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1. Concept and History of the FG5

1.1. The FG5 Absolute Gravimeter

The FG5 absolute gravimeter is a high precision, high accuracy, transportable instrument that measures the vertical acceleration of gravity (g). The operation of the FG5 is simple in concept. A test mass is dropped vertically by a mechanical device inside a vacuum chamber, and then allowed to fall a distance of about 20cm. The FG5 uses a laser interferometer to accurately determine the position of the free-falling test mass as it accelerates due to gravity. The acceleration of the test mass is calculated directly from the measured trajectory.

The laser interferometer generates optical interference fringes as the test mass falls. The fringes are counted and timed with an atomic clock to obtain precise time and distance pairs. These data are fit to a parabolic trajectory to give a measured value for g. This method of measuring gravity is absolute because the determination is purely metrological and relies on standards of length and time. The distance scale is given by a frequency stabilized helium neon (HeNe) laser used in the interferometer. A rubidium atomic time-base provides the time scale used for the accurate timing. The value of gravity obtained with the FG5 can be used without the loop reductions and drift corrections normally required when using relative instrumentation.

1.2. HISTORY

The FG5 is a new generation of absolute gravimeter based on technology developed over the last thirty years by Dr. James Faller of the National Institute of Standards and Technology (NIST), and his colleagues. Beginning with a white-light-fringe interferometric system built in 1962, Faller and coworkers have continuously improved the designs of the instruments. The most recent predecessors of the FG5 was the series of six JILAg gravimeters, built in 1985 at the Joint Institute of Laboratory Astrophysics (JILA), with support from NIST, the Defense Mapping Agency (DMA), the National Oceanographic and Atmospheric Administration (NOAA), the Canadian Geophysical Survey (GSC), the University of Hanover Institute for Earth Measurement, Germany, the Finnish Geodetic Institute, Finland, and the University of Vienna Institute for Metrology and Geophysics, Austria.

1.3. FG5 Design Features

The FG5 incorporates a number of significant advancements in design which reduce or eliminate systematic errors identified in the earlier versions, and which make the FG5 easier to use. These improvements are:

• An inline interferometer beam path which eliminates systematic errors from tilt-induced path length changes.

• Complete redesign of the Superspring, a device for providing an inertial mass that contains a retroreflective corner cube. The new Superspring has improved performance, and at the same time greatly reduced size. The drift problems of earlier designs have been reduced substantially.

• Completely new tripod design, which supports the test chamber, for extra stability. The tripod is now built symmetrically with respect to the drop line.

• Improvements to the electronics reflect new technology and make the instrument smaller and easier to use.

• This absolute gravimeter is designed to work with a new rugged iodine-stabilized laser system (WEO model 100) traceable to the BIPM.

• The system controller has been updated to an Intel-based personal computer with a standard language interface. The decision to use standard PC technology has allowed the FG5 to offer more computing power while reducing the size of the instrument.

• "g", a user-friendly, Windows©-based, full-featured software program takes interferometer data and environmental data. This software provides an immediate value for the local gravity in real-time. The program is also a full-featured post-processing software program that allows complete ability to vary data analysis procedures and to vary environmental corrections.

2. Design: Components and Function

The **FG5 System** (Figure 2-1) consists of a: **Dropping Chamber**, **Interferometer**, **Superspring**, **System Controller**, and **Electronics**. A test mass is allowed to free-fall inside the evacuated **Dropping Chamber**. The **Interferometer** is used to monitor the position of the freely-falling test mass. The **Superspring** is an active long-period isolation device used to provide an inertial reference for the gravity measurement. The **System Controller** (computer) allows a flexible user interface, controls the system, acquires data, analyzes data, and stores the results. The **Electronics** provides high accuracy timing necessary for the measurement and provides system servo control.

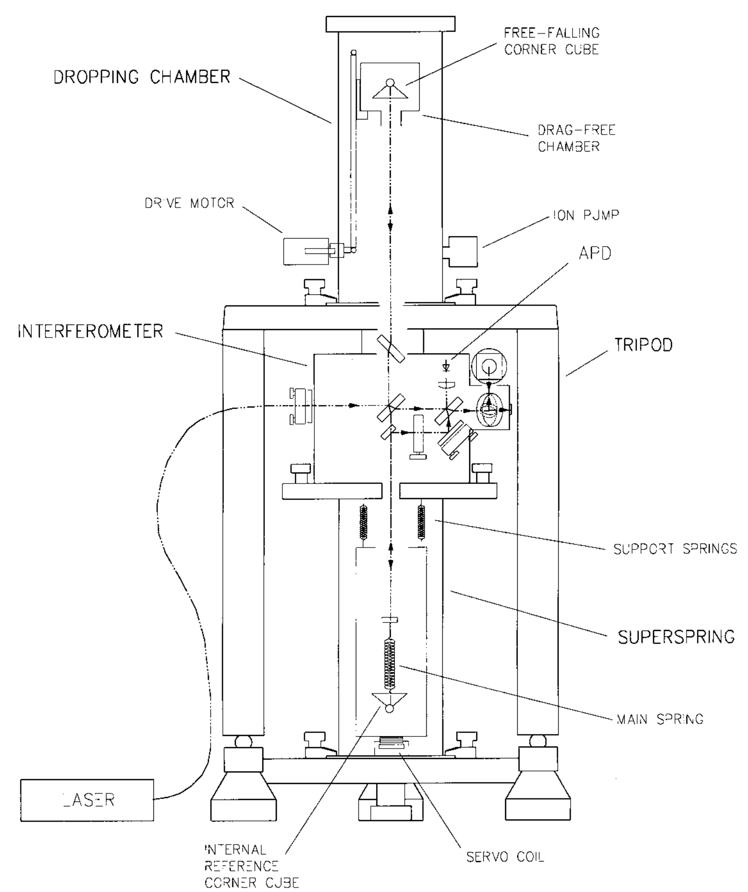

Figure 2-1 **The FG5 System**

2.1. The Dropping Chamber

The Dropping Chamber (Figure 2-2 and Figure 2-3) is an evacuated chamber which contains the **Cart/Drag-Free Chamber** which houses the **Test Mass**. A **Drive Mechanism** is used to drop, track, and catch the test mass inside the drag-free chamber. Laser light (Figure 2-1) 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.

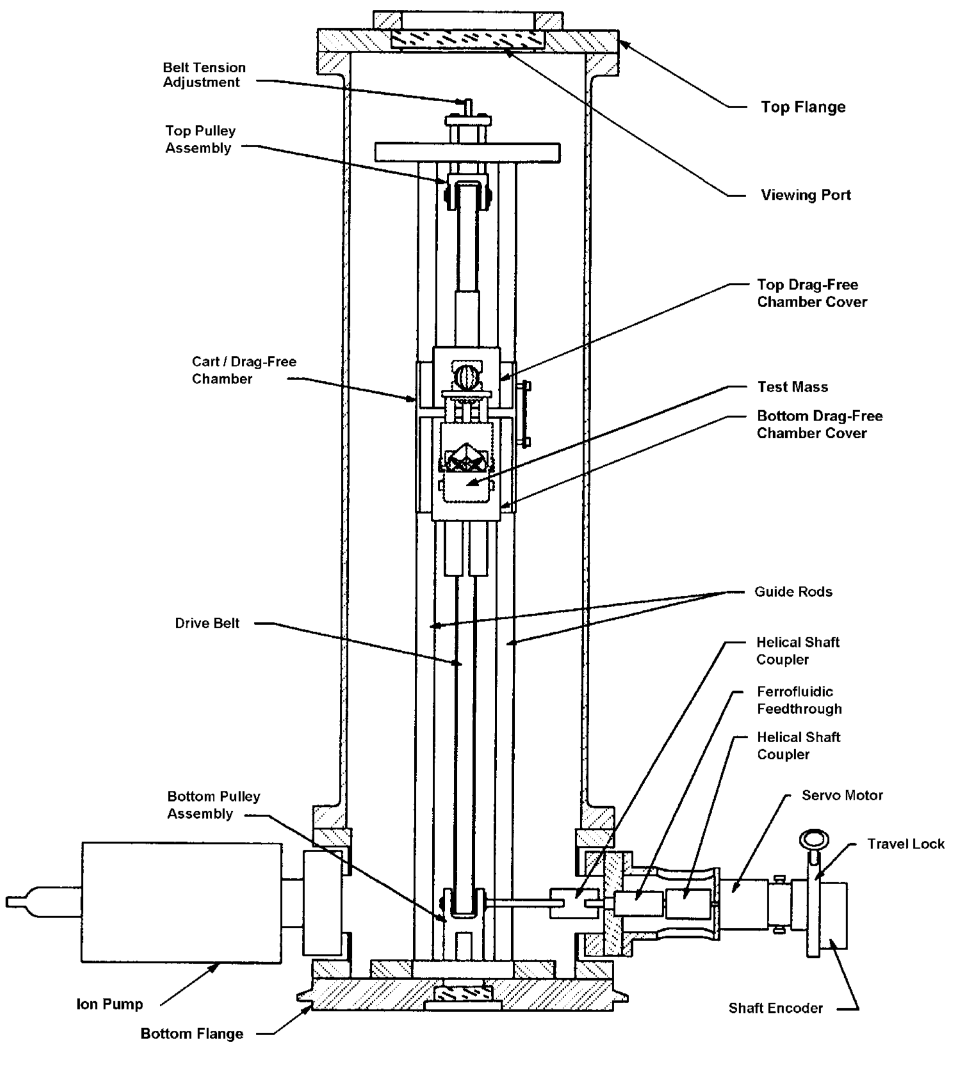

Figure 2-2 Front view of the dropping chamber

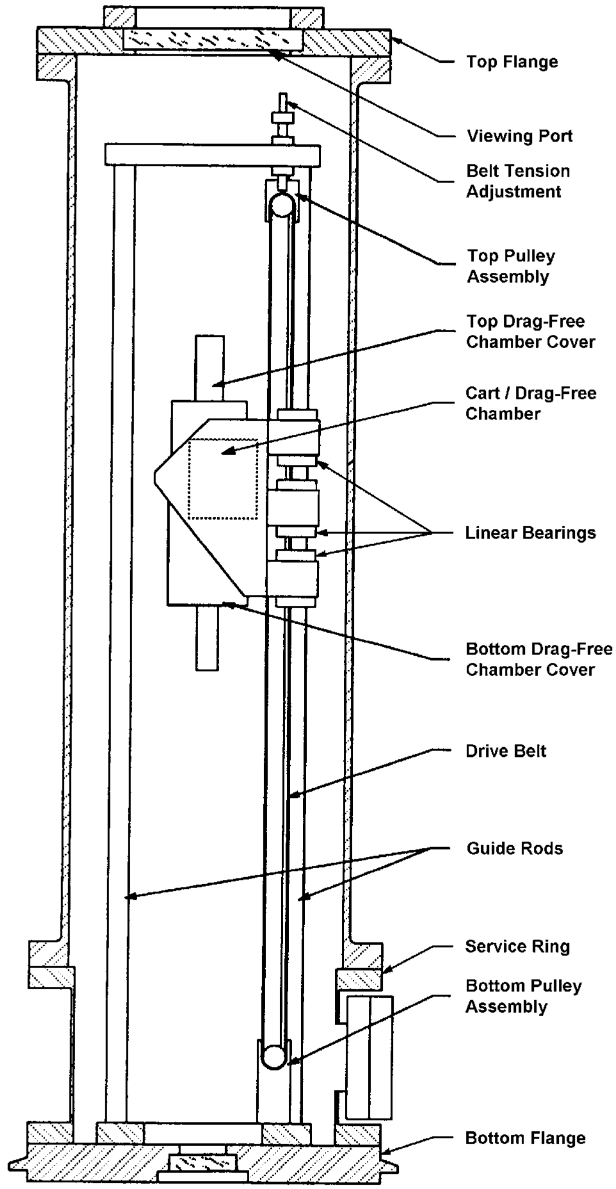

Figure 2-3 **Side view of the dropping chamber**

2.1.1.CART/DRAG-FREE CHAMBER

The **cart /drag-free chamber** (Figure 2-4 and Figure 2-5) houses the **test mass**. The purpose of the drag-free chamber is to reduce the residual air drag inside the evacuated dropping chamber. The chamber 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. A **L**ight **E**mitting **D**iode **(LED)** , located on the cart, directs light through an **optical glass sphere** attached to the test mass. The sphere focuses the light onto a **linear detector**, also mounted on the cart. This system senses the position of the cart with respect to the test mass. A **servo-motor/drive belt system** (Figure 2-2) moves the cart inside the Dropping Chamber, using active feedback from the position sensor to maintain the cart in a constant position relative to the test mass during free-fall. Since there is essentially no relative motion between the test mass and the drag-free chamber, the effects of residual air drag are eliminated.

