer
D950126: LED Fixture
D970180: Winch Fixture
D960145: Height Adapter
D960753: Fixture, Wire and Optics
D960761 Lifting Fixture

D960145: Height Adapter for ETM, ITM4k, ITM2k
D970571: Height Adapter for MMT3-4k, RM-4k
D970579: Height Adapter for MMT3-2k, RM-2k
D970554: Height Adapter for BS4k
D970555: Height Adapter for BS2k

D970569: Height Adapter for FM

NO LONGER USED ITEMS:

D970074: Magnet-to-Dumbbell Standoff Fixture

D60050: Magnet Standoff Assembly Fixture (for all LOS and MMT3 except BS)

D970552 LOS2 Magnet/Standoff Assembly Fixture

4.2. Descriptions

- **Set Screw Tool**

Used to ease in the installation of the spring plungers in the Sensor/Actuator Plates.

- **Magnet-to-Dumbbell Standoff Fixture**

Used to configure and bond the magnets to the dumbbell shaped aluminum standoffs.

- **Magnet/Standoff Assembly Fixture**

Used to position and epoxy the magnet/standoff assemblies to the face and sides of the optic.

- **Guide Rod Fixture**

Used to position and bond a guide rod and a wire standoff to the side of the optic.

- **Fixture, Test Mass and LOS2 Test mass Fixture**

Used for the prototype test. These aluminum dummy optics have the same size, wedge, chamfer and approximate mass as the ETM and BS.

- **Measuring Microscope**

Used to align the sensor/actuator plates to the magnet/standoff assemblies glued on the optic or dummy mass.

- **Microscope Bushing**

Mounted on the bore of the measuring microscope and used to adapt the bore of the microscope to the bore of the holes for the sensor/actuator head assemblies in the sensor/actuator plates. This bushing is also used to align the centerline of the microscope (crosshairs) to the centerline of the outside diameter of the bushing.

- **PZT Buzzer**

Used for sliding the wire standoff along the side of the optic to change the pitch balance of the optic. It is a rod or tube to which a PZT is attached. The PZT is driven while the vibrating rod is placed against the end of the standoff to produce small displacements of the standoff.

- **LED Fixture**

Used to position and mount the LED relative to the photodiode in the sensor/actuator head. Use of this fixture will be covered in another document

- **Winch Fixture**

Used to microposition the suspension wire vertically.

- **Height Adapter**

Used to adapt suspension to its correct vertical position relative to the laser beam.

- **Fixture, Wire and Optics**

Used to position the wire and to protect and move the optic into position in the suspension support structure.

- **Lifting Fixture**

Mounted to a fork lift, this fixture allows for the assembly to be moved into place on the optical table.

5 ASSEMBLY/BALANCING SPECIFICATION

5.1. Magnet Preparation

Make sure there are (i) a matched set of 2 north and 2 south magnet/standoff assemblies for use on the face of the optic, (ii) a matched set of 2 south magnet/standoff assemblies for use on the side of the optic, (iii) a matched set of PAM screws. If there are, select them and record which optic they were used on in the corresponding Magnet/Standoff Assembly Quality Conformance Worksheet E990197. If not make them up according to the instructions in Magnet/Standoff Assembly Preparation Specification, E990196.

5.2. Optic (or Dummy Mass) Preparation

5.2.1. Wire Standoff and Guide Rod (With Guide Rod Fixture)

5.2.1.1 Materials

Optic or Dummy Mass
D960755 LOS Large Wire Standoff or appropriate
D960146: Guide Rod
Perkin Elmer Vac-Seal epoxy resin
D960147: Base Plate of Guide Rod Fixture Assembly and blocks for use with ETM, MMT3, FM
D970574: Guide rod blocks for use with ITM4k
D970573: Guide rod blocks for use with ITM2k
D970568: Guide rod blocks for use with RM
D970550: Guide Rod Fixture Assembly and Blocks for use with BS4k, BS2k
solvents; isopropanol, acetone
6” length of clean copper wire (never having had insulation)
UHV aluminum foil
lint-free wipes
small vacuum chamber with backing pump

