Absolute Gravimeter Workshop 2006

FG5 Version

2006
Absolute Gravimeter Workshop^3
Micro-g LaCoste, Inc.
Lafayette, Colorado

Introduction (and Disclaimer)

Welcome to the Micro-g Solutions Absolute Gravimeter Workshop! The materials here are meant to be “notes” that go along with actual participation in the workshop. Some difficult-to-document procedures may not be perfectly described here, but the thought is that these notes will serve as reminders for the hands-on experience of the workshop.

These materials also assume the user is familiar with the standard set up of the instruments and their principles of operation. Please consult the Operator’s Manual for your instrument for discussion of these topics.

Finally, when in doubt, it is usually best to consult Micro-g directly if there are specific problems or issues with your gravimeter.

Thanks for your interest in the workshops, and happy measuring!

1. Laser

For a complete discussion of the theory behind, and operation of, the WEO lasers, please consult the WEO operator's manual.

1.1. Cleaning

(Again, see WEO Operator's manual for a full discussion) Open the 8 screws that attach the cover to the base. Take care, as there is high voltage (HV) inside the laser head. While cleaning or aligning the components of the laser head, monitor the output power of the laser by using either a laser power meter or the DC output on the laser controller.

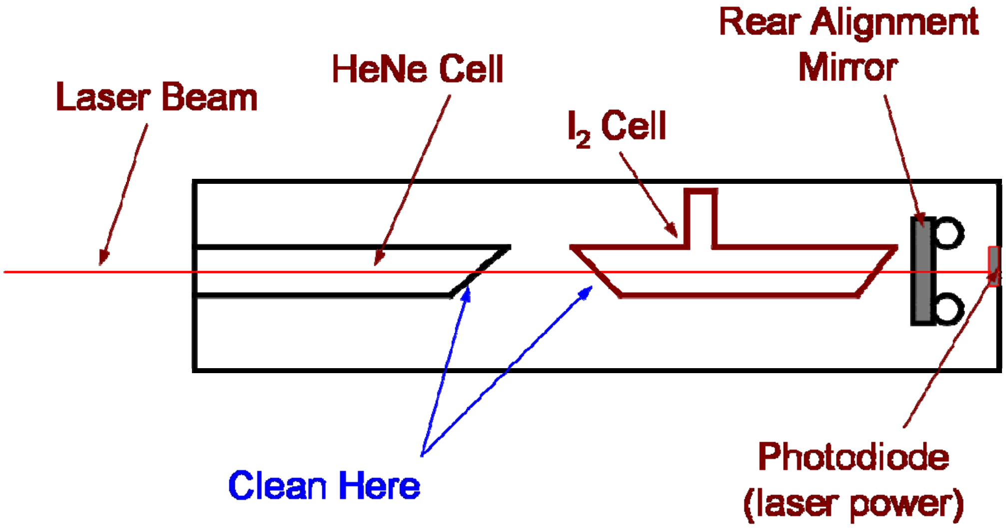

Figure 1. Laser cleaning schematic. Clean at the points indicated above. The rear mirror alignment also governs laser power and needs to be optimized.

1.1.1. First, use a can of clean, compressed air to blow away any dust from the inside of the laser unit. See Figure 1.

1.1.2. To clean a glass surface (of the HeNe cell or the iodine cell): Fold lens paper in half, 3 times, lengthwise. Then, fold this along its length such that you have an approximately 1x1 cm piece of lens paper. While folding the paper, take care not to touch the final surface with your fingers. Clamp this into a non-conducting hemostat. Apply 1-2 drops of pure ethanol (or acetone) to the lens paper, and applying moderate pressure, swipe the paper across the class. Do not "scrub" the paper back and forth.

Repeat the above procedure (discarding the lens paper after each single swipe) until the output power of the laser stops increasing. It is possible that a single swipe might be "bad" in that it results in a lower output power. Keep repeating the cleaning procedure until the output power is stable and maximized.

1.2. Internal Alignment

1.2.1. Rear mirror. It is possible that with a large change in temperature or a shock to the laser head, the orientation of the rear mirror of the laser cell might become slightly misaligned resulting in a reduction of output power. While monitoring the output power of the laser, carefully turn one of the screws on the mirror mount located at the rear of the laser head. Turn in the direction (if any) that increases the laser power. Then try the screw diagonally opposite of the first screw, and repeat the procedure. Note that the total adjustment will most likely be a small (1/16?) of a turn.

Note that if, for some reason, the light is extinguished (the laser stops "lasing"), only the screw being adjusted at that time can possibly bring the laser light back (that is, do not attempt to try any other screws at this point).

Iterate the procedure until the laser power is maximized.

1.2.2. Iodine cell. It is also possible to increase the output laser power, by loosening the screws that hold the iodine cell in place and slightly rotating the cell until the power is maximized.

1.3. Fiber Optic Alignment

The laser light reaches the interferometer via a fiber optic cable. Aligning the fiber to the laser head correctly is extremely important: not only does a proper alignment insure the maximum output power (and therefore, maximum interference fringe amplitude), it also governs the stability of the laser power. It is crucial that the fiber be aligned with the direction of the laser beam and also rotated about its axis so that its polarization matches that of the laser beam.

Note that to make adjustments to the fiber system generally requires the use of a light power meter. Contact Micro-g for assistance in obtaining an appropriate power meter.

1.3.1. Optical Isolator. Between the laser head and the entrance to the fiber optic coupler, the laser light passes through an optical isolator. This component allows the laser light to travel through it, but does not allow (reflected) light to return back to the laser cell. This is important because any errant light entering the laser cell (referred to as "feedback") can interfere with the stability of the frequency lock.

The isolator is optimized at the factory to provide maximum feedback rejection and the user should not have to adjust it. However, if it is noticed that a piece of the isolator is loose, contact Micro-g immediately to receive information on reassembling the isolator (or receiving a replacement). If a piece is loose, it is extremely likely that isolator is no longer functioning and that the laser will not lock reliably.

The two necessary adjustments regarding the isolator are these:

- The whole unit must be rotated so that its polarization matches that of the laser. Simply place a power meter at the output of the isolator and rotate the isolator until the power is maximized. Clamp the isolator in place.
- The mount of the isolator must be translated in the two dimensions perpendicular to the beam such that the beam goes through the center of the isolator. A “trick” is to place a piece of lens paper before the isolator. This scatters the laser light, and illuminates the whole opening. Place a piece of white paper *after* the isolator and note the position of the bright center of the beam relative to the illuminated hole. Translate the isolator until the beam is centered.

1.3.2. 5-axis Mount. The fiber is coupled to the laser head via a “5-axis” mount. The name refers to the fact that the mount allows lateral translation of the fiber relative to the beam in both the X and Y directions (2 axes), the mount allows tilt of the fiber in both pitch and yaw (2 axes), and the mount allows longitudinal translation of the fiber so as to focus the laser beam into the fiber (1 axis). Note the mount also allows rotation of the fiber relative to the beam (yet one more axis for an actual total of “6”)---the subject of the next section. See Figure 2.

- 🟡 **Whole-mount Translation Screws.** Translates the whole 5-axis mount relative to laser beam
- 🟠 **XY Screws.** Translate internal lens relative to laser beam and 5-axis mount
- 🔵 **Focus Screws.** Move lens back and forth relative to fiber
- 🟢 **Rotation Lock Screws.** Lock rotation of fiber to fix fiber polarization relative to laser beam.
- 🔴 **Internal Screws (No-adjust)**

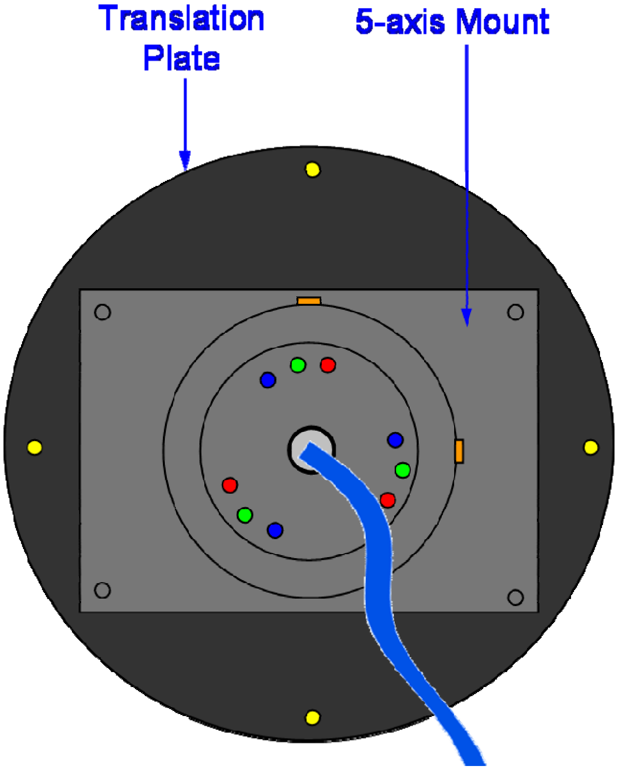

Figure 2. The screws on the 5axis mount (and the translation plate the mount is attached to). You may need to contact Micro-g to determine which screws are which on your particular mount.

Getting laser light through a fiber is somewhat tricky and requires a lot of patience and practice. However, the principles are quite simple. You are trying to align the entrance of the fiber with a laser beam focused down to a few microns in diameter. Both the location of the fiber entrance and the fiber's angle must coincide with that of the laser beam. Refer to Figure 3 while performing the following steps:

- Attach the 5-axis mount to the translation plate that attaches to the laser head (the fiber should not be connected to the mount at this point). Translate the plate such that the laser light is traveling through the center. (Verify by holding a piece of paper up and making sure the beam is not clipped)
- Attach the fiber to the 5-axis mount and tighten firmly.

- Use the X and Y screws on the side of the 5-axis mount to get some light through the fiber. While you should never look directly into the fiber, it should be possible to see the output end of the fiber “glow” with a small amount of light. If no light is visible, slowly translate the X and Y screws in a search pattern while looking for a “glow” at the output end of the fiber. When a small glow is visible, it is now best to attach the fiber to a laser power meter.
- Using the power meter, carefully adjust the X and Y screws until the power is maximized.
- Slightly loosen the 4 screws that tighten the translation plate to the laser. The screws should be loose enough to allow translation, but tight enough so that the plate does not move on its own. Translate the plate until the power is maximized.
- Iterate translating the plate and using the XY screws to maximize the power.
- Now use the three screws on the front to adjust the focus of the fiber (distance from the fiber entrance to the focusing lens) turn each screw approximately ¼ turn in the direction that increases power. In general you need to turn all three focus screws in the same direction and then determine if the power has increased in decrease. Usually one screw by itself will lower the power. Also, while adjusting the focus, it is probably necessary to iterate with the XY screws and translation screws.
- After many (10 or more) iterations of XY, translation, and focus the laser power should be maximized.