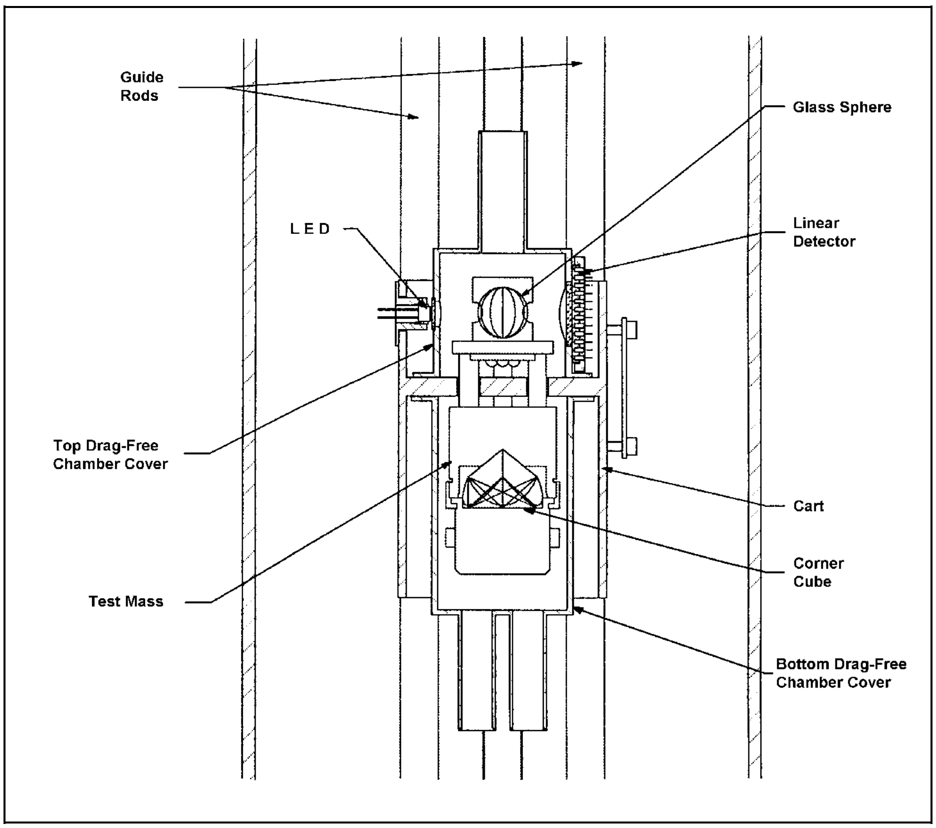

Figure 2-4 **Front view of the cart/drag-free chamber**

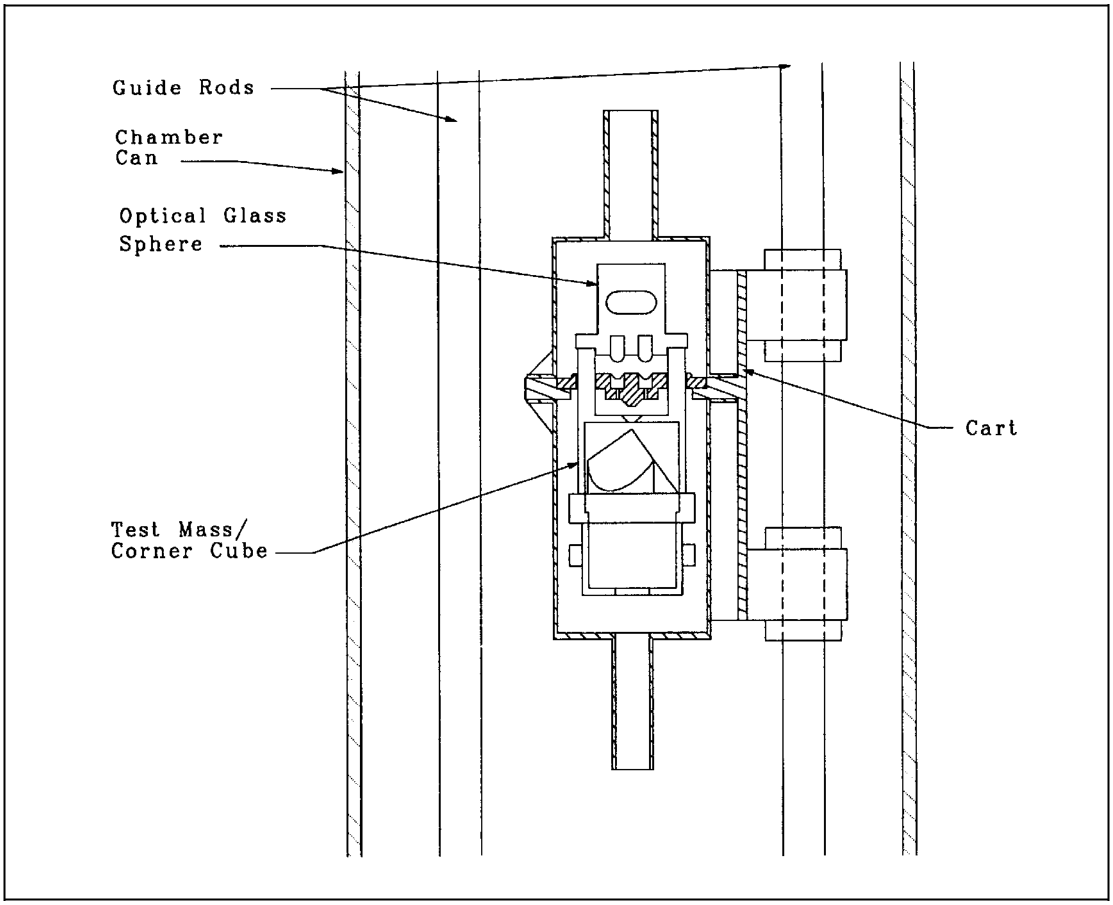

Figure 2-5 Side view of the cart/drag-free chamber

2.1.2.TEST MASS

The Test Mass (Figure 2-4 and Figure 2-5) 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[1].

[1] Peck, Edson, J. Opt. Soc. Amer., **38**, (1948)

2.1.3.DRIVE MECHANISM

The drive mechanism (Figure 2-2) is a support structure inside the dropping chamber on which the cart/drag-free chamber travels up and down, driven by a DC servo motor.

2.1.4.SERVICE RING

The **Service Ring** (Figure 2-6 and Figure 2-7) is the base of the Dropping Chamber. It provides connection and mounting for the following:

- A bellows-type **vacuum valve** for the initial evacuation of the vacuum system
- A **Ferrofluidic rotary vacuum feedthrough** which connects the motor shaft to the cart drive mechanism
- A **servo motor/rotary shaft encoder** assembly which moves the cart and senses its position
- An **electrical vacuum feedthrough** which allows connection of the test mass tracking electronics to the controller
- An **ion pump**, mounted on a 2¾″ Conflat flange, which maintains the vacuum once the chamber has been evacuated by the roughing pump
- Spare **2¾″ Conflat and Mini-Conflat flanges** are blanked off, and can be used for additional vacuum accessories

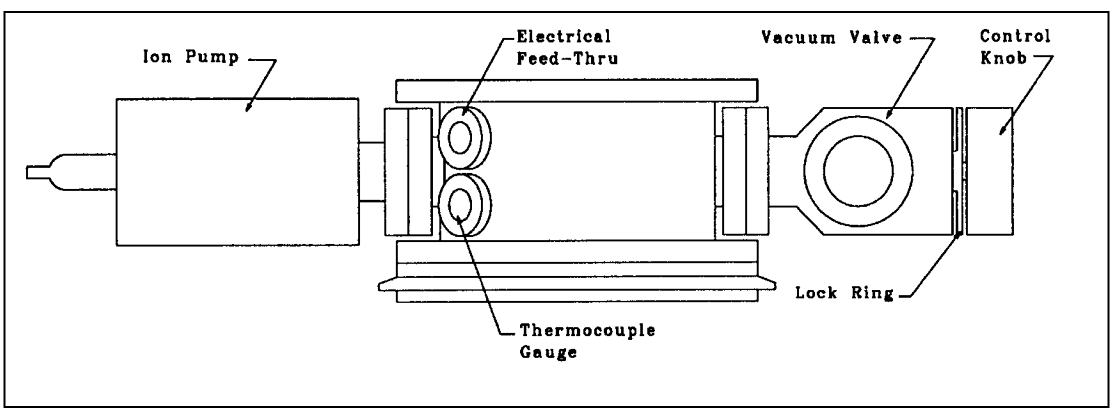

Figure 2-6. **Side view of the service ring.**

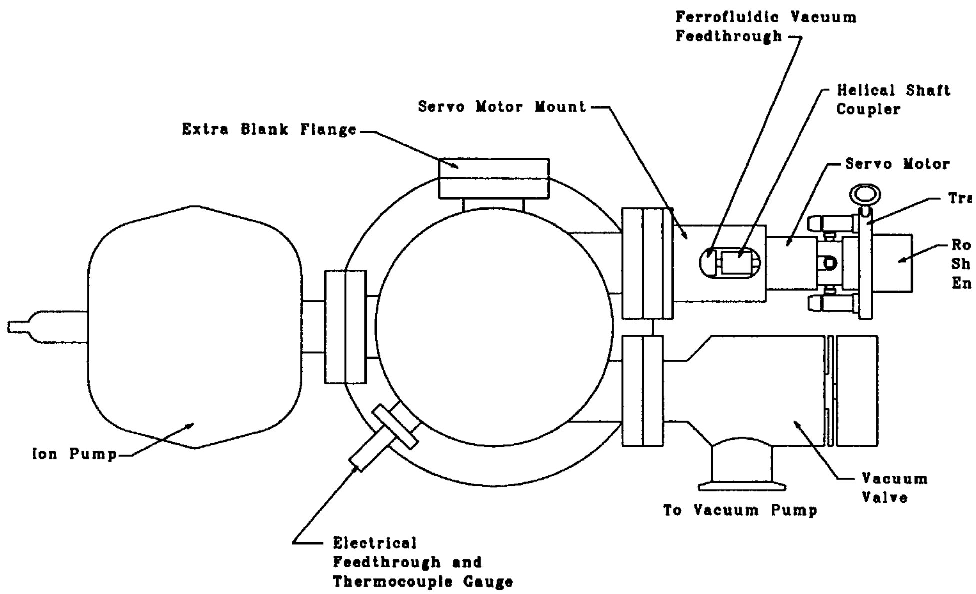

Figure 2-7 **Top view of the service ring.**

2.1.5.VIEWING PORT

The **viewing port** (Figure 2-2 and Figure 2-3) is located in the top flange of the dropping chamber. It allows visual observation of the dropping chamber interior when the rotation monitor is not fitted to the system. The rotation monitor (when fitted to the system) is mounted to the top flange of the dropping chamber, directly above the viewing port. When the rotation monitor is not mounted, a cover for the port is used to exclude ambient light from the interior of the dropping chamber during measurements.

2.1.6.THE DROP

In drop mode, a signal from the computer to the dropper controller initiates the drop sequence. The cart drag-free chamber is driven slowly from its bottom position to the "hold" position at the top of the drop. A second pulse initiates the drop, and the cart accelerates downward at more than 1 g, leaving the test mass in free-fall.

When the cart has traveled about 5 mm downward from the hold position (as measured by the shaft encoder) a separation of about 3 mm between the cart and test mass has been achieved. The dropper controller then uses feedback from the linear detector to maintain this separation for the remainder of the drop.

The free-falling test mass generates an interference fringe for each half-wavelength ($\lambda/2$) of its movement. As the mass accelerates downward, the fringes occur more and more closely in time. The resulting signal from the avalanche photo diode (APD) is a "chirped" sine wave (Figure 2-11) whose frequency is proportional to the free-falling test mass's velocity.

Approximately a million fringes are generated during a single drop. A zero-crossing discriminator (comparator) transforms the sinusoidal fringe signals from the APD into a series of square Transistor-Transistor Logic (TTL) pulses. The pulses are scaled (i.e., divided) by a user-defined factor which is set in the software (typically 1000). A Time Interval Analyzer (TIA) measures the time interval between each scaled pulse. The g-program fits each time and distance pair to a parabolic trajectory to determine the value of g.

When the cart and test mass have descended past the catch point, the controller signals the cart to reduce acceleration and then come to a stop. The falling mass catches up to the descending cart and is brought gently to rest.

The system resets for the next drop. The entire sequence takes about 2 seconds and can repeated up to thirty times per minute.

2.2. The Interferometer Base

The interferometer base is an aluminum housing which supports the **optics** for splitting, directing, and recombining the laser beams.

2.2.1.LASER

The FG5 employs a stabilized helium-neon laser to provide an accurate and stable wavelength used in the interferometric measurement system. There are two lasers which are currently available for the FG5.

- The Winters Electro-Optics Model 100 iodine stabilized laser. This laser is a primary standard for the definition of the meter at the Bureau International des Poids et Measures (BIPM) in Sevres, France. It is a highly stabilized distance standard having an absolute frequency accuracy of 1 part in 10^{10} (50 kHz).
- The Micro-g Solutions Model ML-1 frequency/intensity stabilized HeNe laser is characterized by a slow, linear drift. Unlike the WEO Model 100 Iodine Laser, it must be periodically calibrated to achieve the best accuracy. However, it is more rugged than the iodine laser.

2.2.2.OPTICS AND BEAM PATH

Refer to Figure 2-1 and Figure 2-8 for the following description of the beam path. The optical fiber directs the laser beam from the laser head to the interferometer base. At the input of the interferometer, a lens collimates the light from the optical fiber. It is then directed to **beamsplitter #1**, where it is split into the **test beam** and the **reference beam.** The **reference beam** is split again at **beamsplitter #2** and travels to the **Avalanche Photo Diode (APD)** and the fringe viewer. The path length of the reference beam remains constant.

The **test beam** is reflected vertically at **beamsplitter #1**, and passes through a compensator plate and a window in the bottom of the Dropping Chamber. It is then reflected back down by the corner cube in the test mass. The test beam returns through the window, the compensator plate, and passes down through the interferometer base to the superspring. The test beam passes through the top window of the superspring chamber to a corner cube in the superspring mass.

The test beam is then reflected back through the window to the interferometer base, where it reflects off mirror #1, passes through the translator plate (twiddler), reflects off mirror #2, and is recombined with the reference beam at beamsplitter #2.