5.2.1.2 Fixture Assembly

1. Clean fixtures: Clean the base plate and the side blocks of the guide rod fixture thoroughly per LIGO Vacuum Compatibility, Cleaning Methods and Qualifications Procedures document, LIGO-E960022. Clean and bake the guide rod and wire standoff per the same specification.
2. Prepare baseplate: Put the baseplate on a clean work surface with the serial number the right way up as viewed from the position of the worker. Engage the two side blocks with the dovetail slides on the guide rod fixture, taking care to match left and right. It is important to do this step before placing the optic, because the blocks foul on the optic when it is in position. Slide the blocks to their lowest position to give plenty of space for bringing in the optic. Cut three small strips (.50” x 1.00”) of Kapton tape and place on the etched circle in the base plate. This Kapton is used to protect the bottom face (the high reflective surface) of the optic.
3. Position optic on baseplate as follows: (i) the face of the optic should be concentric with the etched circle, (ii) in all cases for the core optics and MMT3, the anti-reflective side should be up, that is, the arrow etched on the side of the optic should point down (towards the floor), and (iii) with one exception (the recycling mirror), the edge of the optic with the arrow should be towards the “bottom” side of the baseplate (towards the worker). Make fine adjustments to the position and angle of the optic until the four etched lines on the side of the optic line up with those on the base plate. Be careful to allow for parallax. Before sighting on the line on the baseplate, position your eye so that the line on the near side of the optic lines up through the body of the optic with the one on the far side.
4. Check the sides of the optic for cleanliness. If marks are present, clean them off with the appropriate solvent and lint-free wipes.
5. Position left and right blocks: Snug them up against the side of the optic and tighten the screws that hold the top blocks to the base plate to finger tightness.
6. Prepare adhesive applicator: Clean the copper wire with acetone and alcohol with lint-free wipe.
7. Prepare epoxy: Mix the two epoxy components of a Vac Seal “bipax” together thoroughly, approximately 2 minutes. Dispense from the middle of the container into a boat made of clean UHV aluminum foil. Degas the epoxy for 3 minutes at 10 torr (or the vacuum from any typical backing pump).
8. Position and glue the wire standoff and guide rod: Position the guide rod in the smaller vertical v-groove. If there is difficulty inserting the guide rod into the v-groove, move the top block down a bit, along the wedge, insert the guide rod, and then cinch the block back into position, holding the guide rod in the v-groove securely. Dip applicator wire in epoxy and withdraw it, leaving a tiny amount of epoxy on the wire. Apply epoxy on the wire to the vertical line of contact between the guide rod and the optic that is furthest away from the magnet/standoff assembly. Be sparing in epoxy at this point as more glue will be used later to secure this guide rod. Take care not to get epoxy on the fixture. Insert the wire standoff in the other vertical v-groove and apply epoxy in the same way. Be sure to apply epoxy to the vertical line of contact between the wire standoff and the optic that is furthest away from the magnet/standoff assembly.
9. Check the adhesive joints: If preparing an optic rather than a metal dummy mass, look through the optic at the two glue joints and make sure that the glue has spread over the whole area of the joint.
10. Cure epoxy: Leave the assembly for 24 hours or more. Vac Seal cures fully in 72 hours so if that time is available, it should be used to allow the assemblies to fully cure. Note that the side blocks which existed as of this version of the balancing procedure are **not** rated for a high temperature cure.
11. Remove the guide rod fixture: After curing, unscrew the fasteners that hold the top blocks to the base plate,

one side at a time, and slowly, carefully, move the top blocks down the wedges.

5.2.2. Applying Magnets (With Magnet/Standoff Assembly Fixture)

5.2.2.1 Materials

1 set of magnet/dumbbell standoff assemblies for LOS
Perkin Elmer Vac-Seal epoxy resin
D99????: Baseplate for use with Magnet/Standoff Assembly Fixture
D990190: BS Magnet/Standoff Assembly Fixture
D990159: Generic LOS Magnet/Standoff Assembly Fixture
D990186: “Ears” for use with ETM, MMT3, FM
D990187: “Ears” for use with ITM4k
D990189: “Ears” for use with ITM2k
D990188: “Ears” for use with RM
D960763: Fixture, Test Mass (Dummy Mass) or Optic or appropriate

Kapton film, 0.0075” thick, **with no adhesive**
solvents: isopropanol, acetone
6” length of clean copper wire (never having had insulation)
small vacuum chamber with backing pump
UHV aluminum foil
lint-free wipes
oven mitts
PFA-440 (heat resistant, low-fluorine) Teflon, approx 400 mm x 400 mm x 3 mm
air bake oven
lab jack (plus extensions as required to reach height of floor of oven)

5.2.2.2 Fixture Assembly

1. Preheat bake oven: Turn on the air bake oven and set the thermostat for 100 C. Lay a sheet of Teflon on the floor of the oven.
2. Clean fixtures: Clean the base plate and top ring of the magnet/standoff assembly fixture thoroughly per LIGO Vacuum Compatibility, Cleaning Methods and Qualifications Procedures document, LIGO-E960022.
3. Prepare baseplate: Put the baseplate on a clean work surface with the two handles at front and back as viewed from the position of the worker.
4. Position optic on baseplate in the same orientation as for gluing the wire standoff and guide rod:(i) in all cases for the core optics and MMT3, the anti-reflective side should be up, that is the arrow etched on the side of the optic should point down, and (ii) with one exception (the recycling mirror), the arrow should be toward the “bottom” side of the baseplate, that is, toward the worker.
5. Prepare the magnet/standoff fixture: Back off the three 1/4-20 set screws in the top ring until the Teflon tips are flush with the the inner surface of the ring.
6. Mount the magnet/standoff fixture: Carefully lower the ring onto the face of the optic with the “top” part of the ring away from the worker. Align the lines on the “top” and “bottom” of the ring with the etched lines on the side of the optic. Advance the set screws by small, equal increments (e.g., 1/4 turn) until they grip the

sides of the optic. Recheck the alignment of the etched lines. If there is misalignment, back off all the set screws a small amount, rotate the ring as appropriate and retighten the screws. Using the depth gauge of a clean set of vernier calipers, check that the distances to the side of the optic from the reference flats on the outside of the ring are equal.