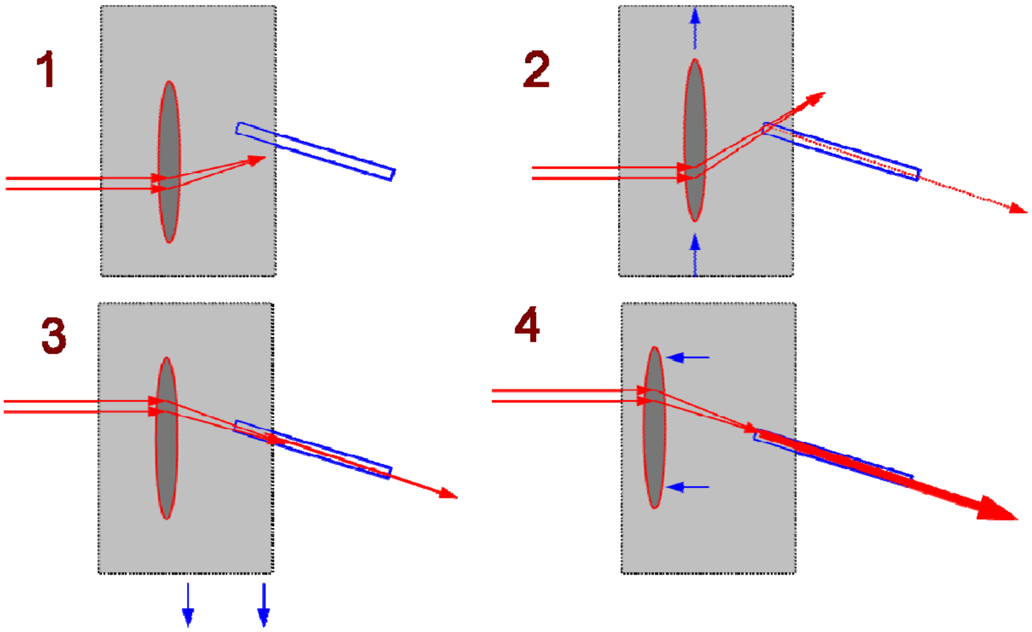

Figure 3. Aligning the fiber to the laser beam. The laser beam (red) enters from the left. The 5-axis mount (light grey) contains the lens (dark grey) and fiber attachment. It is possible to move the lens relative to the 5-axis mount, and to move the 5-axis mount relative to the laser beam (using the translation plate – not shown). 1. general starting position -- poor focus and alignment. 2. Use XY screws to move lens relative to beam to get some light through fiber. 3. Translate whole mount (lens and fiber) to get more light. 4. Use focus screws to move lens relative to fiber to maximize focus. 5. Iterate.

1.3.3. Fiber polarization. When the power is maximized (or at least about 150 μW for an ML-1 laser) it is then necessary to rotate the fiber so as to match its polarization to that of the laser. Note that yes, this most likely means a great (if not complete) loss of light in the fiber! Finally, note that this procedure requires not only a sensitive laser power meter, but a high quality, rotatable, polarizer as well. Generally, this step should be performed by Micro-g personnel.

- Shine the light from the output of the fiber through the polarizer and onto the laser power meter. Rotate the polarizer until the laser power is maximized and note the value. This is the “transmitted” power.
- Now rotate the polarizer until the power is minimized (this might require a rescaling of the power meter). Next, form a coil of excess fiber in your hand and let the heat slightly change the length of the fiber. This will most likely cause the power to increase. Note the maximum value attained. This is the “rejected” power.

- Calculate the ratio of "rejected" to "transmitted". This ratio should be better than 1:100.
    - If the rejection ratio is ≥1:100 then great! Make sure the "large" black screws on the front of the 5-axis mount are tight, fine tune the laser power, and proceed to the Last Step.
    - If the rejection is ≤ 1:100. Note the orientation of the fiber relative to the 5-axis mount. Slightly loosen (so as not to drastically change the angle of the fiber) the 3 "large" black screws on the front of the mount, slowly rotate the whole fiber. There are two optimal orientations of the fiber, 180° apart. If the rejection was close to 1:100, rotate a few degrees. If the rejection was basically 1:1, then rotate approximately 90°. If the rejection was in between, use the above information to estimate a reasonable amount of rotation.
    - Once the orientation has been chosen, use the 5 adjustment screws to get at least 15 μW of light through the fiber again. Repeat the rejection measurement and calculation.
    - Repeat the whole procedure (rotate, regain the light, measure the rejection) until the rejection is at least 1:100. Once 1:100 is achieved, use the 3 "large" black screws to clamp the fiber rotation into place and proceed to the Last Step.
- Last Step!
    - Now that there is laser light through the fiber and the rejection is better than 1:100, we must finally optimize the laser power. As above, use all 5 screws to maximize the power.
    - Next, carefully loosen the translation screws that attach the 5-axis mount to the laser head. Loosen as little as possible so that the angle is not significantly changed and yet the 5-axis mount can still translate. While monitoring the output power, move the whole 5-axis mount relative to the laser beam until the power is maximized. It is often possible to get an additional 15 μW of power using this "trick". When the power is maximized, tighten the 5-axis mount back in place and fine tune with the 5 adjustment screws, if necessary.
- Goals:
    - The isolator will transmit roughly 60% of the laser power
    - The fiber will transmit roughly 80% of the power
    - With a WEO laser producing about 120 μW, it should be possible to achieve 40 μW of power at the output end of the fiber.
    - With an ML-1 laser producing 1.2 μW, it should be possible to achieve 400 μW of power at the output end of the fiber.

2. Dropping Chamber

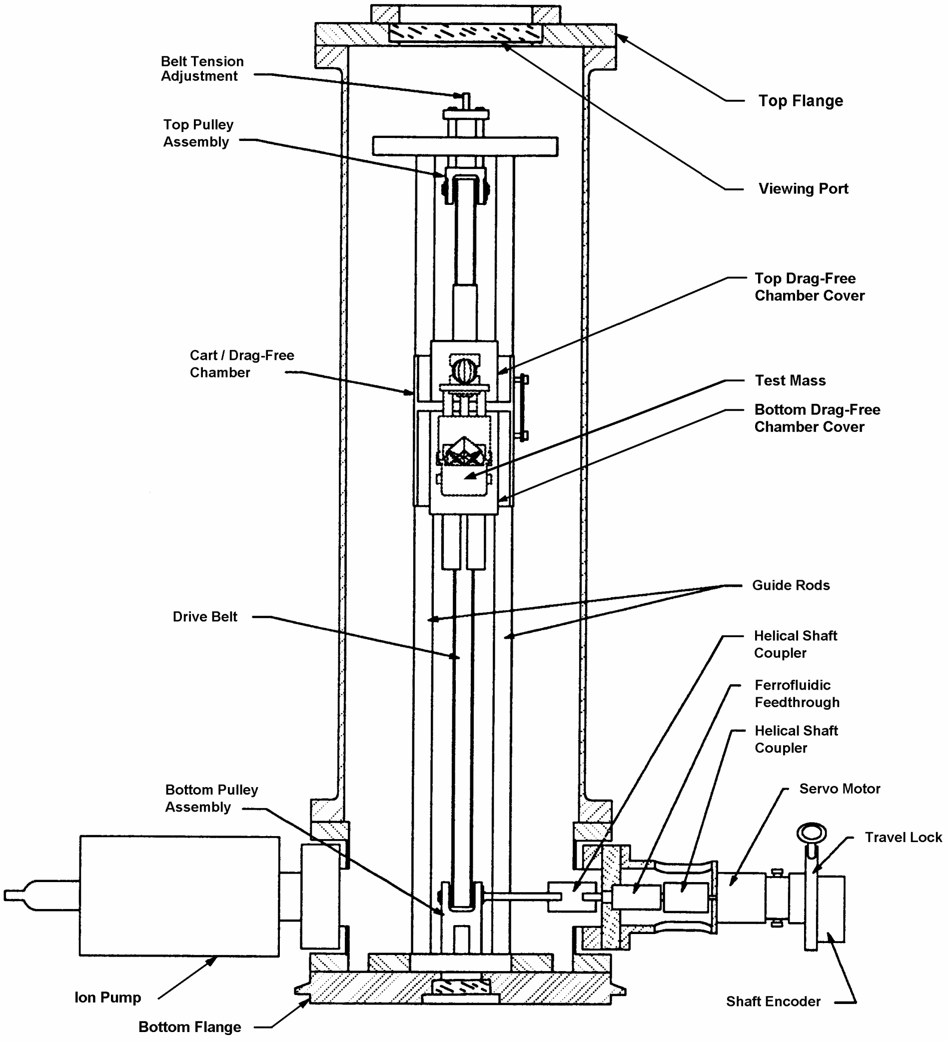

Figure 4. Schematic of the dropping chamber, drag-free cart, and test mass.

The Dropping Chamber is an evacuated volume which contains the Cart/Drag-Free Chamber which, in turn, houses the Test Mass. A drive mechanism is used to drop, track, and catch the test mass inside the drag-free chamber. Laser light passes through a window in the bottom of the dropping chamber to the corner cube (inside the test mass), then is reflected back down through the window to the interferometer.

2.1. The Cart

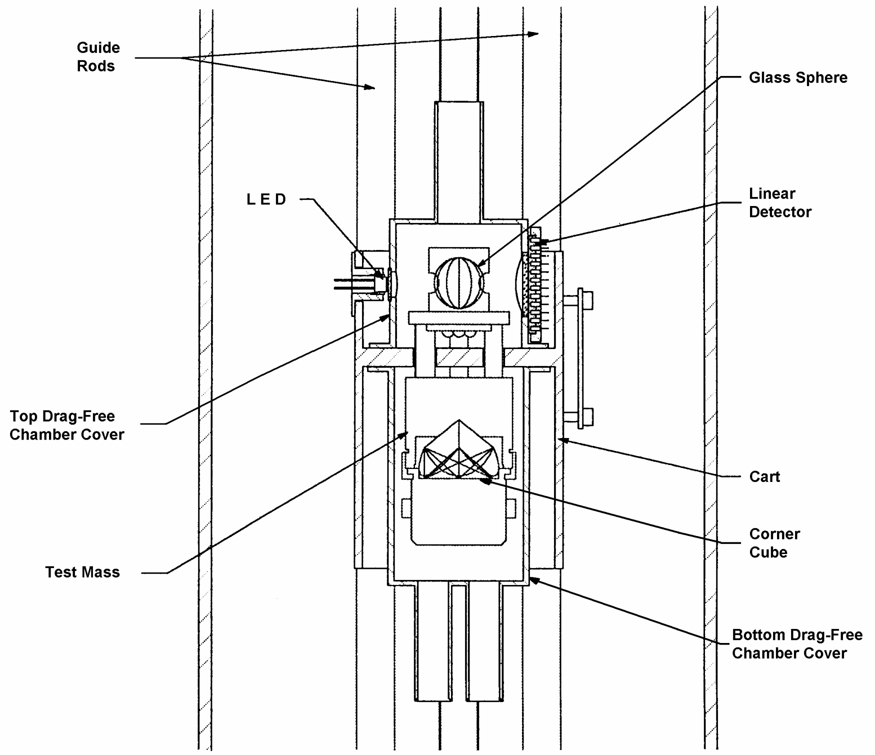

Figure 5. Schematic of the drag-free cart and test mass.

The cart /drag-free chamber houses the test mass. The purpose of the drag-free chamber is to reduce the residual air drag inside the evacuated dropping chamber. The cart also reduces magnetic and electrostatic forces on the test mass, and provides a convenient method for dropping and catching the test mass, as well as returning it to the top of the chamber for the next drop. By keeping track of the cart position using a shaft encoder, and using the interferometer (fringes) to establish the object position, the distance between the cart and the mass can be determined. (For historical reasons, this is referred to as “Sphere Detection”.) During freefall, this separation is maintained at a constant distance by using a servo-motor drive system to control the cart inside the Dropping Chamber. Because there is essentially no relative motion between the test mass and the drag-free chamber, the effects of residual air drag are eliminated.