This interferometer is a Mach-Zender interferometer with a fixed (reference) arm and a variable (test) arm. During a drop, the motion of the test mass/corner cube affects the path length of the test beam. The interference fringes which result from the recombination of the test beam and the reference beam provide an accurate measure of the motion of the test mass relative to the mass suspended on the superspring.

Two separate complementary, recombined beams are produced at beamsplitter #2. The vertical recombined beam is focused by a lens to strike the detector (APD), and the interference fringes are converted to a Continuous Wave (CW) signal. The CW signal is then converted to a Transistor Transistor Logic (TTL) signal and transmitted to the time interval analyzer.

The other recombined beam travels horizontally until it reaches the attenuator plate (rattler). This beam is split and reflects "rattles" between the beamsplitter coating and the uncoated side of the attenuator plate. Three beams of decreasing intensity emerge from the coated side. The first and brightest of these beams travels horizontally into the fringe viewer. The second and third beams are deflected vertically by a mirror. A flag in front of the mirror blocks the second beam, allowing the third (dimmest) beam to exit the interferometer where it is reflected off mirror #3 and enters the collimating telescope. The collimating telescope is used to compare this weak reference beam with another beam reflected off of an alcohol pool to allow alignment of the laser beam with the local vertical.

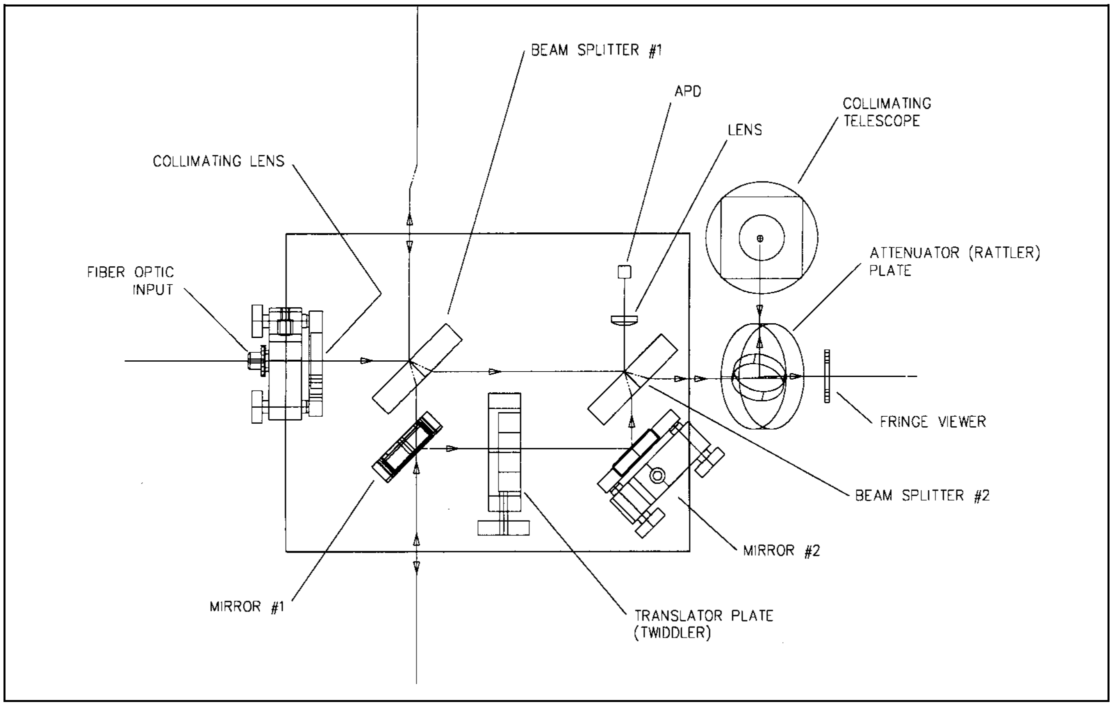

Figure 2-8 **Side view of interferometer optics and beam path**

2.3. The Superspring

The superspring (Figure 2-9) 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.

2.3.1.SUPERSPRING MASS

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

2.3.2.SPHERE DETECTOR SYSTEM

The superspring sphere detector system (Figure 2-10) 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.

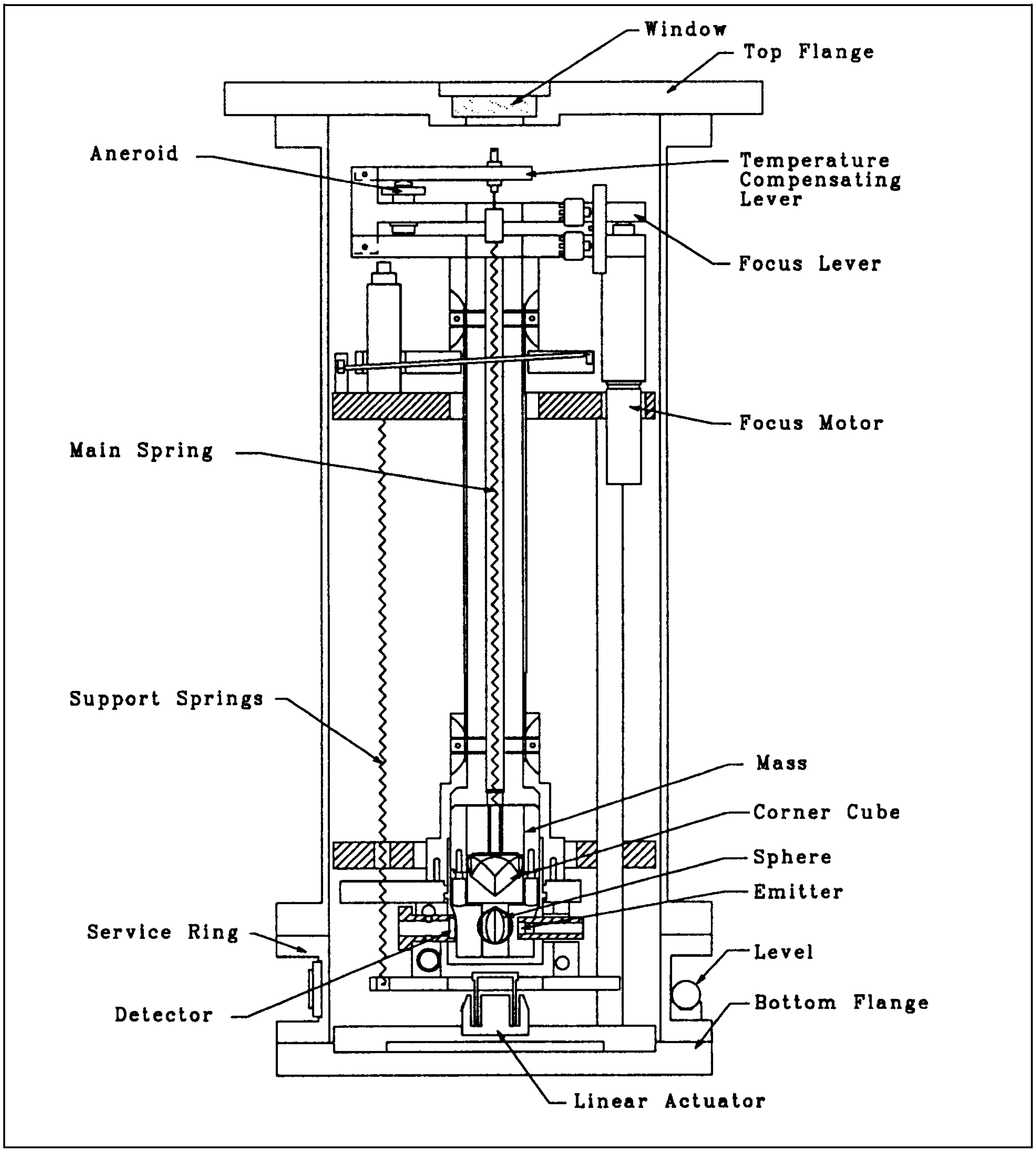

Figure 2-9 The Superspring.

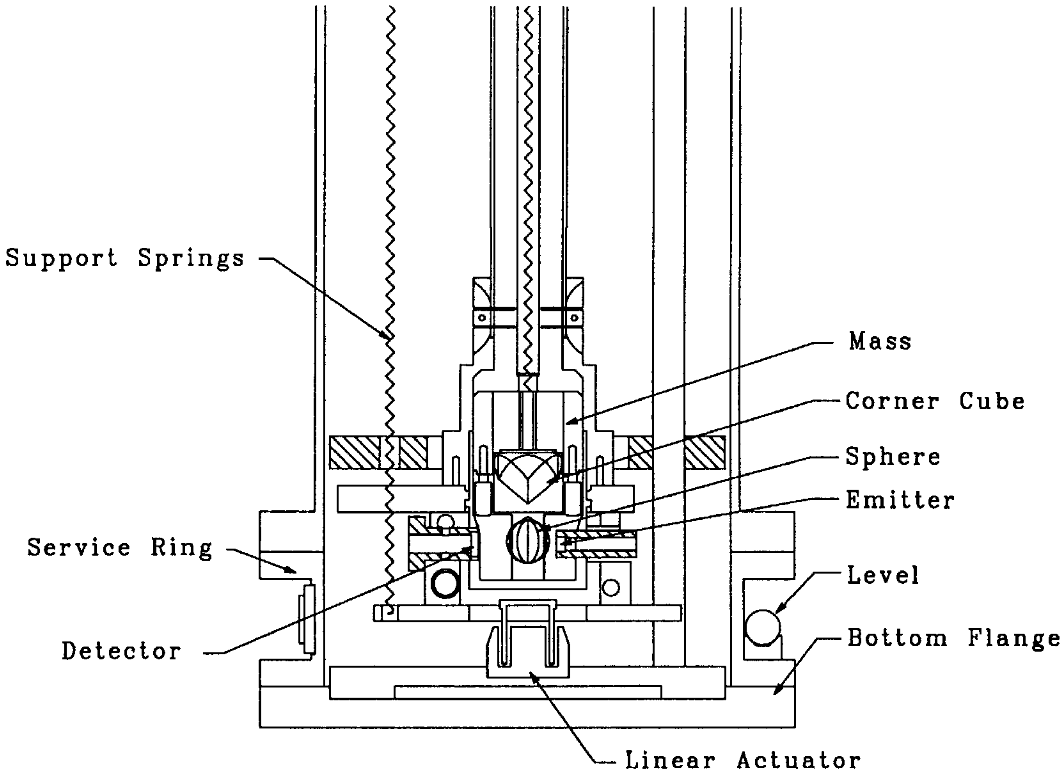

Figure 2-10 **The Superspring sphere detection system**

A rough adjustment of the spring length is made with a DC motor-driven lever system that supports the mainspring at the top of the mainspring housing. Temperature-related length changes of the mainspring are compensated with an aneroid wafer assembly (Figure 2-9).

2.4. The System Controller

The system controller is an IBM-compatible PC which is used to control the gravimeter (initiate drops) as well as collect data (distance and time) for computing the gravity value. It is also used to collect environmental and rotation monitor data if the FG5 is equipped with these systems.

2.4.1.REQUIRED HARDWARE

A Pentium II or better PC running Windows98©

- Memory: >32M RAM
- Hard Drive: 500Mb or larger recommended for high density data storage
- Combination A/D converter and Parallel Input-Output (PIO) board
- Time Interval Analyzer (TIA)

2.4.2.OPTIONAL HARDWARE

- Micro-g Solutions Environmental Sensors Package
- Micro-g Solutions Rotation Monitor

2.4.3.SOFTWARE

The FG5 software, "g", is a Windows©-based application. The software provides FG5 data acquisition, real-time processing, post processing, and diagnostic testing. It also allows the user to customize the data acquisition for each site including input/output files, printing options, and session control. The software also allows user input of site-specific information such as site name/code, geodetic coordinates and elevation, nominal air pressure, and gravity gradient. In addition, the software allows the user to apply (or not apply) all the gravity corrections independently. These options are available both in the real-time and post-processing modes.

See the "g" Software Manual for additional information.

2.5. Electronics

2.5.1.TIMING SYSTEM

The timing system (Figure 2-11) consists of four main components:

- Avalanche Photo Diode (APD)

- Rubidium Oscillator
- Time Interval Analyzer (TIA)

The Avalanche Photo Diode (APD) is located in the interferometer (Figure 2-8). It detects the fringes created when the test and reference beams are recombined. An ultrafast comparator chip located on the APD board detects the zero-crossings of the sinusoidal fringes and outputs a TTL (square wave) version of the frequency-swept fringe signal. During a drop, the fringe signal sweeps from DC to about 6 MHz.

The Rubidium Oscillator is an atomic resonance-controlled oscillator (or equivalent) which outputs a stable sinusoidal signal of 10 MHz.

The Time Interval Analyzer (TIA) scales the fringes using a software-specified scale factor and outputs the time of occurrence for each scaled fringe.