7. Move the optic into the oven: Open the oven door. Working quickly, set up a lab jack in front of the door, with the top level with the floor of the oven. Put a sheet of Teflon on the top of the jack. Move the baseplate with the optic on it onto the lab jack, being careful to keep it level so that the optic and top ring do not slide around. Slide the whole assembly into the oven and close the door. Wait 1 hour for the temperature to return to 100C.
8. Prepare the plungers: Lay out a clean piece of UHV foil in a convenient position near the oven. Lay out the plungers on the foil in an arrangement similar to the magnet positions in Figure 1. The magnets are placed so that polarities of the magnets alternate; this is to minimise coupling of the optic to time-varying ambient magnetic fields. For each magnet/standoff assembly, double-check the magnet polarity and standoff type and install it into the corresponding plunger, with the standoff end outwards and with only about 1 mm of the magnet visible. Gently press on the end of the standoff to ensure that the magnet/standoff assembly is gripped firmly and will not slide into the plunger.
9. Prepare the adhesive applicator: Clean the copper wire with acetone and alcohol with lint-free wipe.
10. Prepare the epoxy: Mix the two epoxy components of a Vac Seal “bipax” together thoroughly, approximately 2 minutes. Dispense from the middle of the container into a boat made of clean UHV aluminum foil. Degas the epoxy for 3 minutes at 10 torr (or the vacuum from any typical backing pump).
11. Slide the optic out of the oven: Open the oven door and set up the lab jack in front of the oven with the Teflon sheet on top. Using oven mitts, slide the optic far enough out that the ‘ears” on the side of the Magnet/Standoff Assembly Fixture are readily accessible.
12. Apply the epoxy and insert the plungers in the fixture, starting with the sides. Dip applicator wire in epoxy and withdraw it, leaving a tiny amount of epoxy on the wire. Apply epoxy on the wire to the end of a standoff. Optimum adhesive thickness is .003” [.08mm] or a volume of 3.9×10^{-6} in^3 [$.06mm^3$]. Epoxy should only cover a diameter of about .02” [.5mm] with a height of .01”[.3mm]. Insert the plunger holding the magnet/standoff assembly into fixture. Have an assistant apply gentle pressure to the side plungers for about 30 s after they have been inserted while you are working on the face plungers. Make sure to preserve the configuration of magnets established in Step 8.
13. Cure epoxy: Slide the optic back into the oven and close the door. Allow to bake for 2 hours.
14. Remove the plungers: using a lint-free wipe to protect your hand from the hot metal, squeeze each plunger so that it releases the magnet/standoff assembly and withdraw it.
15. Let the optic cool: Where possible, just slide the optic back into the oven, turn the oven off and allow the optic to cool in situ. If the oven is required again immediately, use extreme caution in removing the optic to avoid burns to workers and damage to the optic.
16. Remove magnet/standoff fixture: Loosen the three 1/4-20 set screws that hold the Magnet/Standoff Assembly Fixture to the optic. Slide the ring off straight upwards, using extreme care to ensure that the ears maintain safe clearance from the side magnets.
17. Test the strength of the bonds: For each magnet in turn, allow the flat surface of a clean razorblade to stick to the flat end. Pull the razorblade straight off along the axis of the magnet. If the magnet/standoff assembly survives the bond is adequate. Note the results of the test in the corresponding Large Optics Suspension

Quality Conformance Worksheet, E970153.

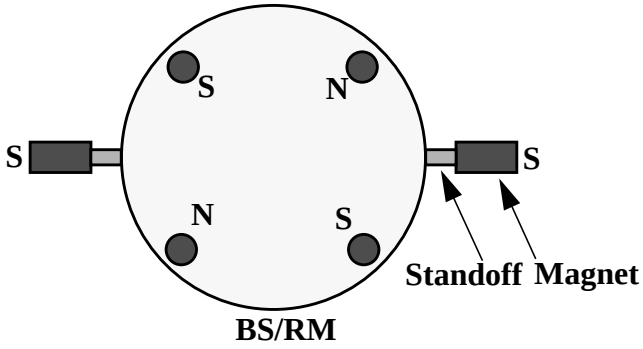

Figure 1: Polarities of the magnet/standoff assemblies.

5.3. Suspension Assembly

5.3.1. Materials

D??????: suspension block
D970180: Winch fixture (2 of)
4 silver-plated 1/4-20 x 1.5”??? socket head screws
8 3/8” silver-plated Fluorel-tipped safety stop screws
8 1/2” silver-plated Fluorel-tipped chamfer stop screws
4 Teflon caps for lower safety stops

NOTE: Due to space constraints, the LOS3 structure (used for the FM) requires custom chamfer stop screws without heads on the OSEM side of the structure. The LOS2 (used for BS) has custom safety and chamfer stop screws.