2.2. Test Mass

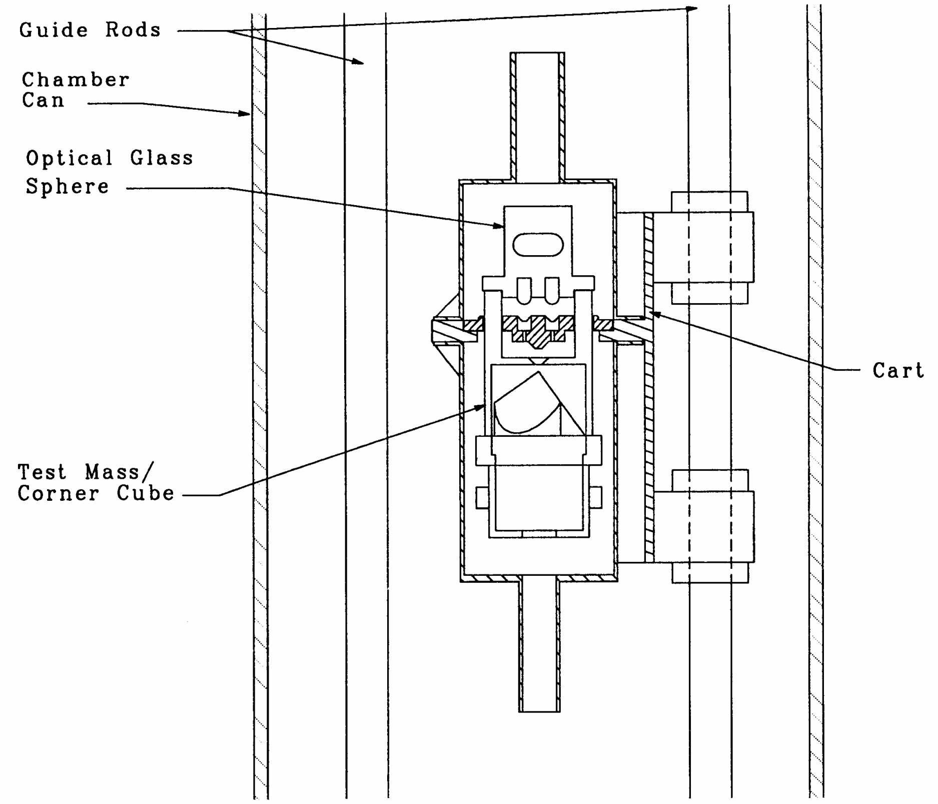

Figure 6. Detailed view of the test mass.

The Test Mass is a retroreflective corner cube surrounded by a support structure and balanced at the optical center of the corner cube. The corner cube is a three-surface mirror which has the special optical property that the reflected beam is always parallel to the incident beam. In addition, the phase shift of the reflected beam is virtually constant with respect to any slight rotation or translation of the corner cube around its optical center.

2.3. XY detector to set chamber bubble levels

The bubble levels on the dropping chamber are used to ensure that the cart precisely catches the test mass at the bottom of the drop (even if they are not precisely vertical with respect to the outside of the chamber, or even if they are not exactly straight).

Make sure the chamber is well separated (5 or more turns of the feet) from the interferometer and that the laser beam traveling into the chamber is vertical (using the alcohol pool).

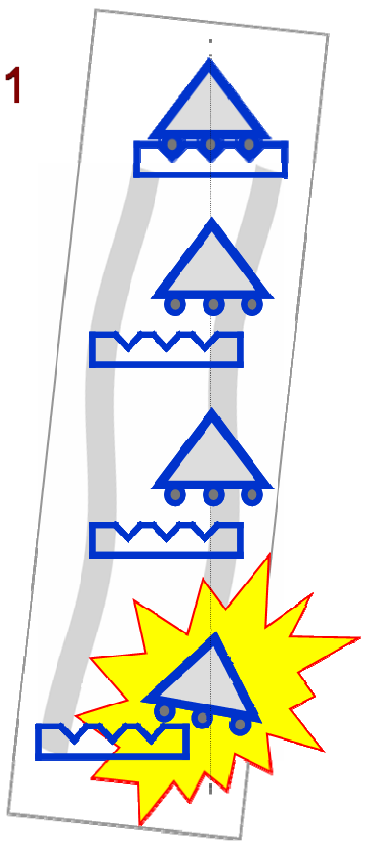

Figure 7. Chamber alignment. Plot 1 shows poor alignment . Plot 2 shows the dropping chamber tilted such that the cart position at the bottom of the drop is directly below the top of the drop. Note that, in general, the tilt of the chamber is not necessarily vertical.

Place the XY detector in the path of the vertical beam and attach the power cable to the Auxiliary output connector on the power supply. Attach the X and Y outputs to Ch1 and Ch2 of an oscilloscope and place the oscilloscope in “XY” mode (500 mV/div on both channels and ~250 ms in time). Use the oscilloscope’s position knobs to center the two grounded channels in the middle of the oscilloscope. Finally, attach the Σ (or sum) channel to a digital voltmeter.

With the scope then set to DC coupling on both channels, use the adjustment knobs on the XY detector to center the signal in the oscilloscope. Manually run the cart up and down using a 4 mm Allen wrench. Watch the value on the voltmeter, and make sure that it doesn't change by more than 10% throughout the travel of the cart (thus indicating that laser light is staying on the detector the whole time). If the spot moves visibly as the cart is raised and lowered, use the tripod feet to tilt the chamber so that the spot appears stationary. Then repeat the above: center the signal and make sure the spot stays on the detector throughout the cart's travel.

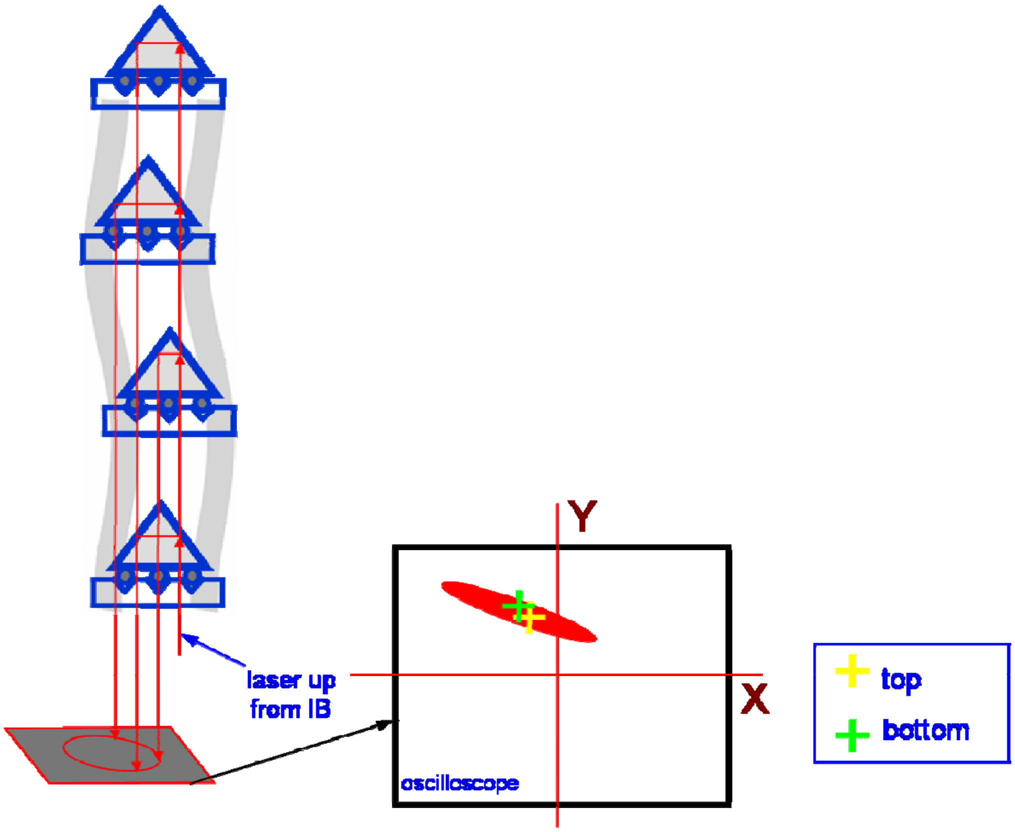

Figure 8. Using the X-Y detector to set dropping chamber bubble levels. In general, as the cart is lifted up and down, it will also move slightly sideways. Thus, the reflected laser beam will appear to translate. Tilt the chamber until the position of the reflected beam at the top of the drop is the same as at the bottom of the drop. Then set the bubble levels to read zero.

Manually lift the cart to the top of its travel. Note the position of the signal on the oscilloscope (it might be necessary to adjust the X and Y ranges, though it is best if both channels have the same V/div). Now watch the motion of the signal as the cart is slowly lowered. As an example, say the signal moved “down to the left by two divisions”. With the cart at the bottom, use the appropriate (trial and error) combination of dropping chamber tripod feet to “move” the signal in the same direction, and the same amount, as the signal moved as the cart was lowered (in our example, “down to the left by two divisions”). Here “tripod feet” refers to the large feet on the ground used to decouple the dropping chamber tripod from the interferometer.

Repeat the procedure: raise the cart, note the position, watch the motion as it is lowered, and adjust the appropriate tripod feet. As the chamber angle is improved, it will become necessary to go to finer and finer voltage scales to see changes in the motion. When the top and bottom position agree on the oscilloscope to ~10 mV, the chamber is aligned.

Note that if the rods are slightly bent, the signal might do a little “loop” or “wiggle” as the cart is raised and lowered. This is normal. It is only important that the top and the bottom of the travel are overlapped.

Once the chamber is aligned, center and lock the bubble levels.

Then, re-couple the dropping chamber tripod to the interferometer. If necessary, tilt the Superspring tripod to make sure the Superspring bubble levels are centered. Use the spanner wrenches provided in the FG5 toolkit to tilt the tripod such that the dropping chamber bubble levels are centered to agree with those of the Superspring. See Figure 9 for the location of the feet used to tilt the dropping chamber tripod relative to the interferometer base.

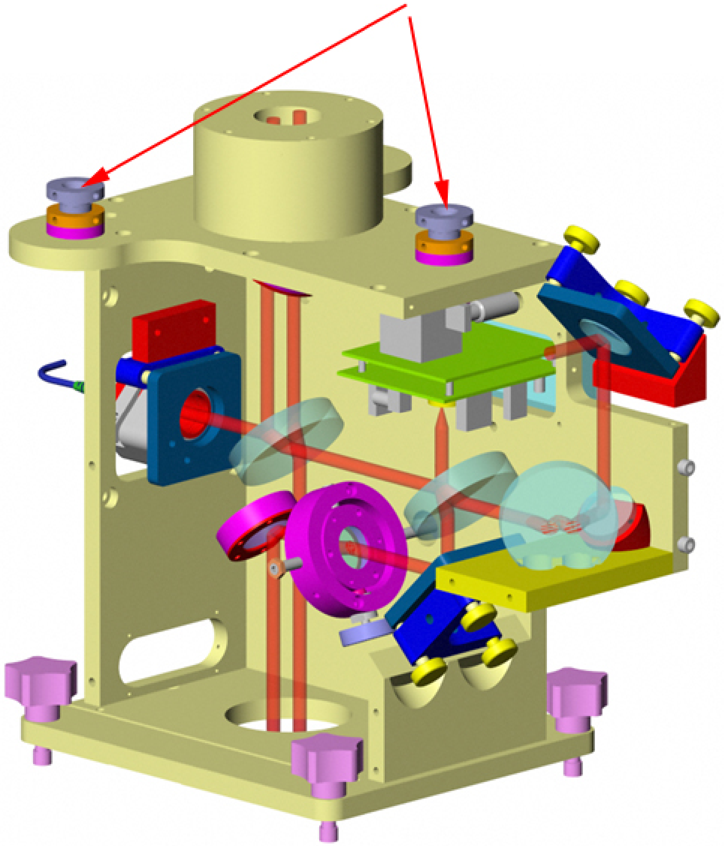

Figure 9. The red arrows indicate the feet used to tilt the dropping chamber tripod so that the dropper bubble levels agree with those of the Superspring. They are adjusted using the FG5 spanner wrenches.

2.4. Dropper Tuning

As discussed above, the motor/servo system maintains a constant distance between the test mass and the cart during the drop. It is also tuned to gracefully catch the test mass at the end of the drop. The dropper electronics are adjusted at the factory to optimize this servo. However, with time or some other change, these electronics may need to be adjusted.

To observe the drop, attach an oscilloscope to OBJECT POSITION on the dropper controller electronics. (Setup: 50 ms/div, 2 V/div, Ch1: OBJECT POSITION, “normal” trigger with positive slope at -8V).

2.4.1. Nominal results:

As the cart pulls away from the test mass (placing it in freefall), the OBJECT POSITION will increase away from zero. Then the cart will start to maintain a constant distance from the mass. This is portion is termed the "hover" phase of the drop and lasts approximately 200 ms. It should be as flat as possible. Then at the end of the drop there should be a soft catch with minimal bouncing as the test mass comes into contact again with the cart. See Figure 10 for details.