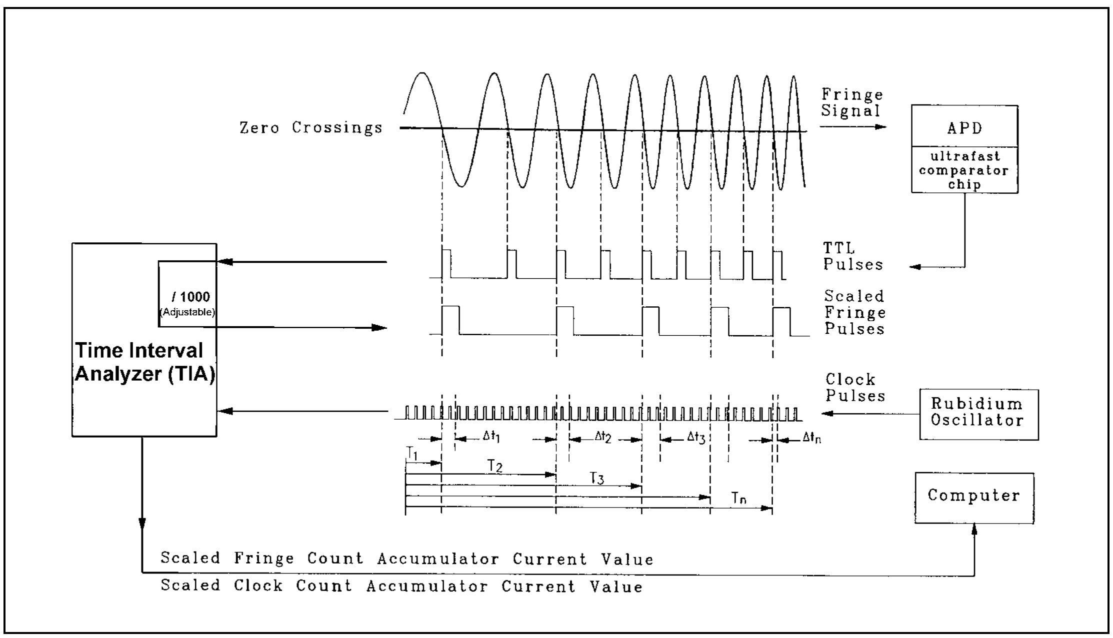

Figure 2-11 Timing diagram

2.5.2.DROPPER CONTROLLER

The dropper controller uses three modes to operate the dropping chamber. These modes are OSC, AUTO, and MANUAL. The operator also controls the status of these modes and the dropper triggering with the RESET and INIT switches and the trigger source (INT/EXT) switch. See Chapter 4 for a detailed discussion of the modes and switches.

The dropper controller can direct the motor in the Dropping Chamber to lift the cart and test mass to a specified height, to move the cart at a specified velocity, and to track the test mass during free-fall.

The motor drives the cart/test mass assembly by turning a pulley and stainless steel drive belt which is attached to the cart. The motor also turns an optical shaft encoder that provides accurate information to the dropper controller on the position and velocity of the pulley.

Information on the relative position of the test mass to the cart during free-fall is provided by a sphere detector system. An LED and a linear detector are mounted on opposite sides of the cart, and an optical glass sphere is mounted on the test mass. The sphere focuses a beam of light from the LED onto the linear detector, indicating the precise location of the center of the sphere relative to the cart. The dropper controller uses this information to determine whether to maintain, increase, or decrease current to the motor to achieve the appropriate relative position of the cart and the test mass. This feedback system is a conventional analog servo system.

2.5.3.SUPERSPRING CONTROLLER

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 test beam constant. Three systems provide coarse and fine adjustment of the spring support structure: a motor attached to the top of the mainspring, a **linear actuator** coil and magnet system, and an **aneroid wafer assembly**. A controller circuit board drives the motor and the coil and magnet system, while the aneroid wafer assembly responds automatically to temperature changes.

A sphere detector system similar to the one used in the Dropping Chamber 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 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.

2.5.4.LASER CONTROLLER

The laser controller supplies power and enables operator control for the WEO Model 100 Iodine stabilized laser or the Micro-g Solutions Model ML-1 frequency/intensity stabilized laser. See Chapter 3 for setup and operation.

2.5.5.POWER SUPPLIES

There are two primary power supply units which are required to operate the FG5:

The power mains module is located in the rear of the electronics case. It is the primary input for AC power, and contains all the DC power supplies which are required to operate the FG5. Note that it accepts AC voltage from 100-240 V, 50-60 Hz.

The Micro-g Solutions Model 125 Portable Ion Pump Power Supply is located in the dropping chamber travel case. It supplies power to the ion pump for both AC and DC operation. See the Model 125 manual for operating instructions. Note that it accepts AC voltage from 100-240 V, 50-60 Hz.

2.5.6.OPTIONAL SYSTEMS

There are two optional systems for the FG5: the Environmental Sensors Package and the Rotation Monitor. The environmental sensors package can be added to the system by itself, but if the rotation monitor is purchased, the environmental sensors package must be included in the system.

2.5.6.1.ENVIRONMENTAL SENSORS

The Environmental Sensors Package is used to record environmental data (temperature and atmospheric pressure) as the system is operating. Atmospheric pressure data is used to compute and apply the local barometric pressure attraction correction while the system is operating. The primary components of the environmental sensors package are:

- **Temperature Probe:** The patch panel (Channel 0) contains a built-in temperature sensor that records ambient temperature. Note that temperature is not actually used in the gravity determination calculation. It is recorded purely for diagnostic reasons.
- **Pressure Sensor:** A digital barometer is used to sense the atmospheric pressure. It is mounted on the inside of the power mains module at the rear of the electronics case, and is read in to the computer via patch panel Channel 4.

2.5.6.2. ROTATION MONITOR

The rotation monitor (Figure 2-12) is used to monitor and record the rotation of the test mass during each drop. The rotation monitor consists of a rigid anodized aluminum housing mounted on the top flange of the dropping chamber, above the viewing port. The rotation monitor employs a very sensitive optical lever system to measure and record the rotation of the test mass which can be used as a means to reject bad drops or determine when the mechanical system is not functioning properly. A diode laser produces a visible beam which is directed onto and reflects from a mirror attached to the top of the dropped object. The reflected beam is sent through a lens and is focused onto a two axis position sensitive photodetector. This system rejects translation and is only sensitive to rotation. The diode laser beam reflects off mirror #1 and the beamsplitter (mirror mount #2). The beam then passes down through the dropping chamber viewing port, where it reflects off a flat mirror which is mounted to the top of the test mass. The return beam from the test mass mirror passes through the beamsplitter and reflects off mirror #3. The beam then passes through the 200 mm focusing lens, which is adjusted to eliminate cross coupling of translations which would otherwise appear as rotations. The beam is then reflected off mirror #4 and enters the detector box. The output from the quad detector is used to provide rotation information to the computer/system controller. Each rotation monitor is calibrated by Micro-g Solutions to determine the rotation and translation sensitivity. These data are used to calculate rotation errors. The rotation data can also be displayed on the computer screen, and is recorded in the DDT output data file.

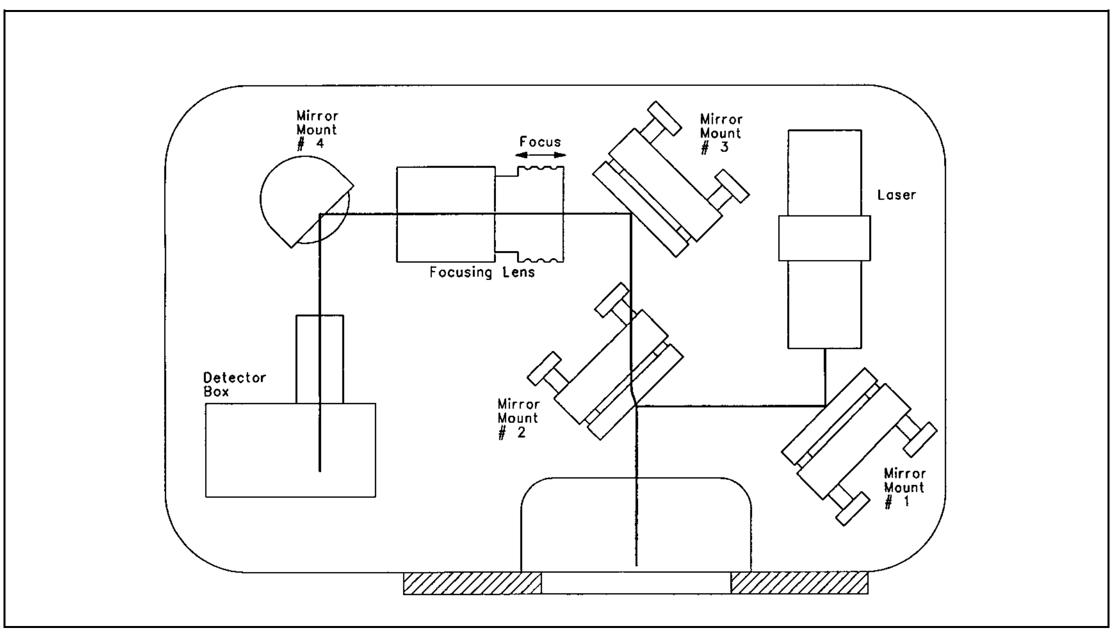

Figure 2-12 **Rotation Monitor**

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3. How to Set Up and Run the FG5

3.1. Setting Up the FG5

NOTE: These instructions are based on the assumption that all subsystems of the FG5 are aligned correctly and operating properly. If adjustment or alignment is necessary, consult chapter 4, "Adjustment and Maintenance" for instructions, before proceeding with set up. When setting up the FG5, it is helpful to use the FG5 Setup Checklist in Appendix D.

Locate and mark a reference point on the floor where gravity will be measured. THE FLOOR SHOULD BE AS CLEAN, SMOOTH, AND LEVEL AS POSSIBLE. IT IS BEST TO SET UP THE FG5 ON A CONCRETE OR HARD TILE FLOOR!

3.1.1.ELECTRONICS CASE

1. Place the electronics case in a convenient location about 1 meter from the reference mark.
2. Check the input voltage settings and make sure they are set to the proper AC line voltage. If the instrument is not set to the correct voltage see appendix A for instructions on switching the input voltage settings.
3. Make sure the following switches are **off**:
   - Main AC power (rear)
   - Main DC power (rear)
   - Laser power (main AC power and key switch)
   - Superspring coil
4. If the ion pump has been maintaining the dropper vacuum on battery power, open the dropping chamber case and apply AC power to the ion pump power supply. See the Ion Pump Model 125 Manual for more details.

5. Open the Interferometer case, and place the laser on the floor about 1 m from the reference mark. Take care not to stress the fiber optic.
6. Connect the main AC power cable from the mains power input (rear of electronics case) to the AC power receptacle. If a GUPS (or similar uninterruptible power supply) is used with the FG5, the GUPS should be connected to the main AC power source and the FG5 AC power supply should be connected to the GUPS output.
7. Turn on the main AC and DC power switches on (rear of electronics case).
8. Connect the applicable power cables to the laser and Turn on the laser power. Consult the instructions below for the proper laser.

3.1.1.1. Model ML-1 Laser:

3.1.1.1.1. Warm Up

(Consult ML-1 operating manual for more details)

- Set the MODE switch to the WARMUP position.
- Turn on the main power switch and the key switch for the laser tube HV.
- Set the heater current to 0.3 V using the front panel monitor to view current..
- Allow the laser to warm up for at least half an hour before locking.

3.1.1.1.2. Operation

- After the laser is warm, turn the REMOTE switch ON (the REMOTE LED should light). This allows the computer to control the red/blue side-lock choice.

3.1.1.2. WEO Model 100 Laser

- Turn on the power (main power and HV key switches).
- Select the proper iodine peak (usually "E").
- Set the servo control to AUTO.
- **Do not adjust any other controls.** Nominal control settings are:

Signal Monitor Section**:**

Meter Select:	1F
Gain	1
Time Constant	1

Temperature Control Section:

Body Temp Mode	TEMP

Temperature Control Section

Meter	BIAS
Bias Voltage	Set to 0V (meter)

- **Allow the laser to warm up for at least two hours (or until the temperature of the laser has stabilized)** before beginning observations.

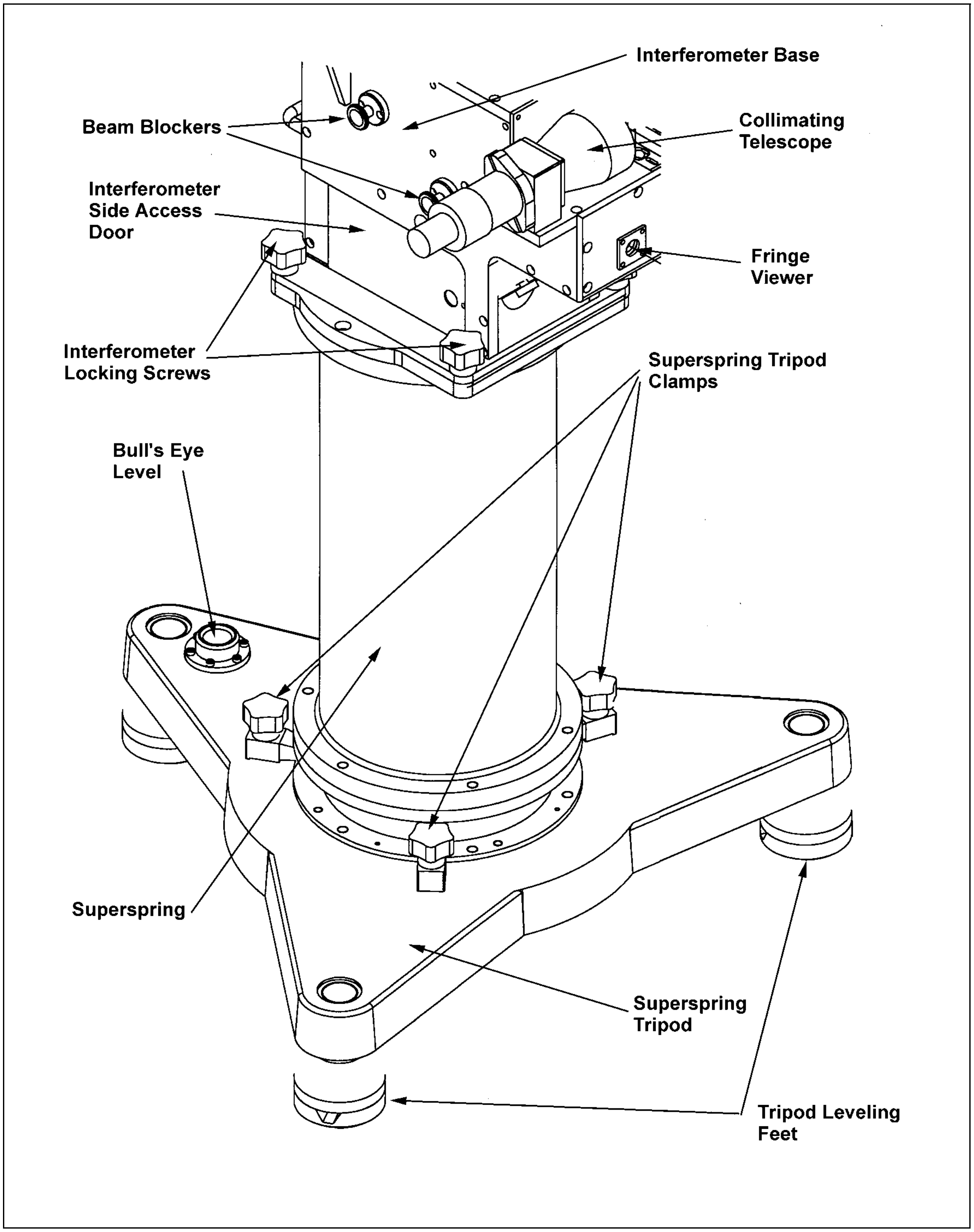

Figure 3-1: Superspring / Interferometer Setup

3.1.2.SUPERSPRING

Figure 3-1 illustrates the location of the superspring and interferometer base for setup.