5.3.2. Procedure

1. Clean and bake all components of the suspension assembly, except the suspension wire, per LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures, LIGO-E960022.
2. Prepare the suspension block and winch fixtures: Set the suspension block on top of the LOS structure, and insert the attachment screws with their washers. Before tightening the screws, use a clean set of vernier calipers to ensure that the edge of the suspension block is parallel to the top edge of the structure. Using oversize washers and 1/4-20x1.5” long screws, attach a winch to each of the threaded holes on the top of the suspension block, with the rocker of the winch closest to the front of the suspension block. Fit suspension block clamps (6 in all) to the suspension block and the winch fixtures, leaving all screws very loose.
3. Screw in the 8 chamfer stop screws and the 8 safety stop screws into their respective brackets until they protrude past the inside of the bracket by about .25”.

4. Install the socket head set screws, into the Sensor/Actuator Brackets in preparation for the installation of the Sensor/Actuator Assemblies. The Set Screw Tool may be used with the cross head spring plungers instead of a regular screw driver.

Note: Do not install the height adapter yet. Although it is part of the suspension assembly, if it is installed before the optic is suspended, access to the suspension block is awkward at best and impossible at worst.

5.4. Optic Installation

5.4.1. Suspension Structure Assembly and Optic Hanging

5.4.1.1 Materials

Optic or dummy mass with magnet/standoff assemblies, guide rod and wire standoff from above.
D960132: Structure for ETM (LOS1a)
D970560: Structure for ITM4k (LOS1b)
D970572: Structure for ITM2k (LOS1d)
D970561: Structure for MMT-4k
D970578: Structure for MMT3-2k
D970564: Structure for RM4k (LOS1c)
D970577: Structure for RM2k (LOS1e)
D970505: Structure for BS4k (LOS2a)
D970539: Structure for BS2k (LOS2b)
D970507: Structure for FM (LOS3)
0.012” diameter suspension wire (0.008” for BS)
D960755: Large Wire Standoff or appropriate
Bubble level
Perkin Elmer Vac-Seal epoxy resins
6” length of clean copper wire (never having had insulation)
UHV aluminum foil, Ameristat
lint-free wipes
solvents: isopropanol, acetone
38427 Edmund Scientific, Pocket Measuring Microscope
D960016: Microscope Bushing
PZT Buzzer
D960753: Fixture, Wire and Optics
Base Plate
Cradle
Teflon Bracket
Metal Brackets
Teflon Strap
Teflon caps for lower safety stop screws

5.4.2. Assembly

NOTE: It is absolutely essential to have two people for this section of the procedure.

1. Prepare the wire standoff: Clean and bake the other wire standoff per LIGO Vacuum Compatibility, Cleaning Methods and Qualifications Procedures document, LIGO-E960022.
2. Prepare work surface: Level an optical bench using a bubble level to 0.3 mrad or better. Place the LOS structure on a sheet of Ameristat on the table and align it square to the hole pattern as closely as possible by eye. If at all possible, have the structure facing such that when the optic is installed, the side of the optic with the guide rod will be in a convenient position towards the edge of the table (the guide rod is not on the same side for all optics). Make sure there is a clear space for at least 0.5 m behind the structure (on the side with the sensor-actuator brackets) and 1 m in front.
3. Level the top of the structure: For optics to go in BSC chambers (all but MMT3 and RM) check that the top surface of the structure is level to 0.3 mrad or better. If necessary shim the base with sheets of UHV Al foil. For the MMT3 and RM, just ensure the optical table is level and that the base of the structure sits snugly on it.
4. Fit the Teflon caps over the Fluorel tips of the lower safety stop screws.
5. Prepare the suspension wire: Cut two lengths of wire each about 2 m long. The wire should not be baked - only cleaned. Clean the wire thoroughly by wrapping an acetone-soaked lint-free wipe around the wire and gently pulling the wire through the wipe. This should be done a minimum of three times to remove any rust and contaminants. Repeat with isopropanol. Coil one length loosely, wrap it in UHV Al foil and set it aside for later.
6. Install the suspension wire: Thread one end of the wire up through the gap between the side sensor/actuator bracket and the optic, then up to the suspension block, through the jaws of the lower suspension block clamp, around the inside of the dowel pin, and through the jaws of the other suspension block clamp and the winch fixture clamp. Repeat with the other end of the wire, ensuring that the wire is free of twist and kinks. (In the case of the LOS2 structure, ensure that the wire encircles the strut that runs between the front and back reinforcing box-beams.) Tighten the upper and lower suspension block clamps so that they locate the wire against the side of the block, but apply negligible force. Leave a very large amount of slack - enough that the loop can be formed into a large triangle with its corners outside and below the safety stop screw brackets. Tuck the bottom of the loop below the rear brackets and move all the wire as far to the rear as possible.

NOTE: Steps 7 - 9 do not apply to the BS because the cradle does not fit into LOS2. The BS should be picked up with hands at 6 o'clock and 12 o'clock and inserted into the structure manually.