2.4.2. Common Adjustments

2.4.2.1. "Analog" Dropper Controller.

- Catch. This governs the way in which the cart catches the test object. The idea is to make it "soft" so that the object does not bounce (which causes additional wear to the balls and vees).

- On the analog droppers, the two pots governing the catch are CATCH OFFSET and CATCH RAMP. Adjust each by small amounts (1/8 turn) so that the transition back to zero velocity (monitor CART VELOCITY) is smooth. You will also notice that object will bounce less (monitor OBJECT POSITION).

- For a digital dropper. Make small adjustments (1/8 turn) to the POSition GAIN and POSition DAMP potentiometers, while monitoring the OBJECT POSITION output and the FeedForward test point.
  - "Hum" at the top of the drop. On the analog droppers, turn the HOLD GAIN pot down by a small (1/8 turn) amount.

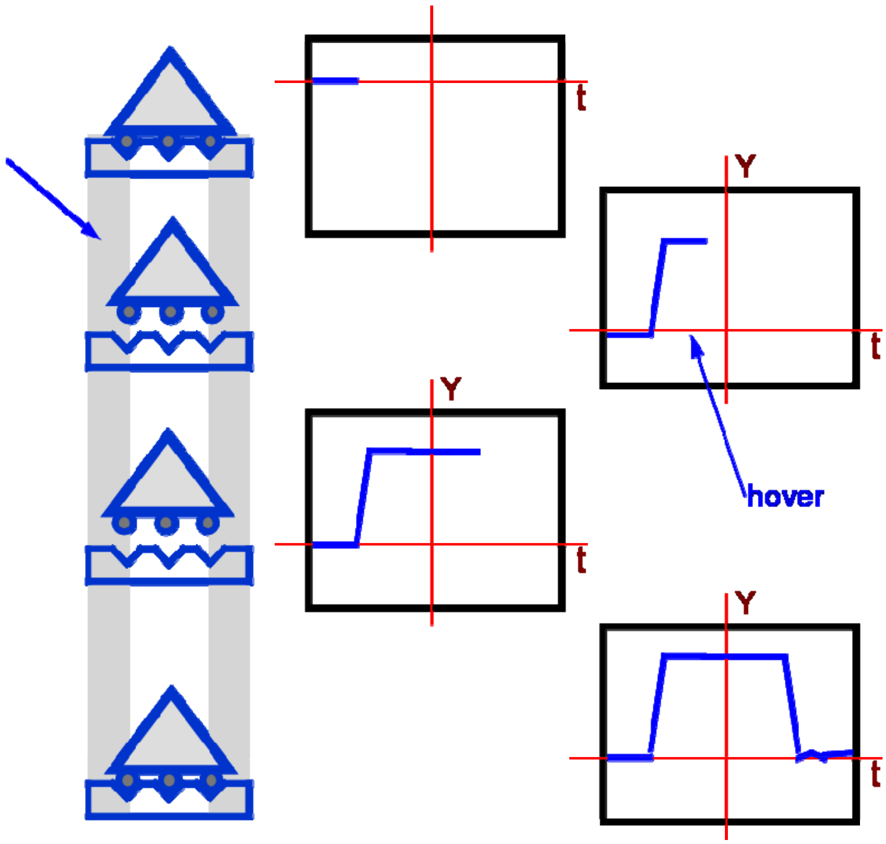

Figure 10. Plot of "OBJECT POSITION" during a nominal drop. As the cart pulls away to put the test mass in freefall, the distance between the cart and test mass increases. The cart then accelerates at the same rate as the test mass, maintaining a constant distance. At the end of the drop, the object is caught gently. The output signal is a plot of the distance between the cart and mass as a function of time.

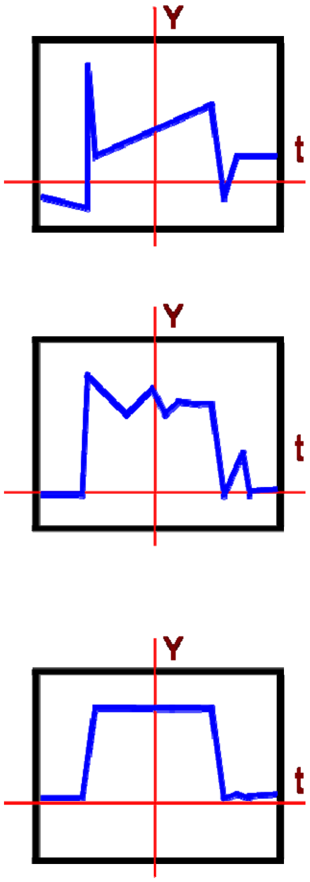

Figure 11. Typical progress in dropper tuning. As each level of control is added and fine tuned – the action of the drop improves.

2.4.3. Tuning a "Digital" Dropper from scratch:

Typically only small (if any) adjustments to the circuit are necessary over time. However, here are the steps for a complete tuning (in this list of instructions, we will not enable the SPHERE SERVO – contact Micro-g for advice on this step):

- Open up the dropper controller and start by turning all FF GAIN, POS GAIN, POS DAMP pots to zero (counterclockwise). Disconnect jumper J6 (this disables the SPHERE SERVO).
- Place the dropper in OSC mode. At first, it will most likely "time out" and go into reset mode.
- Slowly turn up the position gain (POS GAIN) pot until OSC mode completes full cycles.
- It may be necessary to turn up the POS DAMP pot until OSC mode sounds "smooth".

- Use an oscilloscope (set up as in Section 2.4.1, but with 2.5 seconds on the time scale), and monitor the FF (feedforward – TP11) and SERVO (TP6) test points. Monitor FF on a 500mV scale and SERVO on a 2V scale (because the FF signal is 4 times smaller than the SERVO signal, this choice of scales makes the signals appear to be the same size on the oscilloscope.
- Adjust the feedforward gain (FF GAIN) until the average amplitudes of the FF signal and the SERVO signal are the same. The SERVO signal will be more “wiggly” than the FF signal, but just make sure the average signals are the same size.
- At this point there is now too much POS GAIN. So, turn down the POS GAIN until OSC mode just fails (resets). Then turn it back up approximately ¼ turn.

- Now place the controller in DROP mode. If the drop fails (resets), turn up the POS GAIN until it just does not fail. If the drop does not fail, turn down POS GAIN until it does, then back up ¼ turn.
- Now monitor the FF and SERVO signals again. If necessary, adjust FF GAIN until the signals are matched on the oscilloscope.
- Again, turn down POS GAIN until the drop fails, and then back up ¼ turn.
- Now turn up POS DAMP until the drop starts to sound smooth. If the drop then starts to sound “rough” again, then you have turned POS DAMP too far.
- Use the oscilloscope to monitor OBJECT POSITION. Adjust POS DAMP and POS GAIN until the hover portion of the drop looks as flat as possible and that the catch phase looks smooth.

2.5. Venting Chamber to Atmosphere

When opening the dropping chamber, take great care not to contaminate the inside surface of the chamber cover or any of the interior parts. Always wear clean-room gloves when handling internal parts. If any of the parts are contaminated, clean the part using accepted vacuum system cleaning procedures before reassembly. When performing repairs in the field, it is sufficient to wipe or flush the contaminated parts with alcohol. Whenever possible, vent the chamber with dry nitrogen rather than air. This will reduce the pump down time after the chamber is reassembled.

To vent the dropping chamber, remove the clamp and blank flange from the vacuum valve on the service ring. Loosen the vacuum valve lock ring and slowly open the valve by rotating the control knob, allowing the chamber to return to atmospheric pressure. It is best to vent using dry nitrogen, but it can be directly vented to air. In any case, try to ensure that the gas entering the chamber is free of particulate matter.

Remove the six screws holding the top flange to the top of the dropping chamber cover, and remove the flange. Loosen the four snubber lock nuts and back out the screws which position the top ring of the dropping mechanism within the chamber cover. Remove the six screws holding the chamber cover and handles to the service ring, and carefully lift the cover up over the dropping mechanism. Be sure to protect the O-ring surface on the exposed bottom flange of the chamber cover, and keep the flange clean.

Note that whenever the chamber is vented to atmosphere, it is a good opportunity to clean the bottom window of the chamber. It is normal, as the test mass balls and vees wear, for the window to collect a fine dust of tungsten. With the chamber vented, but still fully assembled (i.e. cover in place, etc.), travel-lock the cart, and gently tip the chamber on its side. Remove the six Allen screws that hold the bottom window in place, and remove the window. Clean the window using pure alcohol and lens paper, inspect the o-ring, and reassemble the window. Be sure to tighten the screws in a star pattern to equally distribute the load on the o-ring.

2.6. Drive Belt Replacement

Follow the procedures described in Section 2.5 for removing the dropping chamber cover

- Loosen the belt tension with the tension adjustment set screw located above the top pulley assembly on the top rod ring. The belt is clamped to the back of the cart with two socket head screws. Remove the clamp and slide the ends of the belt off the dowel pin. Remove the belt.
- Before installing a new belt, clean both of the pulleys with acetone or alcohol on a cotton swab. Wipe the new belt with acetone or alcohol to remove any traces of oil or fingerprints.
- Thread new belt around upper and lower pulleys, and place ends over the dowel pin. A wire with a small hook works well to assist in threading the belt around the lower drive pulley.
- Replace belt clamp, but do not fully tighten. Tension belt while manually moving the cart up and down to allow the belt to locate its natural position on the pulleys, then tighten the belt clamp screws.

- NOTE: The drive belt may not run exactly in the center of the pulley. This is normal, but there should be a minimum clearance of 1 mm between the belt and the side walls of the pulley housing (yoke).

2.7. Ferrofluidic Feedthrough Replacement

Note: This process involves working with an assembly that is partly inside the vacuum and partly outside, keep vacuum side clean and do not interchange the flexible couplers.

- Remove the dropping chamber cover as described in the FG5 manual.
- Inside service ring loosen the clamp screw (# 4-40) of the flexible coupler between feed thru and drive pulley shaft.
- On the outside of chamber loosen the clamp screw of the flexible coupler clamp between the drive motor and the feedthrough.
- Remove the three ¼-28 socket head screws that compress the 2 ¾'' conflat and hold the drive motor assembly in place. Remove drive motor assembly.
- Remove the three remaining ¼-28 socket head screws that hold the 2 ¾'' conflat flange/feedthrough in place. Remove the flange/feedthrough form the service ring.
- Remove flexible couplers from feedthrough than remove feedthrough from conflat flange. (use rubber pad on pliers jaws to protect feedthrough when unscrewing from flange)
- Install new ferrofluidic feedthrough into flange, replace flexible couplers to feedthrough shaft ends and mount flange / feedthrough assembly onto service ring using new copper gasket of conflat flange.
- Install drive motor assembly, rotate so travel lock knob points up then torque all six ¼-28 socket head screws in a star pattern until conflat flanges are in contact with each other.
- Tighten flexible couplers inside and outside chamber.
- Replace dropping chamber cover, adjust support screws, replace top flange and align chamber to vertical as describer in FG5 manual.