9. Remove the superspring tripod from the interferometer case and place on the floor over the reference mark. Orient the tripod so the bull's eye level (mounted near one of the leveling feet) is facing the electronics case, if possible. The bull's eye level should be facing south to minimize the effect of the Coriolis effect on the dropped object. The tripod can be centered over the mark by viewing the mark through the hole in the center of the tripod.
10. Rough level the superspring tripod using the bull's eye level.
11. Measure the **lower reference height** using the depth gauge provided. The lower reference height is the distance between the superspring tray ring and the reference mark (approximately 5-15 cm). Place the depth gauge parallel surface on the machined inside ring of the superspring tripod. Pass the gauge rod through the hole in the center of the superspring tripod and extend it until it hits the reference mark on the floor. Tighten the locking screw and measure gauge length using the scale fixture which is used to measure the upper reference height (see step 37). Record this value in the system check log.
12. Place the superspring on the tripod. Orient the superspring so the travel lock (brass knurled knob on the service ring) is pointing toward the bull's eye level.
13. Clamp the superspring to the tripod by turning the three 5-lobe knobs fully clockwise. This rotates the clamps in place over the base of the superspring.
14. Level the tripod using the two precision level vials on the base of the superspring. **Be sure to adjust the cross level first, then the long level**. The cross level is opposite the superspring travel lock (knurled brass knob). If the long level is adjusted first, it will change when the cross level is adjusted. When the cross level is adjusted first, it does not change when the long level is adjusted. Only turn two of the feet while leveling; this insures that the lower reference height does not change.

Note: While leveling the superspring and dropping chamber tripods, note that turning the tripod feet clockwise ***lowers*** the dropping chamber tripod and ***raises*** the superspring tripod.

3.1.3.INTERFEROMETER

15. Remove the interferometer base from its shipping case taking care not to stress the fiber optic. Remove the dust cap from the top superspring window and place the interferometer base on the superspring. Orient the interferometer base so the fiber optic input is located directly above the superspring travel lock. The alignment pins on the top of the superspring assure that the interferometer base is oriented correctly.
16. Lock the interferometer base in place by tightening the four 5-lobe knobs.

3.1.4.DROPPING CHAMBER TRIPOD

17. Remove the tripod tray from the superspring case and place it carefully upside down on the floor.
18. Remove the three tripod legs from the dropping chamber case and attach them to the tray. Tighten the legs by using the ~30 cm “cheater” bar.
19. At this point the interferometer will be used to support the dropping chamber tripod. First, remove the dust cap from the top of the interferometer base.
20. Carefully place the dropping chamber tripod on the interferometer. Orient the tripod so that the small hole is
21. Carefully remove the dropping chamber from its case by the handles and gently place it into the pocket in the top of the tripod tray, allowing the two vertical alignment pins in the tray to engage the sockets in the dropping chamber base. Orient the dropping chamber so the ion pump is directly above the beam blocker controls on the interferometer.
22. Lock the dropping chamber in place with the three clamps by turning the 5-lobe knobs fully clockwise. This rotates the dropping chamber clamps in place over the base of the chamber.
23. Release the cart travel lock by turning the motor shaft slightly counterclockwise with a 4 mm hex wrench or ball driver to release the

pressure on the travel lock mechanism. While holding this position, pull out the brass knob, rotate it 90° in either direction, and gently release it so the pin in the shaft rests in the lock. Gently release the wrench or ball driver from the motor shaft.

3.1.5.ION PUMP

(If the ion pump is already on and maintaining the chamber vacuum, skip to step to "Leveling the Dropping Chamber" below)

24. Recheck the AC, BAT, and HV switches on the ion pump power supply, and make sure they are off.
25. Connect the ion pump HV cable to the ceramic connector on the pump. Connect the small green safety ground umbilical of the HV cable to one of the banana jacks located on the base of the dropping chamber near one of the handles. Connect the safety HV ground to the other banana jack on the base of the dropper. Tie both cables to a tripod leg with a velcro strap.
26. If the vacuum in the dropping chamber has remained intact since the previous use, the ion pump alone may be sufficient to pump down the chamber. The ion pump will probably start if it has been off for two hours or less. Appendix B discusses the use of the turbo pump.
27. Before turning on the ion pump, set the front panel meter select knob to **PUMP VOLTAGE (kV)**. Turn on the pump and check the meter. The voltage should be at least 2 kV within 5 minutes after turning on the ion pump. An **increasing** voltage usually indicates that the ion pump is starting. Nominal voltages (at operating pressure) are:

    4 kV on AC

    3 kV on battery power

28. If the ion pump does not start within 5 minutes, shut off the power at the ion pump power supply, and prepare to pump the dropping chamber with the turbo pump. See appendix B for instructions.

3.1.6.LEVELING THE DROPPING CHAMBER

Note: While leveling the superspring and dropping chamber tripods, note that turning the tripod feet clockwise ***lowers*** the dropping chamber tripod and ***raises*** the superspring tripod.

29. Check the superspring levels and adjust, if necessary, by leveling the superspring tripod.
30. When the superspring levels are centered, the dropping chamber tripod levels should be within two divisions of the center position. If the levels do not agree, this may indicate a problem. Consult the section on adjustment and maintenance for instructions.
31. Remove the blue pads and brass tripod feet from the superspring case. Make sure the pads and tripod feet are clean.
32. Place a tripod foot under each leg of the tripod. Raise each foot and slide a blue pad under the foot.
33. Center the cone in each foot under the nylon ball on the end of each tripod leg. Turn the leveling adjustment screws on the feet counterclockwise, raising them until they just contact the balls. It is important that there is no horizontal tension between the foot and the tripod leg because it will cause the dropping chamber to shift sideways when it is lifted. It is helpful to rotate, or wiggle, the foot slightly (while it is in contact with the nylon ball) to release any horizontal tension.
34. After each foot is in contact with the tripod leg, rotate each tripod foot leveling screw one revolution (counterclockwise), using the mark on the top of the adjustment screw as a reference. Rotate each tripod foot leveling foot one additional revolution as described previously. The two total turns raise the tripod off of the interferometer so there is no contact between the two components. Each counterclockwise revolution of the leveling screw raises the tripod about 0.75 mm.
35. Level the tripod tray by adjusting the tripod feet (not the superspring tripod legs). Be sure to adjust the cross level first, then the long level. The cross level is parallel to the telescope and the long level is perpendicular to the telescope. If the long level is adjusted first, it will change when the cross level

is adjusted. When the cross level is adjusted first, it does not change when the long level is adjusted.

36. It is best to adjust the levels by *raising* the proper adjustment foot. This will prevent the dropping chamber from contacting the interferometer.

! THERE MUST BE **NO** CONTACT BETWEEN THE TRIPOD/DROPPING CHAMBER ASSEMBLY AND THE INTERFEROMETER DURING OPERATION. THIS ALSO APPLIES TO CABLES. CABLES CONNECTED TO THE INTERFEROMETER **MUST NOT** TOUCH THE DROPPING CHAMBER/TRIPOD, AND CABLES CONNECTED TO THE DROPPING CHAMBER/TRIPOD **MUST NOT** TOUCH THE INTERFEROMETER/SUPERSPRING.

37. Check the superspring levels and adjust, if necessary, using the leveling feet on the superspring tripod.

38. Measure the **upper reference height** using the scale fixture provided. The upper reference height is the distance between the top of the interferometer base and the bottom of the dropping chamber. Loosen the clamp on the scale and pass the scale up through the access hole in the dropping chamber tripod while pulling the scale slightly towards yourself (the hole is located directly above fiber optic input on the interferometer base) until it contacts the top of the interferometer base. The upper reference height is approximately 5 cm. Record this value in the system check log. The sum of the upper and lower reference heights (approximately 15 cm) will be entered as the reference height term in "g" Process | Setup| Information. See the FG5 Software Manual for instructions.

3.1.7.CABLE CONNECTIONS

39. If the computer is not mounted in the electronics rack, remove it from its shipping case and place on the top of the electronics case. Make sure the power switch is off.

40. Connect the computer power cable to the power supply panel.

41. Connect the gray ribbon cable from the “rear of the patch panel to the connector on the computer. Note the location of Pin 1 (white arrow) in both cases.
42. Connect the BNC cable from the interferometer base “TTL” connector to the “FRINGES” connector on the computer time interval card, identified as “Channel A” in the Time Interval Analyzer (TIA) operating manual.
43. Connect the BNC cable from the “10 MHz” connector on the power supply to the “CLK” connector on the computer time interval card, identified as “EXT CLK” in the TIA operating manual.
44. Connect the BNC cable from the TRIG OUT connector on the dropper controller to the “TRIG” connector on the computer time interval card, identified as “EXT ARM” in the TIA operating manual.
45. Connect the barometer cable from the power supply to Channel 4 on the patch panel.g
46. For the WEO Model 100 laser:

    Connect the BNC cable from the OUTPUT connector on the front panel of the laser controller to Channel 3 of the patch panel . Make sure the meter select switch on the laser controller is set to the “1F” position.
47. For the Model ML-1 Laser: Connect the LASER LOCK on the patch panel to the REMOTE BNC on the back of the ML-1 controller (this allows the laser mode to be switched from “red” to “blue”). Connect the DIG C5 output on the patch panel to REMOTE2 BNC connector on the back of the ML-1 controller (this enables the warmup/lock mode) .
48. Connect the BNC cable from the SPHERE OUT connector on the superspring controller to the Channel 1 of the patch panel.
49. Connect the BNC cable from the METER MONITOR connector on the ion pump power supply to Channel 2 of the patch panel. Set the meter select switch to the 10^{-4} μA scale.
50. Connect the BNC cable from the TRIG OUT connector on the patch panel to the TRIG EXT IN connector on the dropping chamber controller.

51. Attach the rest of the system cables as described below. Both ends of all cables are labeled with the proper location for each connector.

- MAKE SURE THE DROPPING CHAMBER IS IN STANDBY (PRESS THE RESET BUTTON TO FORCE THE DROPPING CHAMBER CONTROLLER INTO STANDBY). Connect the dropping chamber signal cable (**white** Lemo connector) from the power supply to the electrical feedthrough on the service ring.
- Connect the rotary shaft encoder cable (**blue** Lemo connector) from the power supply panel to the blue Lemo connector on the motor drive assembly.
- Connect the DC motor power cable (**orange** Lemo connector) from the power supply panel to the orange Lemo connector on the motor drive assembly.
- Connect the APD power cable (**green** Lemo connector) from the power supply panel to the interferometer base "power" connector.

3.1.8.THE SUPERSPRING

52. **Make sure the COIL switch on the superspring controller is OFF**. Connect the superspring control cable (**yellow** Lemo connector) from the power supply panel to the connector on the base of the superspring.

! DO NOT ATTACH SUPERSPRING CONTROL CABLE WHEN THE COIL SWITCH IS ON.

53. Adjust the leveling screws on the superspring tripod, if necessary, to level the superspring with the two precision level vials on the base.

! **CAUTION:** DO NOT ADJUST THE LEVELING VIALS THEMSELVES. They are preset to provide the correct internal vertical reference for the superspring.

3.1.8.1. TRAVEL LOCK

54. Release the superspring travel lock by pulling out the brass travel lock knob until it engages the shaft and *slowly* rotating it counterclockwise until it reaches the stop (180°). Slowly release the lock knob. The arrow on the lock knob points down when it is locked (up when it is unlocked).
55. If necessary, one can use the travel lock knob to damp excess spring motion. Carefully pull the knob out, and slowly turn it clockwise until the travel lock just touches the spring support structure. Then slowly return the knob to the unlocked position.

3.1.8.2. SUPERSPRING ZERO-POSITIONING

56. Allow the spring to settle for at least two minutes before setting the zero-position of the mainspring. Use the DC motor to move the top of the mainspring relative to the inner support structure. The zero-position is monitored on the front panel BNC of the superspring controller marked SPHERE OUT. The position can be adjusted manually or automatically to be within about ±20 mV of 0 V.