7. Place the cradle baseplate near the LOS structure on the front side (opposite the sensor actuator brackets) and put the cradle on top. Adjust the height of the top of the baseplate by placing one or more lint-free wipes under it so that it is level with the bottom plate of the LOS structure and the cradle can slide smoothly from one to the other.
8. Move the optic onto the cradle: This step assumes the optic starts lying HR (or BS) side down on the baseplate of the gluing fixture. Standing the optic up is possibly the most risky part of the procedure and should be carefully rehearsed. The side magnets are at the 3 o'clock and 9 o'clock positions around the edge and are extremely easy to knock off. The sequence of holds described below keeps hands away from the magnets and eliminates awkward wrist angles, thus minimising the risk of injury to personnel and damage to the

optic. One person should pick up the optic with hands placed at 6 o'clock and 12 o'clock. The stronger hand (i.e., typically the right hand) should be at 6 o'clock and the fingers should be horizontal, i.e., tangentially around the edge of the optic. The first person should then rotate the optic so that it is standing up, with the weight on the hand at 6 o'clock. A second person should then take the optic, using hands at 4:30 and 7:30 and with fingers pointing parallel to the cylinder axis. The second person should have the face magnets towards them so they are easy to see and cannot be knocked off if their fingers curl behind the optic. The second person should place the optic on the cradle with the arrow exactly at the bottom (or exactly at the top in the case of the RM).

9. Move optic into place: Rotate the cradle on its baseplate until the face magnets on the optic point towards the back of the structure. Slide the baseplate up to the bottom plate of the structure. Carefully slide the cradle off the baseplate, onto the bottom plate and into the structure, checking continually that the optic does not bump into any of the brackets, until it is symmetrically located both left-to-right and front-to-rear relative to the safety stop brackets. Screw in the lower safety stops until they touch the optic. Then screw each stop in one turn further so that they lift the optic about 1 mm above the cradle. Push the cradle out from underneath the optic towards the front of the structure (not the back as in previous versions of this procedure) and remove it. Screw in the chamfer stops and the upper safety stops so that there is a 1-2mm gap between the optic and the end of the stop.
10. Post a person to safeguard the side magnets: Have a second person watching throughout the next few steps to make sure the wire does not come too close to the side magnets. This requires a lot of care because the wire is magnetic. The assemblies should withstand the wire being pulled off straight in any direction against the force of the magnetic attraction. However the assemblies are no match for a taut wire trapped on one side and wanting to be on the other side. Be especially careful to avoid the wire getting hooked in the waist of the dumbell standoff.
11. Take up the slack in the wire: Move the bottom of the wire loop forward into the gap between the front and rear safety stop brackets. Pull the ends of the wire so that the loop tightens around the optic. On the side of the optic with the wire standoff, let the wire drop into the groove in the standoff. On the other side, let the wire rest on the guide rod,a few mm to one side of the magnet standoff assembly. Tighten one upper suspension block clamp. Apply moderate tension with fingertips to the end of the wire on the other side and tighten the other upper suspension block clamps. It should be possible to pull the wire a few millimetres away from the optic using only tweezers.
12. Insert the second wire standoff: Hold the wire away from the side of the optic (and the magnet!) with a pair of tweezers and insert the second wire standoff below the guide rod but snugged up against it, using a second pair of tweezers. Position the wire standoff so that its central groove is directly below the centre of the guide rod, and make sure the wire drops into the groove. If the standoff is difficult to insert or if it will not hold its position beneath the guide rod, adjust the tension in the wire slightly with the winch fixture and try again.
13. Suspend the optic: Slowly, lower the safety stops that support the bottom of the optic and suspend the mass. Try backing off the chamfer stops and note which direction the optic tends to tip. Use the PZT buzzer to micro-position the wire standoff so that the optic/dummy mass will hang stably at very roughly the desired angle (as judged by eye).
14. Check the line of the wire underneath the optic: Check that the part of the loop below the standoff lies in the same plane as the part above, as nearly as possible as judged by eye. If the wire bends at the standoff when viewed from the side, it will cause a substantial pitch of the optic which is likely to change over time as the

wire relaxes. A bend of the wire sufficient to displace the bottom of the loop about 5 mm from the centreline is equivalent to about 3 mrad of pitch. If the wire is bent, raise the lower safety stops to take most of the tension off the wire, and push it into line using a pointed tool such as the nose of a pair of tweezers.

15. Set up the winch fixtures: The cradle leaves the optic slightly higher than its working position so it is convenient to set the initial position of the winches so there is plenty of scope for lowering. (This may not apply for the BS, which is inserted manually.) For each winch fixture in turn, hold the back of the lever up under the head of the main screw (it tends to fall under its own weight) and adjust the main screw until the the lever is slightly nose up. Still holding the lever in position, put tension on the end of the wire and tighten the wire clamp on the nose of the winch.
16. Do a preliminary adjustment of the position of the optic in roll and vertical using the winches. Put sensor-actuator head assemblies (without PAM screws) in the brackets. Do not bring them close to the magnets at this point - the risk of damage is too great. Leave several mm clearance - somewhat more than the chamfer stop to optic distance. Sight through the sensor-actuator heads, controlling for parallax by positioning your eye so that the aperture at the far end of the sensor-actuator head is centred in the aperture on the closer side. Adjust the lengths of the wires on each side until the magnets on the face of the optic line are centered in the square holes for the sensor/actuator head assemblies. At this stage, concentrate on roll, that is, make sure that the magnets on opposite sides are in the same relative vertical positions with respect to the corresponding sensor/actuator heads. The final absolute adjustment in vertical can only be done after the final pitch adjustment, because the lever arm of half the thickness of the optic times a typical pitch angle amounts to a non-negligible vertical displacement of the magnets.