3. Superspring

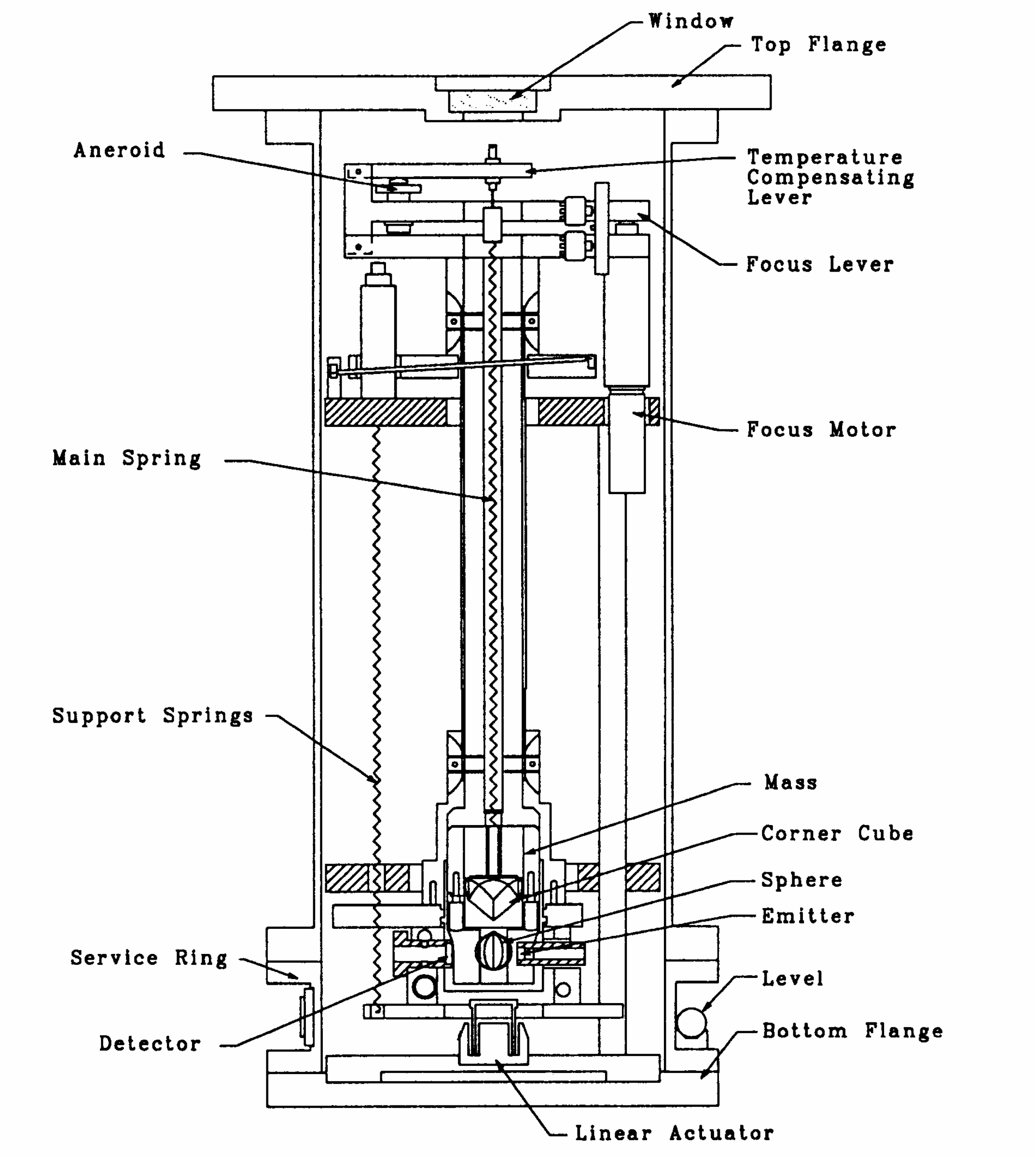

Figure 12. Schematic of the Superspring. The support springs hold the "middle stage" of the system. This middle stage, in turn, supports the main spring. Motion of the mainspring relative to the middle stage is measured and minimized.

3.1. Theory

The superspring is a long period, active vertical isolator used to compensate for small vertical motions of the first beam splitter. The superspring has a short (20 cm) mainspring with a natural period of about 1 second. The mainspring is contained in a support housing that is actively servo-controlled to track the superspring mass at the end of the mainspring. The resulting system is a long-period (30-60 second) spring-mass system which is suspended from the interferometer base. The superspring isolated ground motions occurring at a higher frequency than its own enhanced natural frequency.

3.2. Superspring Mass

The superspring mass contains a corner cube retroreflector and an optical glass sphere.

3.3. Sphere Detector

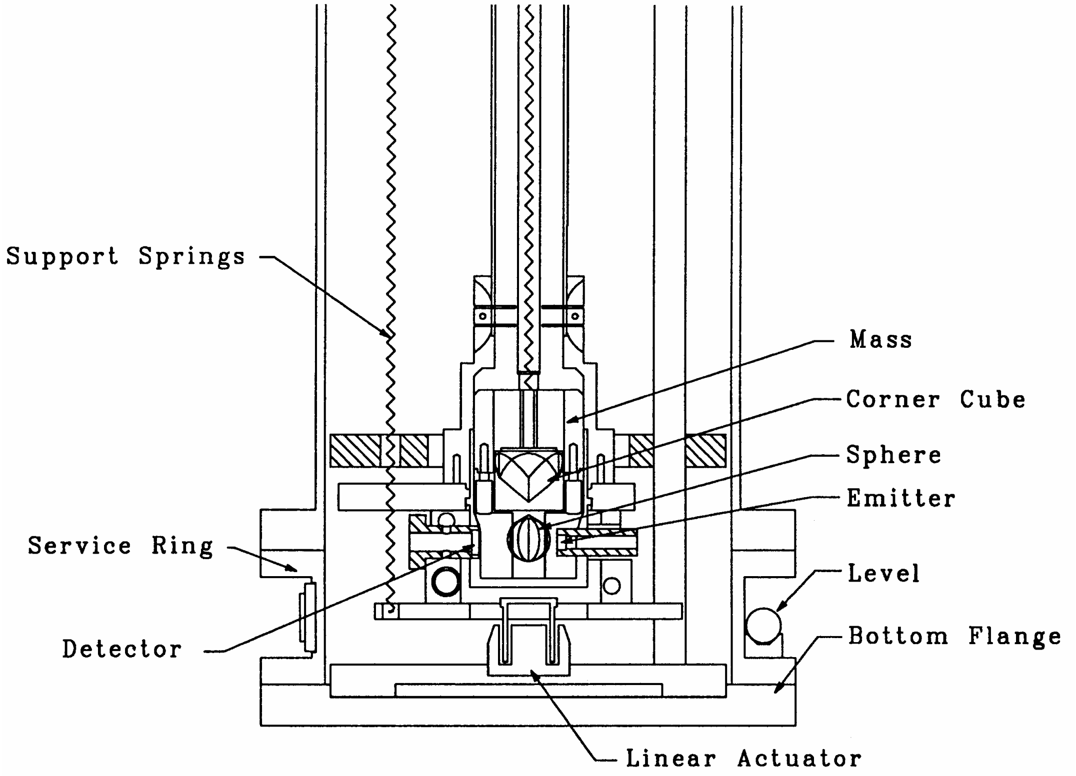

Figure 13. Detail of the sphere detection system to monitor motion of the corner cube.

The superspring sphere detector system senses motions of the superspring mass relative to the support housing. An infrared light emitting diode (LED) located on the support housing directs light through an optical glass sphere attached to the superspring mass. The sphere focuses the light onto a split photodiode detector, also mounted on the support housing. The support housing is itself servo-driven to cancel these motions using an electromagnetic coil-type linear actuator (coil) is mounted between the support housing and the superspring base. As vertical ground motion occurs the linear actuator moves the support housing up or down as needed. The apparatus is constrained to move only vertically by a linear way system constructed of five flexures (delta rods) arranged in an upper V-shaped array, and a lower triangular array.

3.4. Superspring Electronics

The purpose of the electronic and mechanical systems for the Superspring is to isolate the reference mass from any vertical motion of the instrument in order to keep the path length of the beam constant. Three systems provide coarse and fine adjustment of the spring support structure: a motor attached to the top of the mainspring and a linear actuator coil and magnet system. A servo circuit drives the motor and the coil and magnet system.

A sphere detector system provides information on the position of the reference mass relative to the mainspring support system. An infrared LED and a photo detector are mounted opposite each other inside the mainspring support housing. A sphere attached to the bottom of the mass focuses the light from the LED onto the detector, which transmits the resulting signal to a sphere signal preamplifier.

The zero-position (center-of-range) of the sphere on the test mass can be adjusted by moving the top of the main spring with a small DC motor with a very large gear ratio for fine control.

The main servo electronics control, the coil-magnet forcer, moves the main spring support in such a way to keep the main spring length constant. This active servo effectively weakens the main spring, synthesizing a long period isolation device. The active period of the superspring is nominally about 60 seconds.

3.5. Setting the Superspring Position

3.5.1. The superspring servo has a limited range in which it can function optimally. Changes in temperature or local gravity (e.g. altitude changes during a survey) can cause the spring to either stretch or compress, which in turn, can cause the test mass to be positioned either too low or too high in its range of motion. As was mentioned above, there is a motor inside that the allows the user to position the test mass in the center of its range, and the optical sphere system to gauge the test mass’s location.

The sphere detector is split into two halves. When light shines on the detector, the upper half measures positive voltage and the lower measures negative voltage. If the test mass is exactly centered in its range, the sum of the two voltages is zero. As the mass moves up or down, away from the center, the voltage will either become more positive or more negative.

With the newer Superspring controller, the user simply has to make sure that the servo is not engaged, and then enable “Superspring Zero”. Monitor the SPHERE output with a voltmeter and wait until the spring positioned is centered around zero. Then disable “Superspring Zero” and wait for the position to settle down. Then enable “Superspring Servo”.

With older controllers, the motor is manually controlled to set the spring to its desired location (nominally zero volts) and is activated by turning the MOTOR switch to MANUAL. To move the mass up (more positive SPHERE voltage) turn the adjustment knob above “5” (or UP, on the ½-rack superspring controllers). To move the mass down (more negative SPHERE voltage) turn the adjustment knob below “5” (or DOWN, on the ½-rack superspring controllers). In either case, it is only necessary to get the mass to within 10 or so mV of zero. Then turn the MOTOR switch back to OFF.

Once the test mass is positioned, it is best to let the superspring “settle down” until its motion is a few 10s of mV before activating the servo (COIL ON).

3.5.2. “S” Curve.

If, for some reason, the mass is extremely far from the center of its range (e.g. due to an extreme change in either the temperature or the local gravity), the spring controller may appear to be behaving incorrectly: it may appear to go the “wrong way” (e.g. more negative, even though the motor is set to lift the mass – See Figure 14). This is because all of the light from the LED is not actually on the detector. As more light misses the detector (either going off the top or bottom), the absolute value of the voltage becomes less and less, making it appear that the spring is nearer zero than it actually is. (**Note that this problem is handled automatically in the newer Superspring controllers**.)

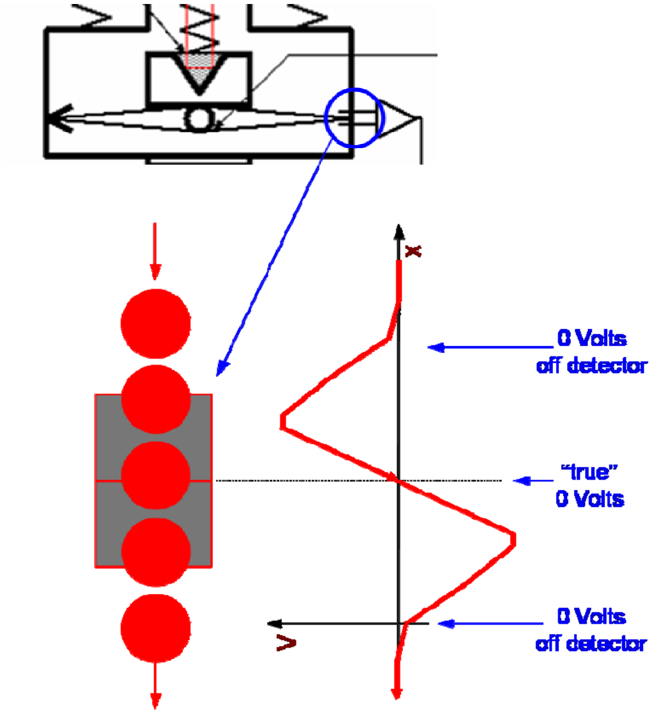

Figure 14. If the LED light is off of the detector, the SPHERE position will read about zero volts. As the light is brought on the detector, the voltage appears to go the "wrong" way. Keep moving the spring position until it is about the "true" zero value.