    The rotary knob on the front panel can be set to MANUAL, WINDOW, AUTO, or REMOTE. The REMOTE setting should not be used. The MANUAL setting allows the user to apply a voltage to the DC. motor that can be varied with a front panel trimpot labeled MOTOR. The middle of the trimpot range applies no voltage. Turning the knob towards UP causes the motor to lift the mass (increasing positive voltage on the sphere BNC), while turning the knob towards DOWN lowers the mass (decreasing the voltage on the sphere BNC).

    AUTO causes the motor to seek the zero-position automatically.

! NOTE: IN AUTO, THE DC MOTOR IS ALWAYS ACTIVE. THE SUPERSPRING SHOULD NOT BE LEFT IN AUTO DURING NORMAL OPERATION (WHEN THE COIL SERVO IS ACTIVE)

The WINDOW setting turns on the motor only when the spring position is out of range (indicated by an LED on the front panel). In this case, the AUTO mode is activated until the position is moved to zero, and then the motor is deactivated. The superspring can be left in this condition, but it is still advisable to turn the rotary knob to OFF before closing the superspring coil loop (switch set to CLOSED on the front panel). **WINDOW mode is currently not supported by the FG5 software.**

When setting the zero position, it is very important to make sure that the mass is hanging freely, and is not out of range. A substantial variation in SPHERE OUT voltage (many 100s of mV) when the servo loop is open indicates that the mass is hanging freely. It is possible for the mass to be out of range of the detector. In this case, a small positive or negative voltage indicates that the mass is above or below the detector, respectively. This can happen if there is a large change in gravity (usually as a result of a large latitude and/or elevation change) from one site to the next. The zero position can be set by using the AUTO mode, which moves the mass to the zero position. One can also move the test mass position using the MANUAL mode. Before switching to MANUAL mode, first set the trim-pot to move the motor in the correct direction. The trim-pot should be set towards UP if the SPHERE voltage is negative or towards DOWN if the SPHERE voltage is positive.

57. Once the desired zero-position is reached (SPHERE output within 20 mV), deactivate the motor by turning the front panel knob to OFF. The spring should again be allowed to settle down for at least two minutes. Set the coil switch to ON. This switch activates the superspring main servo loop for normal operation. At this point, there may still be a rotation in the test mass (three second period) which is not damped by the servo. This rotation mode will eventually damp out, and the gravity data will be become quieter over the first hour.

3.1.9.BEAM VERTICALITY

58. Loosen the lock on the side access door of the interferometer base (located directly below the beam blocker controls) and slide the door open.

59. Remove the top cap of the alcohol container and place the container inside the interferometer base. By eye, center the alcohol pool left/right, and slide it all the way back until it contacts the rear wall. This insures the laser spot is centered in the alcohol pool.
60. Focus the telescope crosshairs by placing a white card in front of the telescope objective. Place the card at an angle to allow light to strike the card and illuminate the crosshairs.

! DO NOT ADJUST THE *INFINITY FOCUS* OF THE COLLIMATING TELESCOPE (adjust only the eyepiece). THE OPERATOR WHO FOCUSES THE CROSSHAIRS SHOULD ALSO PERFORM THE FOLLOWING ALIGNMENT STEP.

61. Pull out both beam blockers and align the test and reference beams by making the beams coincident in the telescope. **Align the beams by adjusting the two screws on the fiber optic mounting plate** (mirror mount) **on the interferometer base only!** Do not adjust the twiddler or the mirror below the telescope (mirror #2) when the alcohol pool is in the interferometer; only adjust the fiber optic mounting plate. Note that both beams move with respect to the telescope crosshairs as you adjust the mirror mount screws.

3.1.10.FRINGE OPTIMIZING

62. To optimize the fringe signal, the test and reference beams must be made perfectly coincident and parallel. The two interfering beams should be perfectly overlapped and also have no angular deviation for the greatest signal. The translation of the test beam relative to the reference beam is done by adjusting the translator plate (sometimes called twiddler). The angular deviation is minimized by adjusting mirror mount # 2, located below the telescope (see figure 2-8).
63. For convenience, it is possible to move the test and reference beams to the center of the telescope viewfinder by adjusting mirror # 3, located in front of the telescope objective. Note this does not affect the interferometer alignment; it is only for the user's convenience.
64. Look in the fringe viewer and adjust the twiddler until the test and reference beams are coincident (overlapped).

65. Look in the telescope and adjust mirror # 2 so the test and reference spots are overlapped. Use the two knobs that are diagonally opposite of each other. The two beams are now coincident and parallel.

66. Connect the ANALOG output on the interferometer to an oscilloscope, with the following settings:

    Scale = 50 mV/div

    Sweep = 2 μsec/div

    AC coupled input

67. Make sure the laser is locked. Set the dropper to OSC mode and press RESET/INIT. This moves the cart slowly up and down at a constant velocity and produces a constant frequency fringe signal which is useful for adjusting mirror # 2.

68. Maximize the fringe signal on the oscilloscope by adjusting mirror # 2.

69. Maximize the fringe signal on the oscilloscope by adjusting the twiddler. Nominal fringe signal (peak-to-peak) is 280-360 mV. Record this value in the system check log.

70. Terminate OSC mode by pressing TRIG on the dropping chamber controller. This brings the cart safely down the bottom and places the system in RESET mode. Note that you can press the TRIG button at any point in the cart's motion.

3.2. Running the FG5

The FG5 begins observations when the user selects Process | Go in the “g” program.. Consult the FG5 Software Manual for instructions on operating the program. The software manual also includes information about software features, gravity corrections, output displays, and input/output file descriptions, as well as data analysis and trouble shooting.

3.2.1.SYSTEM CONTROLLER

1. Make sure the time and date are correctly set to UT. Do this by double-clicking on the clock in the Windows© Task Bar.
3. Enter the site information into Process | Setup | Information window in “g”.
4. If automatic laser peak detection is desired, check the 1f signals with a volt meter and enter the information in to Process | Setup | System | Laser
5. Enter the desired acquisition parameters into Process | Setup | Acquisition
6. Enter the desired environmental/system corrections into Process | Setup | Control.

NOTE: Make sure the laser is warm and the meter select switch of the WEO Model 100 laser controller is set to 1f (see WEO manual). After reading the 1f signals, be sure to reconnect the BNC cable between the “output” connector on the laser controller and the Channel 3 connector on the patch panel.

3.2.2.DROPPER CONTROLLER

7. Make sure the cart is resting at its bottom position, and the green RESET/INIT light is on. Set the mode switch to DROP. Press RESET/INIT twice. The red light next to DROP should be on. The dropper is now waiting for an external signal from the computer to initiate a drop.

3.2.3.PROGRAM SETUP

8. Begin observations by executing Process | Go with the "g" program. Consult the FG5 Software Manual for more information.

3.3. Shutting Down the FG5

3.3.1.COMPUTER

1. Exit "g".
2. Backup the data if desired.
3. Shutdown the computer.

3.3.2.SUPERSPRING

3. Turn the COIL switch off..
4. Engage the superspring travel lock. The arrow on the lock know points **down** when it is **locked** and *up* when it is *unlocked*.
5. Disconnect the cable from superspring electronics.

3.3.3.INTERFEROMETER

3.3.3.1.OPTION 1: Model ML-1 Laser.

6.

a) Set the switch on the front panel of the laser controller to WARMUP.

b) Turn the REMOTE switch off.

c) Turn the key switch off. The HV indicator light should turn off.

d) Turn power switch off.

3.3.3.2.OPTION 2: WEO Model 100 Laser

6.

a) Set servo control to OFF (recommended but not required).

b) Turn the key switch off. The green indicator light should turn off.

c) Turn power switch off.

3.3.4.DROPPING CHAMBER

7. Press RESET on dropper controller.
8. Disconnect the shaft encoder, motor power, and cart control cables from the dropping chamber.
9. Engage the dropping chamber travel lock.

3.3.5.POWER

10. Turn off any devices that are still on.
11. Turn off the AC and DC power (power supply panel).

3.4. Disassembling and Packing the FG5

NOTE: Please follow these instructions carefully. Care in packing the components properly will result in easier and faster set-up in the field, and will help protect the instrument from damage.

3.4.1. ELECTRONICS

1. Disconnect the following cables from the electronics rack and components.

- APD power cable (green)
- TTL fringe BNC cable
- Laser signal (umbilical) cable
- Laser HV BNC cable
- AC Mains power cord
- AC computer power cord

2. If the storage/movement of the FG5 is less than about 8 hours, it is possible to travel the dropping chamber with the ion pump supply's internal battery backup. Make sure the DC and HV switches are on, and pack the ion pump controller inside the dropping chamber travel case.
3. If the storage is longer term, pack the ion pump supply inside of the dropping chamber travel case, as above, but turn off all the power switches.
4. Put the remaining cables in the zippered pouch which is attached to the inside of the rear electronics case lid.
5. Secure the lids to the electronics case.

3.4.2. SYSTEM CONTROLLER

6. Unplug power cords and printer cable from the computer and place them in the system controller case.

7. Close computer lid and place computer in the system controller case.
8. Close the system controller case and secure all latches.

3.4.3.ROTATION MONITOR (IF INCLUDED)

9. Unplug all BNC and power cables from the rotation monitor, detector box, and electronics rack and store in the rotation monitor case.
10. Remove the rotation monitor from the dropping chamber (two M6x35 screws) and place in the rotation monitor case.
11. Close the rotation monitor case and secure all latches.
12. Replace the two M6x35 screws in the dropping chamber top flange, and replace the viewing port cover.
13. Secure the lids to the electronics case.

3.4.4.DROPPING CHAMBER

14. Lock the cart by turning the locking hub (motor shaft) counterclockwise using a 4 mm Allen wrench or ball driver until the cart stops moving.
15. Pull and rotate travel lock knob 90°, allowing the pin to drop onto the hub, then rotate the locking hub clockwise until the pin engages the hub.
16. Open the three dropping chamber clamps by turning the 5-lobe knobs fully counterclockwise so the clamps are outside the bottom flange of the dropping chamber.
17. Gently lift the chamber off the tripod and set it in its case. If the HV and safety ground cables are still connected, take care not to stress them.

3.4.5.DROPPING CHAMBER TRIPOD

18. Carefully remove the tripod from the interferometer base. Remove the legs from the tripod. Place the legs in the dropping chamber case along with the tripod tray and feet.
19. Close dropping chamber case and secure all latches.

3.4.6.INTERFEROMETER BASE

20. Insert the dust plug into the top of the interferometer base.
21. Loosen the four 5-lobe knobs which attach the interferometer base to the superspring.
22. Remove the interferometer base from the superspring and gently place it in the shipping case along with the laser. Take care not to stress the fiber optic.
23. Close the interferometer case and secure all latches.

3.4.7.SUPERSPRING

24. Pull out the travel lock brass knob until it engages the locking mechanism, and rotate the lock 180° clockwise to lock it in place. The arrow on the lock knob points **down** when it is **locked** and *up* when it is *unlocked*.
25. Insert the dust plug in the top of the superspring.
26. Loosen the three 5-lobe knobs which attach the superspring to the superspring tripod.
27. Remove the superspring from the tripod and place in its shipping case. Note that the bullseye level points toward the air relief valve in the case.
28. Close the superspring shipping case and secure all latches.

3.4.8.TURBO PUMP (IF USED)

29. Make sure the blank flange is in place on the turbo pump intake flange.
30. Make sure all covers are in place on the flexible tube and turbo pump exhaust flange.
31. Unplug the power cord from the turbo pump.
32. Store the power cord and flexible tube in the base of the turbo pump case.
33. Place the turbo pump in the turbo pump case.
34. Close the turbo pump case and secure all latches.

4. Adjustment and Maintenance

NOTE: The FG5 has been engineered to use metric screws and dimensions wherever possible. However, some "off-the-shelf" purchased components use English screws and dimensions.

4.1. The Dropping Chamber

4.1.1. REPLACEMENTS AND ADJUSTMENTS

4.1.1.1. Removing The Dropping Chamber Cover

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.

4.1.1.2. Replacing the Dropping Chamber Cover

Inspect the chamber O-ring and sealing surfaces. Coat the O-rings with a very light film of Apiezon L grease (just enough to make it "shiny"), if necessary, and re-install the chamber cover and lifting handles. Tighten the mounting screws in a star pattern.

With the chamber cover mounted, rotate the four snubber screws on the top rod ring out until they come in contact with the inside of the chamber cover walls. Tighten the screws equally an additional 1/8 turn and lock in position with the locking nuts.

Inspect the top flange O-ring and sealing surfaces. Coat the O-rings with a very light film of Apiezon L grease, if necessary, and mount the top flange to the chamber cover.

NOTE: Whenever the chamber cover is removed or the support snubbers of the top rod ring are adjusted, the vertical alignment of the dropping chamber must be checked and the level bubbles on the tripod tray must be reset. See the section on "Leveling the Dropper".

4.1.1.3. Replacing the Drive Belt

Follow the procedures described previously 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).

4.1.1.4. Adjusting the Drive Belt Tension

Adjust belt tension using the set screw on the top pulley assembly, located on the top rod ring. Tighten the belt adjustment screw until the slack has been taken out and the belt is straight. Then tension the belt by tightening the screw approximately three turns. If you are uncertain of the proper tension, the screw can be tightened until the tension spring is just short of coil bind. The belt can also be tensioned using the torque required to slip the pulley on the belt to determine belt tension. Use a torque wrench to manually drive the motor shaft (drive assembly). Set the torque wrench in the 6-7 inch-lb. range and tighten the set screw until the belt slips on the pulley when rotated into the lower stop.