5.4.3. Optic Balancing

5.4.3.1 Materials

Optic suspended in Large Optic Suspension Structure
Perkin Elmer Vac-Seal epoxy resins
6” length of 20 to 30 ga insulated wire
UHV aluminum foil
lint-free wipes
PZT Buzzer
D960753: Fixture, Wire and Optics ????
cradle and base plate
Teflon Bracket
metal Brackets
Teflon Strap
solvents: isopropanol, acetone

Autocollimator and power supply, #????
Autocollimator holder (with 2 DOF adjustment), #????
Corner cube reference for autocollimator
Newport goniometer stage #????
bubble level
precision right angle, #????

precision optical flat, #????
beamsplitter holder or similar tilt/rotation stage
assorted posts, brackets, dogs, 1/4-20 screws, hex wrench
M6 screws and metric wrench

5.4.3.2 Setup of Autocollimator and Balancing

NOTE: most of the alignment operations in the following procedure are there to eliminate trivial second-order errors and to avoid hunting for the autocollimator image in a large multidimensional parameter space. The alignments that are critical to the final result are indicated specially.

1. Set the goniometer up on brackets at a convenient height and position about 0.8 m from the LOS structure. Note that the threaded holes in the base of the goniometer are metric. Ensure (i) the rotation axis is horizontal and parallel to the face of the optic, (ii) the scale is uppermost and set roughly to zero, (iii) the autocollimator, when fitted, will point very roughly at the centre of the optic (this is not at all critical - the optic is effectively perfectly flat for the purposes), and (iv) the fine adjustment screw is set to the appropriate end of its range such that it has room to move in the direction that will take the autocollimator from horizontal to the desired angle for the particular optic.
2. Setup and roughly align the autocollimator: Attach the autocollimator holder and autocollimator. Using the adjustment on the holder, set the autocollimator to be square on the optical table as close as possible when viewed by eye from above (ignore vertical for the moment). Connect the autocollimator power supply and turn it on.
3. Check zeroing of the autocollimator: Put the corner cube reference over the end of the autocollimator. Focus the crosshairs using the black knurled eyepiece surround, and then focus the calibrated scale using the metallic knurned ring at the back of the autocollimator. Check that the scale disappears when the corner cube is removed and the autocollimator aperture is blocked (if not, the autocollimator is actually focussed on an internal surface and is ten or twenty turns from the proper focus). With the corner cube back in place, check that the crosshairs are aligned with the dot in the centre of the scale. (If not, get the autocollimator realigned/repaired.) Remove the corner cube.
4. Align the autocollimator and optic horizontally: Let the optic hang freely. Rotate the goniometer until the scale due to reflection from the HR surface of the optic is visible in the eyepiece. (Because of the by-eye horizontal alignment of the structure and autocollimator specified above, you should only have to search vertically.) If you need to rotate by a large angle, undo the goniometer lock screw and rotate the goniometer stage with your hands - don't use up the limited range of the fine adjustment screw. As well as the scale from the HR face, there will be one from the AR face. For the usual case of a thick-side-up wedge (all optics but RM), the HR reflection is the one that can be seen with the body of the autocollimator in the higher of the two positions. The two reflections are normally different colours, e.g., orange and pink. Note the colour of the HR refection for future reference. Refocus the autocollimator (it should only take a turn or two). Use the adjustment on the holder to improve the alignment of the autocollimator with the optic horizontally (still ignore vertical).
5. Setup the reference block: Clamp the optical flat to one of the reference surfaces of the right-angle block. Set up the beamsplitter holder on a post in front of the autocollimator. Set the right-angle block on the holder with the optical flat towards the autocollimator and the other reference surface uppermost. Level the

reference surface in both directions with the bubble level (not critical). Rotate the block in yaw until the optical flat is facing the autocollimator as accurately as can be judged by eye. Rotate the autocollimator in pitch until it is as accurately horizontal as can be judged by eye. Look in the autocollimator and continue addjustments in yaw of the block and pitch of the autocollimator until the scale from reflection of the flat on the reference block can be seen. (Because of the by-eye alignment in the previous two steps, this should be close in both directions.) Refocus the autocollimator. Continue fine rotation in yaw until the scale is centred horizontally (not critical).