For example, if the if the light is shining off the bottom of the detector, raising the motor will cause more light to shine on the detector. As the mass is raised further, more and more light comes back on to the lower (negative) side. The spring thus appears to be at a more negative position, even though it is rising. (The converse holds true if the spring is being lowered down from above the detector).

Whether or not the spring is too high or low, the thing to do is this: KEEP GOING IN THE EXPECTED DIRECTION (down, if the voltage is too positive, or up, if the voltage is too negative). Eventually, all the light will be on the detector again and the controller will then behave as expected. As a check, the spring should oscillate between positive and negative voltage when it is around the true zero (center) of its range.

3.6. Trouble Shooting

A Superspring problem usually results in gravity data with a large drop-to-drop scatter. An oscilloscope with a long (>10 minute!) time scale is very helpful in monitoring the status of the Superspring. A two channel recorder can monitor both sphere and coil output. However, if a one channel recorder is used, it is best to monitor coil output. The coil output is a direct measure of the current necessary to servo the spring: the more current, the "harder" the superspring is working. A plot of the coil output can also be helpful in identifying seismic activity or unusually large environmental noise, which produce a larger than average drop-to-drop scatter. During setup, the operator should exercise care in leveling the Superspring. It is always very important to monitor the voltage at the front panel BNC of the Superspring controller marked SPHERE OUT while the servo loop is still open. The sphere position should be moving substantially (+/- voltage) when the loop is open and the Superspring is unlocked. This indicates that the test mass is hanging freely.

3.7. Internal Spring alignment

The spring systems are aligned to tight tolerances, and most major problems (i.e. the spring has been dropped or shipped improperly), require a service at Micro-g Solutions. However, if an alignment problem has been diagnosed, it is possible to make a few alignment adjustments yourself. First, start by leveling the system to the bubble levels (even if the system is out of alignment, this is probably the best place to start). A leveling table is most convenient, though in the field it is also possible to use the actual superspring tripod for leveling purposes.

3.7.1. Flexures. There are five flexures that maintain the vertical translation of the inner spring assembly (See Figure 15). All of these should look straight and have no "kinks" in them. If a flexure looks bent, remove it (if there is more than one bent flexure, remove one at a time), and if possible, replace it. If replacement is not an option, it is possible to straighten a flexure with needle-nose pliers and then verify its straightness by rolling it along a pair of levels. Then install the new (or straightened) flexure. When all the flexures have been replaced (or straightened) it is time to align the system.

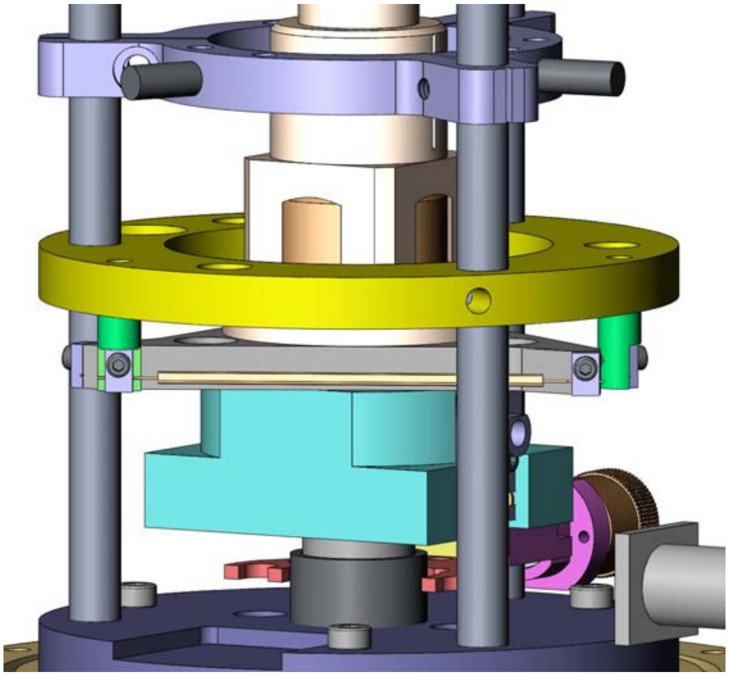

Figure 15. One of 5 flexures is shown just below the yellow ring in the above figure. The flexures (or "delta rods") should be straight, with no visible kink where the wires exit the central brass part.

The alignment is done by tightening the flexures in place such that the assembly is centered with respect to the six (factory-set) alignment pins. An easy way to start is by placing small pieces of paperboard of about the right thickness in all six places. Next, tighten down the screws that connect the flexures to the inner assembly. Finally, tighten the screws that connect the flexures to the outer assembly. Then fine tune. A 0.004" feeler gauge should be able to slide freely between all six alignment pins.

3.7.2. Bubble Levels ("Classic" Interferometer): Once the inner assembly is hanging freely with respect to the pins, it is now necessary to check, and possibly adjust, the bubble levels. Adjust the leveling table such that the cylindrical copper mass is hanging freely. Then fine tune the level such that when looking down the squared-off housing, the cylinder of the inner mass is tangent to the housing on all four sides. Then adjust the bubble levels so that they are centered.

This insures that the spring is hanging centered and freely when the bubble levels are centered.

3.7.3. Bubble Levels ("New Style" Interferometer): Once the inner assembly is hanging freely with respect to the pins, it is now necessary to check, and possibly adjust, the bubble levels. Adjust the leveling table such that the external base of the Superspring is as level as possible (if possible, use an external bubble level). Then adjust the position of the top of the inner spring: Loosening the screw the holds the center spring allows the spring to be translated in one direction, and adjusting the location of the pivot of the main spring allows translation in the other direction (when re-tightening the pivot, make sure it moves freely but without any play). Translate the spring in both directions such that when looking down the squared-off housing near the copper mass, the cylinder of the inner mass is tangent to the housing on all four sides (See Figure 16). Tighten the inner spring into place. Then adjust the bubble levels so that they are centered.

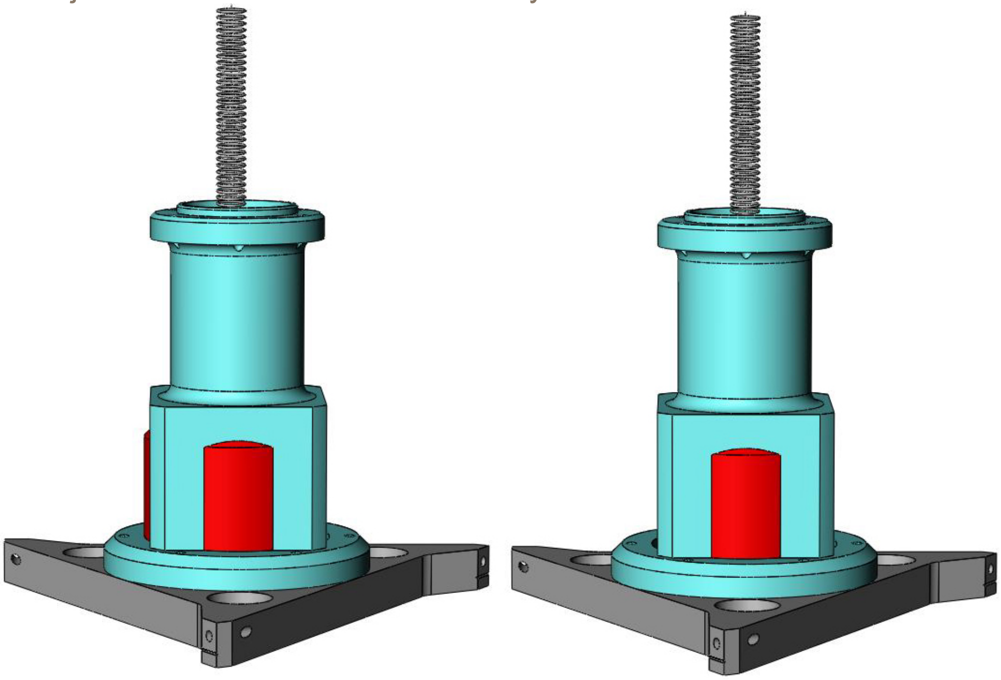

Figure 16. Main spring alignment. The left figure shows the test mass hanging off-center. The right figure: by changing the position of the top of the spring, the test mass is made to hang in the optimal position: tangent to the light-blue housing.

This insures that the spring is hanging centered and freely when the bubble levels are centered.

4. Interferometer Alignment

4.1. Theory

- Reference Beam. The reference beam travels "straight through" the interferometer. It does not travel through either the superspring or the dropping chamber. It is however split into three beams: one onto the photodiode (APD), another into the viewport, and another into the telescope.
- Test Beam. The test beam is split from the first beam splitter, where it then travels through the dropping chamber, then through the superspring, and then is recombined with the test beam in the interferometer. (Note that it too is also then split into three channels: the APD, viewport, and telescope. Note that is very important that the laser beam be vertical and that it traverses its path without "clipping" anywhere.
- Fringes. The interferometer is designed to not only split the beam into two paths, but to recombine them at the APD. To get the best interference between the two beams (the biggest fringe amplitude), it is important that the beams be coincident (in the same place) and parallel.
- The optical translator (or "twiddler") is used to translate the test beam relative to the test beam to compensate for any path offsets in the test beam. The viewport allows the user to see the quality of the overlap.
- The beams are made parallel by adjusting the mirror below the telescope. This changes the angle of the returning test beam relative to the test beam. One can use the telescope to make the two beams parallel (two parallel beams will appear as one spot in a telescope focused to infinity). It is also possible to look in the viewport, and adjust the mirror so that the fringes appear to be concentric (rather than lines across the)
- Verticality. As was mentioned earlier, it is imperative that the test beam be vertical as it enters the dropping chamber. (Note that a non-vertical beam will always result in a gravity value **lower** than the true value). The verticality is determined by comparing the reference beam to a vertical beam returning from an alcohol pool.

4.2. "Classic" Interferometer Alignment

- Periodic adjustments of the beam path can be made with the mirrors. Adjustments of the beam path through the beam expander and the beam splitter assemblies are performed separately.
- The beam should pass through the center of the isolator without being clipped by mirror mounts 1 or 2. The beam should pass through the center of both the microscope objective and the collimating lens. After it exits the collimating lens, the beam should be collimated approximately 5-7 mm in diameter. On a card or paper placed in its path, it should make a round uniform spot.

- The beam should hit the center of mirrors 3 and 4 without being clipped by the button-head screws. It should then pass through both the dropping chamber and the Superspring and return intact. The recombined beam should be centered in the fringe viewer. It should also be focused and steered onto the center of the APD.
- An AL-1 laser mounts to the interferometer base with four 1/4-20 socket head screws. The WEO iodine-stabilized laser mounts using four M6 socket head screws. Tightening or loosening the front lower screw requires use of a short Allen socket wrench.
- The mount of the isolator must be translated in the two dimensions perpendicular to the beam such that the beam goes through the center of the isolator. A "trick" is to place a piece of lens paper before the isolator. This scatters the laser light, and illuminates the whole opening. Place a piece of white paper *after* the isolator and note the position of the bright center of the beam relative to the illuminated hole. Translate the isolator until the beam is centered
- These elements are mounted to the interferometer base by two screws on the bottom (identical to that with the standard isolator). These M4 screws have an M3 socket head. The $\lambda/2$ plate is mounted in front of the Faraday isolator and is used to rotate the linear polarized laser beam to match the polarizer in the Faraday isolator. The $\lambda/2$ plate should be turned until the light going through the Faraday isolator is maximized. The base of this mount has two screws on the bottom with oversized through holes to allow a height and tilt adjustment of the polar angle. There are also 2 screws on the top plate of the mount with oversized through holes to allow adjustment of the azimuthal angle. These are M3 screws which require a M2.5 socket head hex wrench. Note that there is a 1.6 mm horizontal translation of the beam through the Faraday isolator.
- To replace the standard isolator with the $\lambda/2$-Faraday Isolator, remove the five M5 screws (with M4 hex socket heads) which secure the Superspring interface plate to the underside of the interferometer base. This allows access to the two screws which secure the isolator mounting block to the interferometer base.
- Remove the focus lens sleeve and collimating lens sleeve from the spatial filter assembly. Insert the alignment pinholes into the two lens mounts in the spatial filter. The sleeves are held in by M4 screws with a M3 socket head. Steer the beam through the two alignment pinholes. This is easiest if you use the first mirror (#1) to adjust the translation of the beam to pass through the first pinhole and then use the second mirror (#2) to adjust the beam angle so that it passes through the second (furthest) pinhole. This procedure may require several iterations to get the alignment perfect.