4.1.1.5. Replacing the Ferrofluidic Vacuum Feedthrough

The chamber must be vented and opened for this procedure. If possible, use dry nitrogen to vent the chamber.

Loosen the English 4-40 clamp screws on the Helical coupling between the motor and the Ferrofluidic vacuum feedthrough by reaching through the access hole in the motor mount. Remove the three ¼-28 English screws which attach the motor mount to the Conflat vacuum flange on the service ring. Remove the motor mount assembly (including motor, Helical coupling, travel lock plate, and encoder) from the Conflat vacuum flange, leaving the Conflat flange and Ferrofluidic vacuum feedthrough attached to the service ring.

Inside the service ring, loosen the socket head clamp screw on the Helical shaft coupler where it attaches to the lower drive pulley shaft. Remove the three remaining Conflat mounting screws. Remove the Conflat with Ferrofluidic feedthrough attached.

Remove the Helical coupling from the feedthrough, and unscrew the feedthrough from the Conflat flange.

Lubricate the O-ring on the new Ferrofluidic vacuum feedthrough with a light coat of Apiezon L grease. Use pliers with padded jaws (e.g. blue pad) to gently tighten the feedthrough to the Conflat flange.

Reverse the procedure for reassembly.

4.1.1.6.Replacing the V-Plate

The V-plate contains three tungsten V's which support the test mass. Since removal and insertion of the tungsten V's in the V-plate requires special tools, this cannot be done in the field. However, an entire new V-plate assembly can be installed. The dropping chamber must be vented and opened for this procedure (see "Removing the Dropping Chamber Cover" procedures above).

Remove the bottom drag-free cover from the cart by removing the three M3 screws. Detach the LED bracket from the side of the cart and pull it out of the way, being careful not to detach or damage the wires connected to it. Remove the two M3 screws and the threaded post attaching the top drag-free cover to the cart, observing the position of the post. Gently lift the cover off, being careful not to damage the wires connected to it.

To remove the V-plate, the test mass must be partially disassembled. First, note the orientation of the top part of the test mass and the V-plate. It is very important to replace these parts in the same orientation. Remove the three beryllium copper M3 screws that secure the top part of the test mass to the three posts which pass through the V-plate. Now the lower portion of the mass can be lowered through the V-plate. Remove the six M2 screws holding the V-plate to the cart.

Reverse the procedure to replace the plate.

The tungsten balls from which the test mass is held are part of the top hat assembly. If these balls need replacement, send the entire mass assembly to Micro-g Solutions for installation and rebalancing. Reassemble the test mass using the three beryllium copper M3 screws, and pack it carefully before shipping. All the pieces must be included for the balancing to be done correctly.

4.1.1.7. Replacing the Linear Bearings

The chamber must be vented and opened for this procedure. If possible, use dry nitrogen to vent the chamber.

Remove the drive belt as described previously. Loosen the three M6 screws in the split clamps on the top rod ring and remove the top rod ring.

Remove the upper bumper stop assembly from the rod by removing both retaining rings from the rod. Remove the ribbon cable wires connected to the cart. Remove the ribbon cable clamp on the cart, and gently lift the cart off the guide rods.

Two retaining rings secure each bearing to the cart. To remove the rings, they must be wound off the end of each bearing. Slide the linear bearings out of the cart and slide the new ones in. Replace the retaining rings.

NOTE: Venting holes have been added to the linear bearings by Micro-g Solutions. In addition, the normal bearing lubricant has been replaced by a special low vapor pressure oil (Krytox 143AC).

Reverse the above procedure to replace the cart.

4.1.1.8. Replacing the Shaft Bearings—Drive Pulley

Refer to Figure 4-1, Drive pulley assembly. Remove the drive belt as described previously. Disconnect the Helical coupling between the pulley shaft and the ferrofluidic vacuum feedthrough. Remove the five screws holding the bottom rod ring to the bottom flange. Rotate the guide rod structure so that the shaft clears the service ring and lift the structure. Remove the two screws which fasten the pulley yoke to the bottom rod ring and remove the yoke. Remove the bowed retaining ring from the short end of the pulley shaft, noting the orientation of the bow.

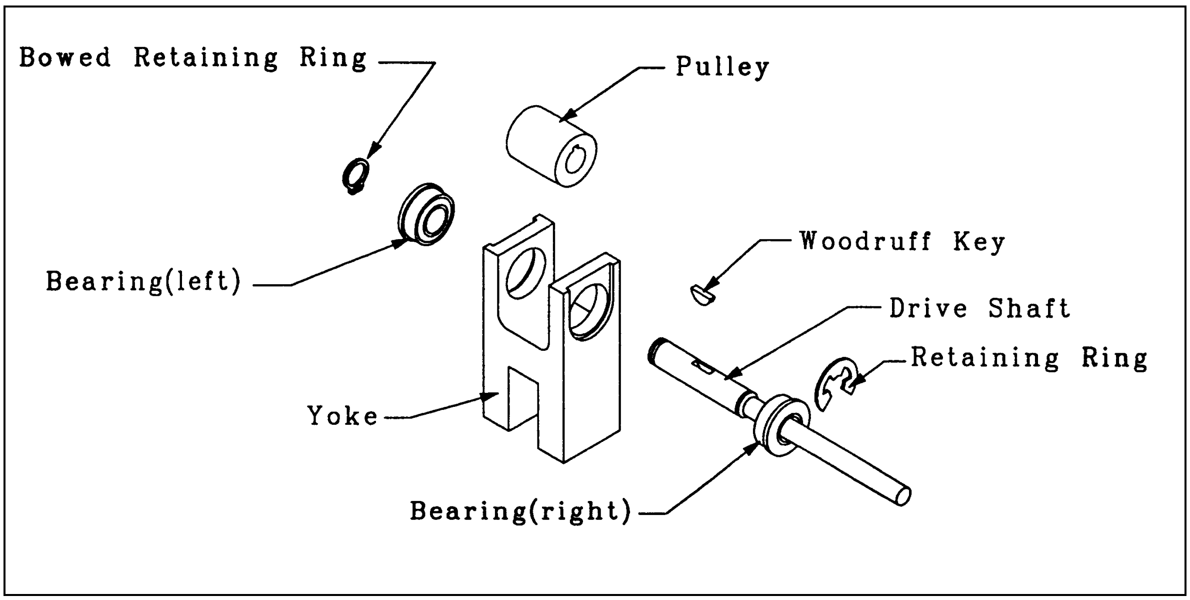

Figure 4-1 Drive Pulley Assembly

!CAUTION: DO NOT DEFORM THE BOWED RETAINING RING.

Remove the retaining ring from the other end of the shaft. Slide out the pulley shaft, taking care not to lose the Woodruff key, and remove the pulley from the bearing mounting yoke. Push the bearings out of the yoke.

Reassemble in reverse order. When reassembling the pulley shaft, be sure that the bowed snap ring is seated fully in its groove.

NOTE: Pulley bearings are specially lubricated with Krytox LVP vacuum grease.

4.1.1.9. Replacing the Shaft Bearings—Top Pulley

The procedure for the top pulley is similar to the drive pulley, except that there is no Helical coupling and no Woodruff key. To access the top pulley assembly, remove snap rings on upper bump stop and slide down shaft. Remove two small retaining rings on top of upper pulley yoke and slide pulley down to remove.

Reverse procedure for replacement of upper pulley assembly.

When reassembling the pulley shaft, be sure that the bowed snap ring is seated fully in its groove.

4.1.1.10. Replacing the Rotary Shaft Encoder

Insert a 1/32" Allen wrench into the access hole at the top right (1 o'clock position) of the encoder. Rotate the shaft until the set screw that holds the disk to the shaft is aligned with the wrench, and loosen the screw. Pry the main encoder housing off the encoder back plate with a flat blade screwdriver. The back plate must remain attached to the travel lock plate with three screws to maintain proper alignment.

To reassemble, snap the new encoder over the encoder back plate, which was left attached to the travel lock plate. Tighten the set screw and remove the Allen wrench from its hole. Rotate shaft to check that the encoder disk is rotating freely inside the encoder. Loosen and retighten set screw, if necessary, until the disk rotates freely.

4.1.1.11. Pumping Down the Dropping Chamber

See Appendix B for instructions on pumping down the dropping chamber.

4.2. The Interferometer

4.2.1. ALIGNMENT

1. Set up the superspring and attach the interferometer base as described in the setup instructions.
2. Center the precision bubble vials mounted on the base of the superspring by adjusting the leveling feet on the superspring tripod.
3. Turn on the laser.
4. 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.
5. 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.
6. Tighten the locking screw on the slide. Then tighten the assembly into the interferometer using the second Allen screw
7. 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).
8. If possible (both spots visible), verticalize the beam as described in the setup instructions.
9. 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.

10. Block the test beam (push in test beam blocker) and pull out the reference beam blocker.
11. Translate the fiber optic input until the beam is centered in the fringe viewer and tighten the screws.
12. Focus the telescope crosshairs and adjust mirror # 3 until the reference beam is centered in the telescope viewfinder.
13. Re-verticalize the beam.
14. Check to see if the reference beam is still centered in the fringe viewer. If the beam is not centered, repeat steps 8-14.
15. 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.
16. 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.
17. 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.
18. Using mirror # 2, make the test and reference beams coincident in the collimating telescope.
19. Use the translator plate (twiddler) to align the test and reference beams in the fringe viewer.
20. Remove the dropping chamber and dropping chamber tripod from the interferometer base.
21. Block the test beam by pushing the beam blocker in.
22. Remove screws that attach the small plate to the back of the interferometer base. See Figure 4-2, APD alignment adjustment access.

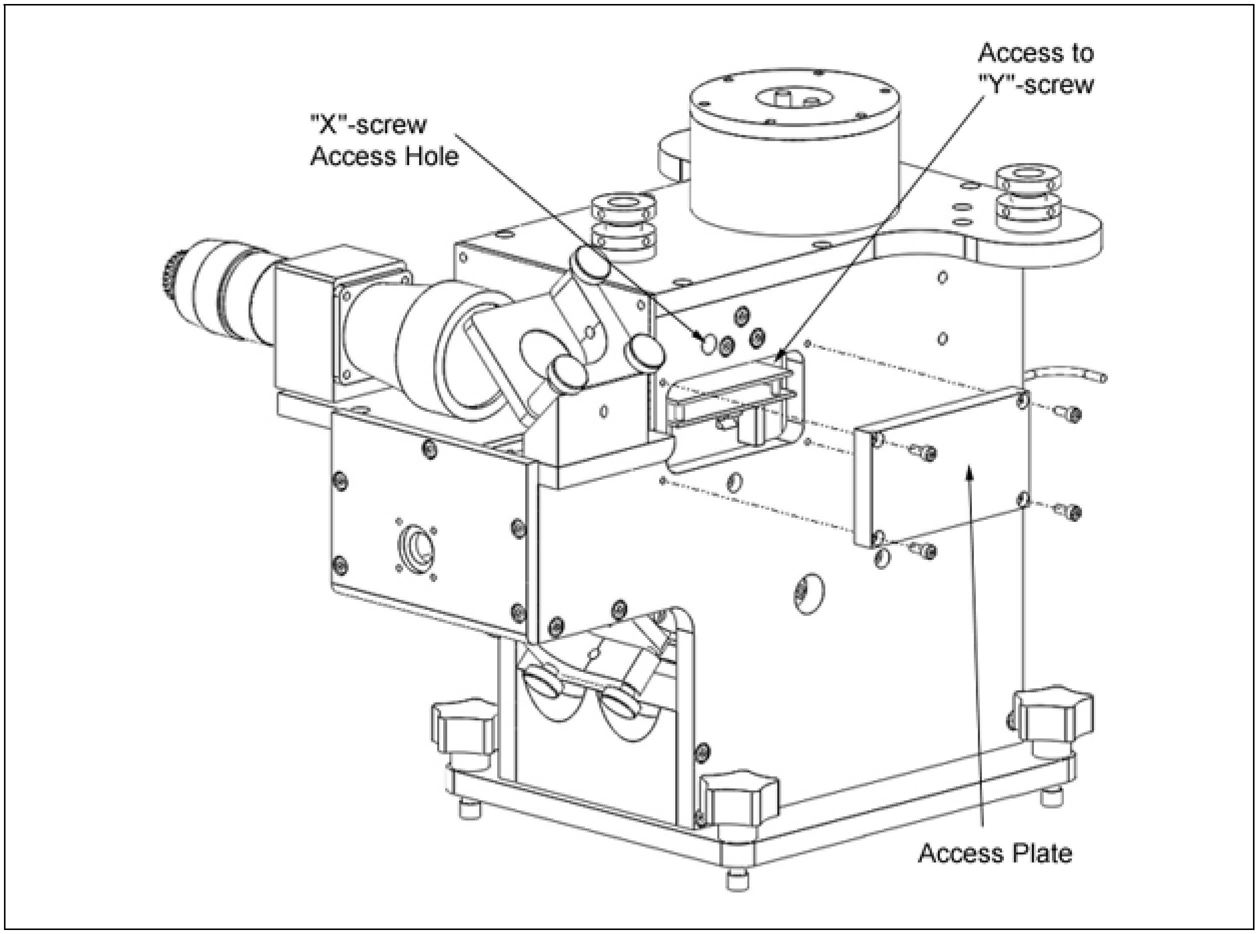

Figure 4-2 APD alignment adjustment access

23. Adjust the X-Y stage of the APD to maximize the voltage at the “analog” BNC on the interferometer base. 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”.
24. Replace the rear plate on the interferometer base and tighten all screws.