6. Level the upper surface of the reference block as accurately as possible in pitch with the bubble level. The zeroing of the bubble level should be checked independently beforehand by the usual method of measuring a flat surface and then repeating with the level reversed. Do not reverse the level while it is on the reference block - the resulting mechnical perturbation will undo any benefits of the check. Leave the bubble level in place for the next step.
7. Decide the autocollimator angle and check the sense of goniometer adjustment screw: Check the sign of the desired angle of the HR surface in E??????. If the HR surface of the optic is to face upwards, the nose of the autocollimator must dip to point directly at it. Conversely, if the HR surface must point down, the autocollimator must tilt up. Check the sense (clockwise or anticlockwise) of the rotation of the goniometer adjustment screw that is required to tilt the autocollimator by an easily visible amount (a degree or more) in the desired direction.

NOTE: there are two versions of the next step depending on the magnitude of the desired tilt. The autocollimator scale is somewhat more accurate than the goniometer scale and should be used where possible, but the goniometer scale has a larger range and is needed in some cases.

8. Set the autocollimator to the desired angle: CASE I - the magnitude of the desired tilt is within the range of the autocollimator scale (30 minutes). Ignore the scale on the goniometer. Using the goniometer adjustment screw, first centre the autocollimator scale vertically (not critical for Case I). Then, turn the goniometer adjustment screw in the direction established in step 7 until the crosshair indicates the correct magnitude as given in E?????? (critical). CASE II - the magnitude of the desired tilt is outside the range of the autocollimator scale. Set the goniometer stage to exactly zero as indicated on the goniometer scale. Using the vertical adjustment screw on the autocollimator holder, centre the autocollimator scale vertically (critical for Case II). Turn the goniometer adjustment screw in the direction established in Step 7 until the goniometer scale indicates the magnitude of the desired tilt (if the rotation takes the goniometer scale to the positive side of zero, or 360 degrees minus the magnitude of the desired tilt if it moves to the negative side of zero and so wraps around).
9. Remove the reference block.
10. Find the scale again: The initial position of the optic will typically put the scale outside the viewfinder. Have an assistant gently touch the optic on the chamfer at top and/or bottom with a gloved finger until the scale enters the viewfinder. Refocus the autocollimator. Note the direction that the optic needed to be pushed.
11. Adjust the position of the wire standoff to tip the optic in the same direction as above until the scale is visible with the optic hanging freely. Continue fine adjustments until the scale is centred to 0.5 minutes or better (critical). View the optic from the side and double check that the relative tilts of the two faces appear as in the diagram in T99????.
12. Adjust the position of the wire standoff to tip the optic in the same direction as above until the scale is visi-

ble with the optic hanging freely. Continue fine adjustments until the scale is centred to 0.5 minutes or better (critical). View the optic from the side and double check that the relative tilts of the two faces appear as in the diagram in T99????.

5.4.3.3 Cementing Wire Standoff

1. Prepare adhesive applicator: Clean copper wire with acetone and isopropanol using a lint-free wipe.
2. Prepare epoxy: Mix the two epoxy components of a Vac Seal “bipax” together thoroughly, approximately 2 minutes. Dispense from the middle of the container into a boat of UHV aluminum foil. Degas the epoxy for 3 minutes.
3. Apply epoxy: Dip conductor wire in epoxy and withdraw it, leaving a tiny amount of epoxy on the wire. Apply epoxy on the wire to the top side and ends of the wire standoff. Apply epoxy to the unglued end of the opposite wire standoff to secure it better.
4. Gently clamp optic: When the optic is balanced, gently move the chamfer stops near the face of the optic, just until contact is made. Make sure that the alignment doesn’t change. (If the optic is fully clamped, the alignment will change upon the adhesive curing.)
5. Cure epoxy: Let the suspension sit for at least 24 hours (72 hours or more if possible).
6. Remove optic: Raise the lower safety stops until they support the optic and take the tension off the wire. Cut the suspension wire in several places and remove it, taking care not to let it touch the side magnets. Bring in the cradle and back off the lower safety stops so as to lower the optic onto the cradle. Continue removing the optic by the reverse of the above procedure.
7. Inspect, bake and clean optic: Carefully inspect the surface of the optic for cleanliness. If the optic exhibits contaminants, clean for light contamination per LIGO-E960022. Care should be taken to keep the solvents away from all glue joints as both acetone and water will soften VacSeal. Bake the optic per that same specification. After baking, clean the optic with CO_2 snow.

5.4.4. Final Preparation

1. Reinstall the optic: Rehang the optic, using a new length of suspension wire, and make sure it is has maintained its balance using the optical lever.
2. Check balance: Determine if this alignment is satisfactory by assuming a maximum vertical positional offset is 500 microns and the maximum horizontal offset is 300 microns. These offset assumptions are valid for a sensor/actuator head assembly that has the LED and photodiode oriented vertically. If the optic is still misaligned vertically from the sensor/actuator plates, use the winch to adjust its vertical position. If the optic is misaligned rotationally, prop it up with the safety stops under it, and gently rotate about the centerline of the optic. The optic may have to be rotated a number of times to position the wire in the same way it was before baking the optic.
3. Tighten suspension block clamps: Tighten the screws for the bottom suspension block clamps. Tighten the top suspension block clamp. Remove the clamp from the winch and screw it into the suspension block, aligning the wire against the dowel pin. Remove the winch. Recheck all clamp screws to make sure the wire is secure.
4. Prepare and mount height adapter: Clean and bake the height adapter per LIGO-E960022 and bolt it to the Large Optic Suspension Assembly with the hardware listed above. Make sure that the hardware has been cleaned and baked per LIGO-E960022. Torque all fasteners to 100 in lb.