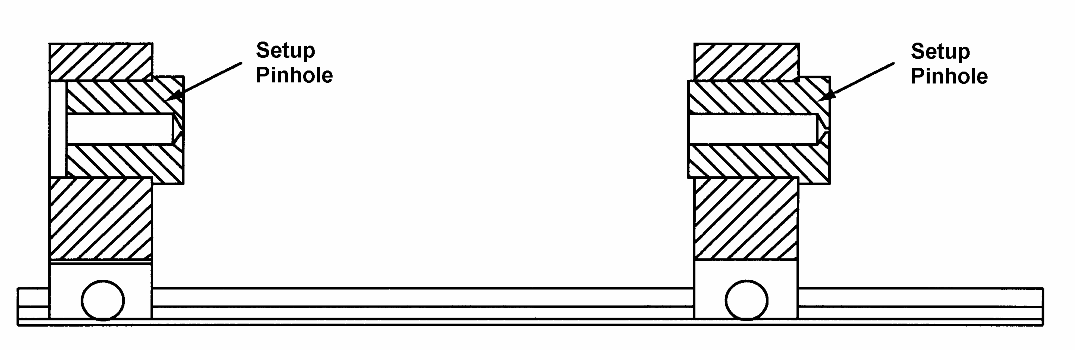

Figure 17. Pin holes for aligning mirrors #1 and #2. Use mirror #1 to steer through the first pinhole, and #2 to steer through the second.

- Remove the alignment pinholes and put the focusing lens (25.4 mm focal length) into the first lens holder. The lens should be inserted so that curved surface is towards the input beam.

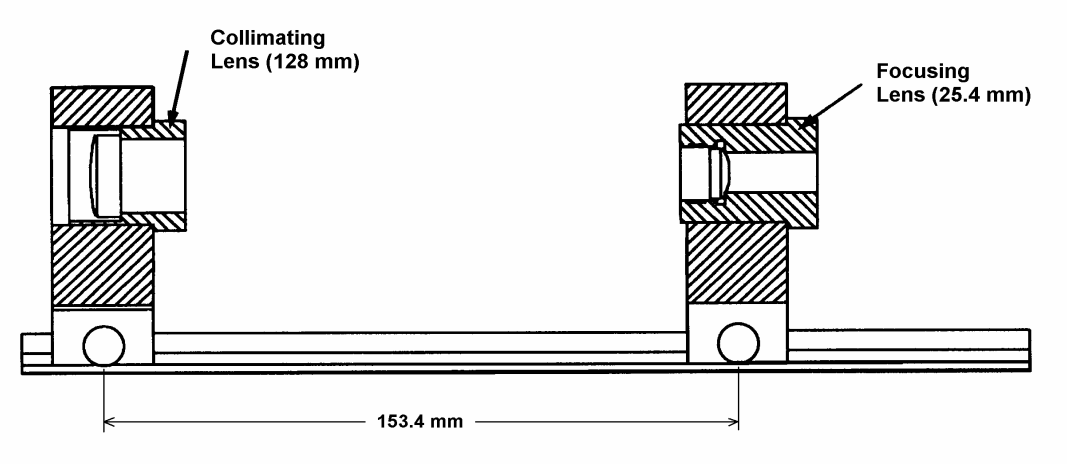

Figure 18. Collimation. Move the collimating lens back and forth until the reference beam in the telescope is as small as possible. Clamp the lens in place.

- Insert the collimating lens (128mm focal length) into the mount and adjust the position of the lens to be about 153.4mm from the optical center of the focusing lens. Look through the telescope at the spot and minimize the diameter of the spot in the telescope by moving the collimating lens back and forth. It is important to make sure that the crosshairs are in focus for the individual performing this alignment. It is critical that the telescope has already been adjusted for infinity focus using an auto-collimation technique and locked in place.

- Now that the beam has been steered through the optical isolator and beam expander, it remains to use mirrors #3 and #4 to steer the beam vertically off of beam splitter #1 through the dropping chamber. This adjustment will be made assuming that the interferometer is referenced to the bubble levels in the tripod tray. First, we must verify or set the tripod bubble levels so that they are aligned with the cart travel inside the dropping chamber.
- First re-install the top middle cover on the interferometer base (leave the two end plates removed for access). Pull the alignment pins out and make sure that the interferometer base handles are in the upright position. Put the tripod tray onto the interferometer base without the feet. Place the dropping chamber onto the tripod tray and clamp it down.
- To make the test beam vertical, one must place a dish of alcohol on the floor below the interferometer base (with the Superspring removed). It is good to use a dish with enclosed sidewalls to reduce wind vibrations and enough width (at least 50mm) to avoid a severe meniscus. Looking through the telescope one can see the reference beam and the return beam from the alcohol surface. The beam is traveling vertically when these two beams overlap in the telescope. Level the beam by adjusting the legs of the interferometer base so that the test and reference beam are coincident in the telescope. Note that this procedure does not rely on the dropper being vertical. At this point the bubble levels are not necessarily leveled, but this not a problem since the following procedures will serve to define the correct level of the tripod tray. Now put the feet under the tripod tray and lift all three until they just barely make contact with the nylon balls on the tripod legs. Then lift all three feet one revolution so that the tripod is not making contact with the interferometer base. You may now level the dropping chamber using the bubble levels (if you believe they are correct). If the bubble levels are not believed to be correct, you can ignore them for the moment. In any case, the test beam is vertical and now we must align the dropping chamber so that the cart travel is also vertical.

- Make sure that the beam coming back from the dropping chamber is full and is not clipped or smeared on the edges. If the beam doesn't go through the dropper, you may have to adjust mirrors 3 & 4 (see the next section for this procedure) or you can alternatively translate the dropper. Then switch the dropper controller to OSC mode in order to make the dropper move smoothly up and down. Initiate the dropper in OSC mode by hitting RESET then INIT. The goal is to level the tripod so that the laser beam coming back from the dropper cornercube does not translate as the cart travels up and down. The laser spot can be monitored by eye, but is much better if monitored using a quadrant photodiode such as the translation detector supplied with the FG5. Put the translation detector on the floor and attach X and Y outputs to channels 1 and 2 on an oscilloscope. Set the scope on XY, 200 mV/div. Move the translation detector into the laser beam path so that the spot on the scope is near the origin. Throughout this procedure it is important that the spot stay near the origin since there are non-linear effects on the edges of the detector. Note the magnitude of movement of the spot on the scope as the cart raises and lowers. Adjust the tripod feet until the spot movement is minimized, moving the detector on the floor to keep the spot near the origin. Note which direction the beam moves as the cart raises: this is the direction the cart is moving as it is lifted. Raise the leg which is in the same direction as the movement of the cart as it moves upwards. When necessary, increase the sensitivity of the scope and again minimize the spot movement by adjusting the tripod feet. Repeat this procedure until the spot movement is below 50 mV in both axes. Make sure the tripod does not touch the interferometer and that the beam returns from the dropping chamber without being clipped.
- Once this procedure is finished, the tripod is adjusted so that the cart is traveling vertically. Without changing anything the bubble levels should now be reset to indicate level.
- Once the cart travel is vertical, the tripod bubble levels should be adjusted to show level. This step is necessary so the cart travel will be vertical when the bubbles are level. Adjust the levels by loosening the M3 screw with a 2.5M socket inside the outer brass screw and adjusting the brass screw, then locking the assembly using the internal screw. The thread on the outer brass screw is delicate and can be damaged easily by turning the brass part when the internal screw is tight (locked). This procedure will ensure that the rods on which the cart travels are vertical when the bubbles-levels on the tripod are leveled. Having the cart travel vertically helps reduce damage to the test mass during the catch phase of the drop.

- This step assumes that the tripod levels have been set so that level ensures that the cart travel is vertical. Now we will adjust the interferometer so that it is referenced to the tripod tray bubble levels that were set in the last step. This next adjustment will ensure that the beam is vertical and travels cleanly through the dropper when the dropper and tripod are sitting on the interferometer base with the bubble levels indicating level. Mirrors #3 and #4 will be used to translate the beam so that it enters and exits the dropper without clipping on the tubes of the drag free chamber. Another requirement is that the beam is also traveling vertically into and out of the dropping chamber. Although both mirrors translate and tilt the beam, it is good to first use mirror #3 as the translation mirror and #4 to adjust the verticality of the beam during the alignment procedure. First, lower the tripod/dropper onto the interferometer base. Level the interferometer base until the levels on the tripod/dropper are centered. Put a dish of alcohol on the floor below the interferometer base. Hold a white card over the dish of alcohol and adjust mirror #3 (farthest from the first beam splitter) until the beam is traveling through the dropper system cleanly. Remove the card and look into the telescope and you will see the reference beam and the return beam from the alcohol dish. Adjust mirror #4 until they overlap in the telescope (this adjusts the verticality of the beam). [DO NOT ADJUST THE LEGS OF THE INTERFEROMETER BASE- WE WANT TO LEAVE THE INTERFEROMETE BASE REFERENCED TO THE BUBBLE LEVELS] Since this procedure may also cause the beam to translate, it is often necessary to iterate the procedure of translation using mirror #3 and aligning with the beam with vertical using mirror #4. This procedure converges rather slowly and takes about 10 iterations.

- The Superspring position must be set so that the test-beam returns cleanly after going into and out of the Superspring. In addition, it is important to get the reference and test beams to overlap in the fringe viewer when the translator plate underneath the interferometer base (twiddler) is in the mid-range position. It may be necessary to adjust the position of the Superspring interface plate (top mounting plate) that attaches to the bottom of the interferometer and supports the Superspring chamber. The five M5 screws should be loosened slightly and the Superspring leveled. These M5 screws have a M4 hex socket head. The Superspring should be unlocked mechanically to let free the reference test mass. The translator plate underneath the interferometer base (twiddler) should be put into its mid range position so that the glass surface is normal to the beam. The top mounting plate can be translated so that the beam travels cleanly through the Superspring. Ideally, the test beam should overlap the reference beam in the fringe viewer. Sometimes there is not enough range on the plate to get the beams overlapped totally in the fringe viewer in the horizontal direction but you should be able to get the two beams to have the same vertical position in the fringe viewer. Finally, tighten the screws on the top mounting plate and re-level the Superspring. Recheck the alignment after screws have been tightened.
- To move the test beam horizontally to overlap in the fringe viewer with the reference beam it is sometimes necessary to translate the final adjustment mirror underneath the interferometer base. Before doing so look through the telescope and adjust the mirror until the two spots are coincident in the telescope. This will ensure that the angle of the reference and test beams are the same even though they may not yet be coaxial. Then you can turn all three screws on the mirror mount in the same direction to translate the test beam relative to the reference beam. Always watch the beam in the telescope and make sure that you end up with the two beams overlapped in the telescope. Once the reference and test beams overlap in the fringe viewer and in the telescope they two beams are coincident and will produce good fringes.
- Preparations and Electrical hookups: Remove the dropper and tripod from the interferometer base (IB) and remove the center section of the IB top cover and the IB top cover containing the fringe viewer. Monitor the DC light level from the avalanche photodiode (APD). It is usually best to do this using a scope. The DC light level is available on the Analog Out port on the interferometer base.

- Steering the beam onto the APD: The beam can be steered onto the APD using the mirror mount holding the APD focusing lens. You should notice that the beam is either on or off of the sensitive APD area (there is not a sharp maximum, but a rather flat response, or "plateau") as you sweep the beam across the APD. See Figure 19. You can verify this by blocking off the light using the REF BEAM beam-blocker.

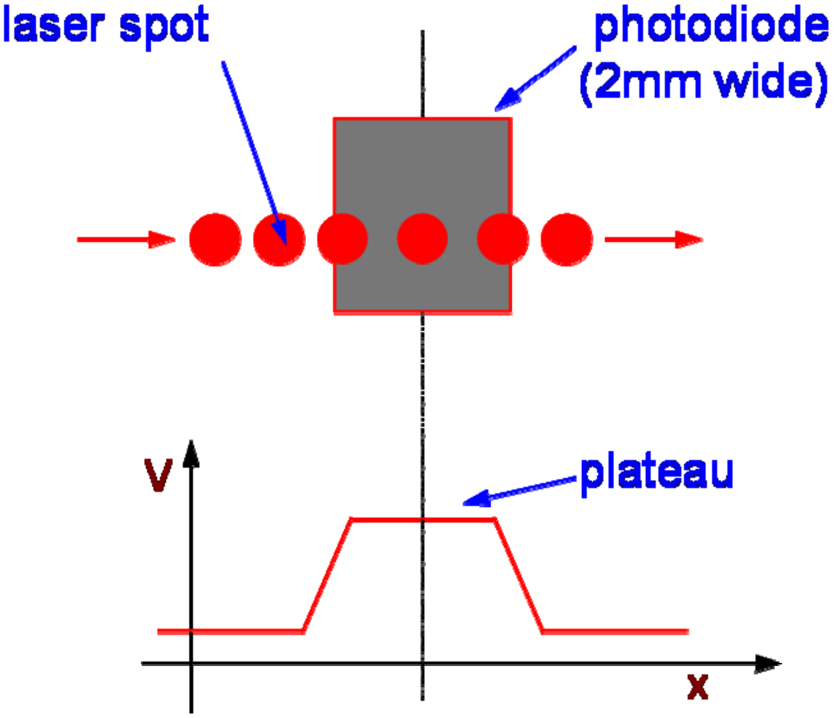

Figure 19. A mirror mount is used to steer the focused beam across the photo-detector. The output voltage appears to form a "plateau" as the spot is swept across. By keeping track of the mirror mount knob positions, it is possible to steer the beam to the center of the plateau, thus keeping the spot away from the edge of the detector. (Only the X direction is shown above – both directions must be centered).

- Focusing the beam on the APD: Change the focus of the APD until the maximum light level is reached. This focus adjustment is not very sensitive, so sometimes it is useful to note the two positions of the lens where the light level decreases by a fixed amount and then set the lens to the mid-position for the maximum level. Tighten the locking nut for the focusing lens.

- Put the dropper/tripod back on the interferometer base. Level the interferometer base to the bubble levels on the dropper and raise the tripod by one full turn of the tripod feet. Mount the Superspring. Align the test beam and reference beam in the fringe viewer. Put the dropper into OSC mode and maximize the fringes using the last mirror adjustment and twiddler underneath the interferometer base. Do not forget to lock the laser. Once the fringes are maximized, you should adjust the λ/2 plate (or optical isolator) so the fringes are as large as possible without clipping on the edges. When the light level is too high, the amplifier will saturate, producing a flattened or clipped response instead of the usual sine-wave fringes that should be produced. Once this light level has been adjusted, tighten the screws holding the λ/2 plate (or optical isolator). Use a M2.5 hex socket wrench for the λ/2 plate or a M3 wrench for the optical isolator.
- Replace all covers and tighten all screws

4.3. New Style Interferometer

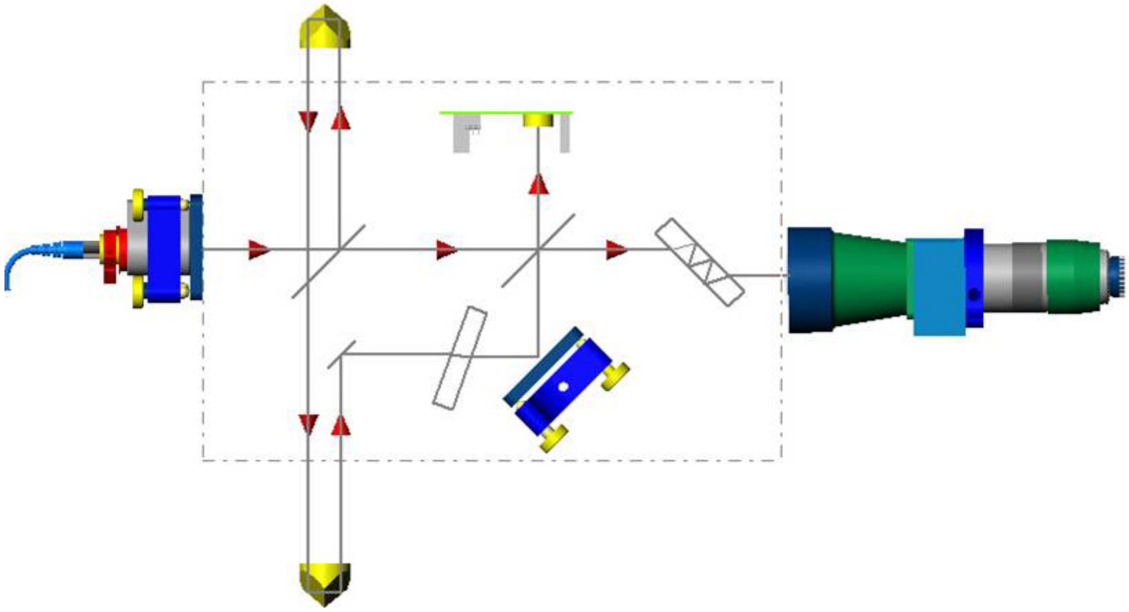

Figure 20. "New Style" Interferometer beam path.

- Set up the superspring and attach the interferometer base as described in the setup instructions.
- Center the precision bubble vials mounted on the base of the superspring by adjusting the leveling feet on the superspring tripod.
- Turn on the laser.

- Roughly collimate the laser beam on the ceiling or on a target above the interferometer base. The collimating assembly is on the output end of the laser fiber. Use a 2.5 mm Allen wrench to remove the collimating assembly from the interferometer. Adjust the collimation of the beam by loosening the locking screw (2.5 mm Allen screw) on the slide of the fiber input and moving the slide. A properly collimated beam should have a diameter of 6 mm.
- Slide the loosened assembly back into the interferometer (note the orientation key) and precisely collimate the laser beam by use of the slide until the beam size in the collimating telescope is minimized.
- Tighten the locking screw on the slide. Then tighten the assembly into the interferometer using the second Allen screw
- Remove the dust plug on the top of the interferometer base and place the dropping chamber tripod and dropping chamber on top of the interferometer (see setup instructions).
- If possible (both spots visible), verticalize the beam as described in the setup instructions.
- Slightly loosen the two screws directly above the fiber optic input on the interferometer base, just sufficient to allow movement of the fiber optic input stage.
- Block the test beam (push in test beam blocker) and pull out the reference beam blocker.
- Translate the fiber optic input until the beam is centered in the fringe viewer and tighten the screws.
- Focus the telescope crosshairs and adjust mirror # 3 until the reference beam is centered in the telescope viewfinder.
- Re-verticalize the beam.
- Check to see if the reference beam is still centered in the fringe viewer. If the beam is not centered, repeat steps 8-14.
- Place the superspring alignment fixture (pigsnout) over the top superspring window. Orient the alignment fixture so the two alignment holes are parallel to the telescope axis.
- Verify that the beam is traveling properly through the superspring by making sure the beam enters and exits the superspring through the two holes in the alignment fixture.
- If the beam is not traveling properly through the superspring, verify that the reference beam is centered in the fringe viewer, and verticality is correct.
- Using mirror # 2, make the test and reference beams coincident in the collimating telescope.

- Use the translator plate (twiddler) to align the test and reference beams in the fringe viewer.
- Remove the dropping chamber and dropping chamber tripod from the interferometer base.
- Next, align the photodiode:
  - Block the test beam by pushing the beam blocker in.
  - Remove screws that attach the small plate to the back of the interferometer base.

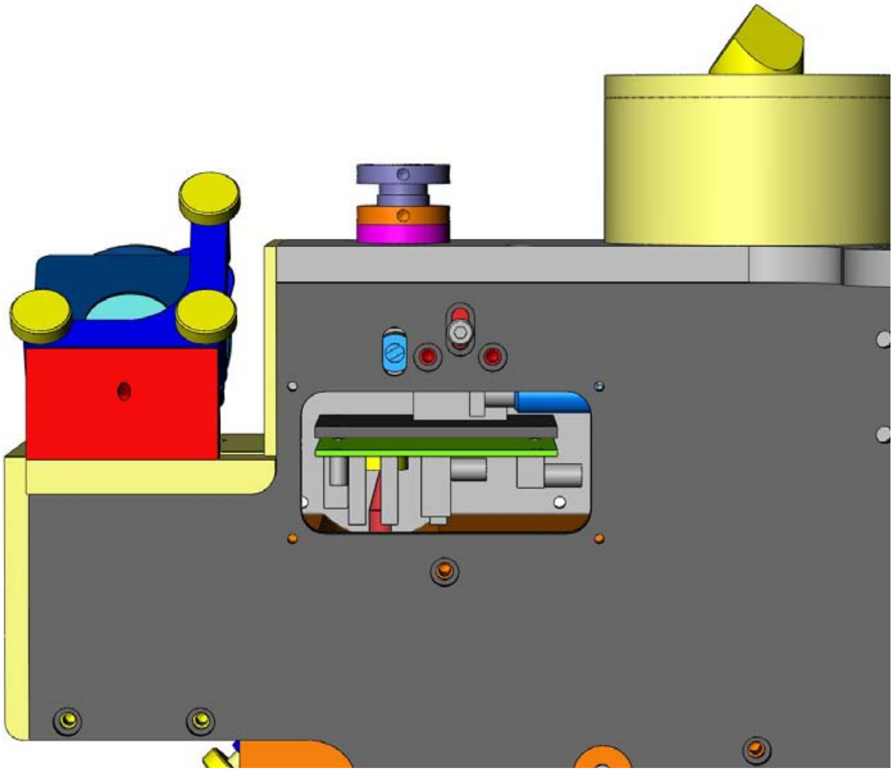

Figure 21. APD alignment screws. Remove the cover from the rear of the interferometer, and locate the two screws shown in blue above. Adjust these screws until the APD is centered on the overlapped laser beams.

- Adjust the X-Y stage of the APD to maximize the voltage at the “analog” BNC on the interferometer base (See Figure 21). This voltage is negative. Adjust the stage to obtain smallest absolute value. A digital voltmeter or oscilloscope is recommended for this procedure. In both the X and Y directions, there should be a “plateau” of stable, less negative voltage. Adjust both the “X”-screw (accessed through a hole on the rear of the I.B.) and “Y”-screw (accessed by “grabbing” the knurled knob of the XY stage) so that the APD is in the center of both “plateaus”. See Figure 19 for discussion of the “plateaus”.
- Replace the rear plate on the interferometer base and tighten all screws.

4.4. Glass cleaning

To clean a piece of optics, it is best to remove it from its mount and place it on a scratch free (lens paper) surface. When removing a piece of glass make sure to note it’s orientation: both in rotation and in which side is facing “out”.

To clean a large, flat piece of glass, place it on a scratch free (lens paper) surface and lay a piece of lens paper over it. Apply 2-3 drops of pure ethanol (just enough to wet the entire surface) to the paper. Then pull the paper towards yourself in such a way that the dry part of the lens paper absorbs the remaining alcohol. Do not reuse the lens paper. Do this until the dirt has been removed and there is no sign of an alcohol “residue” on the glass.

To clean a curved surface, or a surface that is hard to reach. Fold lens paper in half, 3 times, lengthwise. Then, fold this along its length such that you have an approximately 1x1 cm piece of lens paper. Clamp this into a hemostat. While folding the paper, take care not to touch the final surface with your fingers. Apply 1-2 drops of pure ethanol to the lens paper, and swipe the paper across the class. Do not “scrub” the paper back and forth. Discard the paper and repeat the process until the glass is clean.