5.5. Sensor/Actuator Head Installation

- **Materials**

suspension
D960138: Sensor/Actuator Assembly
D970615 PAM Screws
D970501 Magnets
Perkin Elmer Vac-Seal epoxy resin
Kapton sensor/actuator cables
solvents: isopropanol, acetone
solder and flux
deflux spray

- **Assembly**

1. Prepare the sensor/actuator heads and cables: Clean the assemblies along with the cables per LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures, LIGO-E960022.
2. Mount the sensor/actuator heads: Install the 4 cleaned and baked #10-32 set screws or spring plungers in the threaded holes that will hold the sensor/actuator assemblies in place until they are flush with the inside diameter of the sensor/actuator assembly mounting hole in the sensor/actuator bracket. Solder the cables to the wires coming out of the pins on the pin plates. Deflux the solder joints.Mount the sensor/actuator assemblies in the proper configuration, making sure that the optic/dummy mass is fully clamped. Slowly, slide the sensor/actuator assemblies into the holes in the bracket until about 2mm of sensor/actuator assembly protrudes beyond the back of the sensor/actuator brackets.
3. Optimally position the heads: Using an oscilloscope, optimally position the sensor/actuator assemblies with respect to the magnet/standoff assemblies on the optic. This is done by measuring the voltage of the unblocked photodiode and then positioning the sensor/actuator head such that the magnet shadows the photodiode and produces 60% of the unblocked voltage. Use the set screws to clamp the sensor/actuator assemblies in their optimum positions. **Always check the position of the safety stops as a gap of 1mm must be maintained to protect the magnet/standoff assemblies during this procedure**.
4. Optimally position the heads rotationally: Check the calculated vertical resonance for the wire. The orientation of the LED/photodiode pair in each sensor/actuator head affects the magnitude of this resonance's coupling into the pitch and yaw resonant frequencies. While moving the sensor/actuator head assemblies near the magnets on the optic, check the orientation of the sensor/actuator head assemblies. Generally, the optimum position is near to vertical, in that the photodiode is directly over the LED in a vertical orientation. If the oscilloscope shows a sharp spike around the calculated vertical resonance, slowly rotate the head assembly until the spike is at a minimum. Generally this is within 20 degrees of the vertical.
5. Install the PAM screw: Check that the sensor/actuator assemblies damp properly and that critical damping may be achieved. If optic has become unbalanced, pitch alignment magnet (PAM) screws may be used. Clean the screws and magnets per LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures, LIGO-E960022. Using Vac Seal, epoxy magnets into the counterbore of the PAM screws. Allow for the epoxy to completely cure. Screw the assembled PAM screws into the back of the sensor/actuator assemblies, very carefully.

5.6. Height Adapter

5.6.1. Materials

Structure with optic
D960145: Height Adapter for ETM, ITM4k, ITM2k
D970571: Height Adapter for MMT3-4k, RM4k
D970579: Height Adapter for MMT3-2k, RM2k
D970554: Height Adapter for BS4k
D970555: Height Adapter for BS2k
D970569: Height Adapter for FM
18 1/4-20x1.50 long stainless, SHCS (LOS2 assemblies will use more hardware, see top assembly)
18 1/4-20 stainless lock washers
18 1/4-20 stainless flat washers
18 1/4-20 hex nuts

5.6.2. Assembly

1. Screw in the safety screws and chamfer screws to immobilize the optic.
2. Attach the height adapter to the suspension structure.

TITLE

LARGE OPTICS SUSPENSION BALANCING SPECIFICATION APPENDIX 1

- **C.P. Stat Plastic Film for wrapping and bagging**

C.P. Stat 100 ESD sheeting,
1 roll 48” wide by 1000 ft. long,
with CFC certification that it passes
JPL’s specifications.

Caltex Plastics, Inc.
P.O. Box 58546
2380 E. 51st St.
Los Angeles, CA 90058
213-583-4140

- **Inpro-Clean 1300 for cleaning stainless steel**

Oakite Products, Inc.
Berkeley Heights, NJ
800-899-8074

- **Mirachem 500 for cleaning stainless steel**

The MIRACHEM Corporation
2113 East Fifth Street
Tempe AZ 85281-3034
800-662-0333

- **Nitrile Gloves for handling hardware**

Ansell Edmont Industrial, Inc.
Coshocton, OH 43812
614-622-4311

- **Vidaro gloves for use with solvent cleaning**

part nos. 2-MY-31K4-2 or 2-WY-31K4-2
Vidaro Corporation
Kent OH 44240
330-673-0228