4.3. The Superspring

4.3.1.REPLACEMENTS AND ADJUSTMENTS

4.3.1.1.Removing the Superspring Cover

If it is necessary to remove the top flange for any reason, be sure to replace the flange in the same orientation. Align the large ear of the top flange directly above the travel lock knob on the service ring.

! DO NOT OPEN THE COVER BY REMOVING THE BOTTOM FLANGE, DUE TO INTERNAL ELECTRICAL CONNECTIONSTHROUGH THE SERVICE RING.

The top flange and Superspring cover may be removed as a unit by removing the six screws holding the cover to the top of the service ring and lifting the cover assembly straight up.

Most routine maintenance can be accomplished at this point, except for replacing the coil (linear actuator), the mainspring itself, and its upper hanger. To accomplish these tasks, the service ring and bottom flange must be removed.

4.3.1.2.Removing the Service Ring

Disconnect the wires between the bulkhead fitting and the circuit board, emitter, detector, and motor by unplugging the in-line connector closest to the bulkhead (electrical feedthrough connector), then remove the electrical feedthrough from the service ring.

! MAKE SURE TO NOTE THE COLOR CODING ON THE CONNECTORS FOR LATER RECONNECTION.

Remove the travel lock knob by removing the flat-head screw from the center of the knob and sliding the knob off the shaft. The knob is comprised of three pieces: the brass knob, the control spring retainer, and the internal spring. With the knob removed, the two screws holding the travel lock knob assembly are exposed. Remove these and slide the assembly out of the service ring (the travel lock to service ring interface is sealed with Teflon sealer).

The service ring and bottom flange can be taken off together by removing the three screws securing the base plate of the Superspring structure to the bottom flange.

4.3.1.3. Replacing the Coil (Linear Actuator)

The permanent magnet assembly of the coil is attached to the base plate, and the voice coil *pusher* is attached to the emitter/detector block of the support structure.

Remove the service ring as described previously.

Remove the base plate by loosening the three 3mm barrel clamp screws that secure the rods to the plate. Carefully lift rod assembly off bottom plate. Remove two shoulder screws that hold travel lock fork on (from underneath) and slide travel lock fork assembly off main rod. Unhook three support springs from O-rings and remove lower triangular spring plate. This plate is held on by four 3-mm screws. Be careful not to cut or score the O-rings. Note orientation of emitter-detector block and remove block (six 3mm screws in deep counter bore holes). Remove the permanent magnet assembly from the base plate.

Remove the voice coil by removing its three attachment screws inside the emitter-detector block.

Reverse the procedure for reassembly.

4.3.1.4. The Mass Mainspring/Hanger

! The upper spring hanger assembly has a flexible thin wire member which is soldered into the Superspring hanger and the coarse adjustment screw. Mishandling of the mainspring may cause the wire to break, allowing the hanger, spring, and test mass to drop.

! BE VERY CAREFUL NOT TO BEND THE FILAMENT WIRE IN THIS ASSEMBLY.

It is highly recommended that this procedure be done at Micro-g Solutions.

4.3.1.5. Replacing the Flexures

Necessary tools and fixtures:

- A small table with leveling screws that can hold the Superspring (in the field, one could use the entire tripod or just the leveling feet).
- A pulling tool (music wire 16" long with m 1.6 threads on one end) to pull the main spring through the main tube.
- Metric hex wrenches.
- Metric open-end wrenches(m 5.5 and m 6).
- Plastic Gloves: It is best to handle the test mass with plastic gloves.
- Measurement tools (calipers and/or ruler).

Remove the Superspring cover as previously described. Put a dust cover over top of the main tube to keep dust from falling on the test mass and upward-facing corner cube (a piece of paper or foil over the tube will suffice).

Remove the service ring as previously described.

Place a shim of hard foam or rubber between top rod ring and top triangular plate approximately 6mm thick and use a cable tie to fasten the two plates together. (Limiting the travel of the center tube assembly will help to avoid damaging the delta-rod flexures during disassembly).

Loosen the three 3mm barrel clamp screws that hold the three rods to the bottom plate. Disconnect wires from pre amp circuit board and carefully lift rod assembly off bottom plate. Note : it is easier to do the next steps if the assembly is blocked up 6′′- 8′′ so one can work underneath the assembly. Remove two shoulder screws that hold travel lock fork on (from underneath) and slide travel lock fork assembly off main rod. Unhook three support springs from O-rings and remove lower triangular spring plate. This plate is held on by four 3-mm screws. Be careful not to cut or score the O-rings. Note orientation of emitter-detector block and remove block (six 3mm screws in deep counter bore holes).

Note: The test mass, spring, and flexure will come out with the emitter-detector block. Wear plastic gloves when handling copper test mass to prevent finger prints and rubbing off black coating. Remove spring from copper test mass. Note how far upper anchor is screwed into the main spring (count how many spring turns are on the screw). Put the lower lock nut onto the new flexure assembly. Remove broken flexure-anchor and carefully screw new flexure-anchor into spring to the original position.

Thread the pulling tool through one nut, top lever and down center tube. Carefully thread tool into top of flexure (coarse adjustment screw) of main spring assembly. Pull tool up until spring hangs and then thread copper test mass onto lower anchor of main spring assembly (tighten lower anchor). Pull wire tool, lifting test mass ,and guide coarse adjustment screw through top lever. Screw on top nut to hold in position then remove the tool. (Set approximately in center of coarse adjustment screw travel). Rotate test mass so beam holes in top lever and copper test mass roughly match.

4.3.1.6. Assembling the Superspring

Replace emitter-detector block in the original orientation. The emitter (two terminal device with red/white wires) should be oriented below lever pivots. Replace lower triangular spring plate and attach support springs. Slide travel lock fork assembly onto shaft and re-install the two shoulder screws. Replace spring assembly into lower plate being careful of voice coil . Note: do this on a flat surface so the rods seat flush with the bottom of the lower plate , then tighten barrel clamps. Check movement of center tube by blocking up travel lock fork assembly (so it doesn't rub), removing wire tie and foam back, then gently bouncing center tube and checking to see if it moves freely. NOTE: Test mass must be centered in cage (hanging plumb), and wires must not drag. Replace spring assembly into service ring. Insert 6mm screws but don't fully tighten. Replace the travel lock assembly. Rotate the main spring assembly in the service ring so that the travel lock fork has equal clearance around the two shoulder screws, then tighten 6mm screws.

Install electrical feedthrough. Re-connect all electrical connections. Level the Superspring by viewing on each side of copper mass and centering in cage (place entire Superspring on an adjustable table to change where the mass hangs). Note that the mass should hang down approximately 1.5mm from the point where it makes contact with the top of the cage assembly as the system is travel -locked.

Use the Superspring controller to drive the zero-positioning motor (ZPM) until the sphere voltage is zero. Measure the gap between the two levers near the ZPM. Adjust the coarse adjustment screw so that when zeroing the sphere voltage, the motor will end up in its center of travel position (about 6mm gap between lever arms ±0.5mm). Note that when you are far off of the detector the sphere voltage starts at zero and then goes to a maximum and then over a short range goes through zero (it looks like an S curve). Make sure sphere detector voltage goes +/- to assure true zero position.

Viewing from top, carefully rotate the corner cube and visually align the beam holes in top lever with the ones in the copper Test mass, adjust by rotating the coarse adjustment screw and lock in position by tightening both top and bottom nuts.

Note 1: This will take time as the Test mass must settle down after each adjustment.

Note 2: Be careful not to let dust or debris fall onto corner cube. Re-check the level of the test mass and set level bubbles by turning brass screws. Lock position with center lock screw. Replace the Superspring cover as previously described.

4.3.1.7. Replacing the Focus Lever Motor

Loosen and remove the nut on the focus adjustment screw. Lower the focus lever motor assembly off the fulcrum lever.

Loosen the set screw holding the hex bushing to the motor shaft and raise the bushing out of the way. The screws holding the motor to the motor mount are now accessible, and can be removed. Reverse the procedure to install the new motor.

4.3.1.8. Adjusting the Micro-Switches

Adjust the trip positions of the micro-switches that control the limits of travel of the focus adjustment motor by changing the position of the set screws in the actuator arms. The limit switches should shut off the zero-positioning motor (ZPM) when the gap between the focus lever and the fulcrum plate is 4-8mm.

4.3.1.9. The Aneroid Wafer Assembly

To compensate for the thermal expansion and contraction of the Superspring, an aneroid wafer assembly adjusts the position of the top hanger. The position of the aneroid assembly is set by the manufacturer, and should not need to be adjusted.

4.3.1.10. The Delta Rods

Five delta rods (arranged in an upper V-shaped array, and a lower triangular array) provide a linear way system for the internal support structure of the Superspring. If a delta rod needs replacement, contact Micro-g Solutions for parts and procedures.

! THE POSITION OF THE DELTA RODS DETERMINES THE CLEARANCE BETWEEN THE VOICE COIL (PUSHER) AND THE MAGNET ASSEMBLY. IT IS IMPERATIVE THAT THE ASSEMBLY NOT RUB OR DRAG!

To field check the alignment, measure the gap between the support structure pins and the center tube assembly with a feeler gauge. This gap should be equally spaced (approximately .003-.005") all around. If the support pins touch the center tube assembly, a bent delta rod is indicated.

4.4. Timing System and Data Acquisition

4.4.1.TIMING

The timing system consists of the avalanche photo diode (APD) board, the rubidium oscillator, and the Time Interval Analyzer (TIA). Data are taken by two different interface cards inside an IBM-compatible Pentium II (or better) personal computer. The computer processes the data, compiles statistics, and computes a gravity value, including certain corrections (e.g., for the tides and the gradient).

Optical fringes are produced in the interferometer by combining the portion of the laser beam hitting the freely falling and reference retroreflectors (the corner cubes) with the portion traveling directly through both beam splitters. A fringe is produced every time the falling object traverses a distance equal to the wavelength of the laser, lambda, over two ($\lambda/2$). As the velocity of the falling object changes, the frequency (f) of the fringe signal is swept according to $f = 2gt/\lambda$, where g = gravity and t = time. The optical fringes are detected by an APD mounted in the interferometer base.

The zero-crossings of the fringes provide very good fiducial marks which can be used for timing. The zero-crossing points of the a.c.-coupled fringe signal are determined using an ultrafast comparator. The comparator outputs a square-wave version of the frequency-swept fringe signal. The comparator is located on the APD circuit board.

The TIA scales the fringes using a software-specified scale factor (usually 1000), then times each scaled fringe. The TIA times events from t=0 at trigger.

The time of occurrence of each scaled fringe and the distance derived from the number of fringes that have passed can be expressed as a time and distance pair. The data are then fit to a parabola by the computer to determine a best value for the acceleration—a gravity value.

4.4.1.1. Avalanche Photo Diode Printed Circuit Board

This circuit detects the optical fringes produced in the interferometer. The FG5 uses a 50-MHz APD which is powered by a high-voltage module mounted inside the interferometer base.

A high-speed comparator and 50-Ω driver on the APD board minimize noise problems on the long cables between the interferometer base and the TIA. The analog and digital versions of the fringe signal are both available on BNC connectors mounted on the interferometer.

4.4.1.2. APD Board and Photo Diode Supply Module

The APD board is mounted inside the interferometer base, along with the high voltage power supply module. The APD is mounted directly on the board. The APD's high-oltage bias is zener-limited to 600 volts (on-board). A potentiometer is used to set the voltage supplied to the APD.

The analog output is buffered by an OP AMP directly from the APD. The zero-crossing of the fringe signal is determined by the high speed comparator, which in turn drives a 50-Ω line driver chip. A 40-mV hysteresis is implemented on the discriminator to avoid multiple triggering. Positive zero-crossings of the fringe signal are detected and begin the leading edge of the TTL fringe signal. This TTL fringe signal leaves the board through an SMA connector, and is available outside the interferometer on a BNC connector labeled TTL. The TTL signal is used for timing by the gravimeter electronics.

All on-board voltages are derived from the ± 15V supply with linear regulators: ± 6 volts for the APD , and ± 5 volts for the discriminator and 50Ω TTL driver.

APD SIGNALS		
CONNECTOR	**TYPE**	**DESCRIPTION**
Digital (SMA)	output	TTL fringe signal (50-Ω)
Analog (SMA)	output	buffered fringe output
HV	6 Pin Amp	HV Module
Power	3 Pin Amp	power from Lemo connector
*NOTE: The Power Technologies module is supplied from the +15V supply, and is connected to J3, J5, and J6 of the APD board.		

Table 4-1

4.4.1.3. Rubidium Oscillator

The FG5 uses a rubidium oscillator as a frequency standard (atomic clock). The oscillator generates a 10-MHz sine wave with amplitude of .5Vrms into 50 Ω. It is used by the TIA card in the personal computer to provide accurate time information. The clock is located in the power supply mains and is connected to the TIA card via a BNC cable.

4.4.2.DATA ACQUISITION

4.4.2.1.Computer Interface Cards

The computer running the system is a Pentium II machine (or better). The combination A/D converter and Parallel Input Output (PIO) board is used for interfacing the computer with the environmental sensors. The other computer card is the Time Interval Analyzer (TIA). Inputs for the TIA are listed in the table below.

TIME INTERVAL ANALYZER (TIA) INPUT SIGNALS			
Name	**Type**	**Destination**	**Description**
Channel A	BNC	Interferometer Base "TTL"	FRINGES
Channel B	BNC	NOT USED	
Trigger Arm (EXT ARM)	BNC	Patch Panel "trigger out"	External Trigger
External Clock (EXT CLK)	BNC	Power Supply "10 MHz"	External Clock

4.5. DROPPER CONTROLLER

The dropper controller is a flexible control circuit (programmable servo controller) that can direct the motor to servo the cart (and test mass) to a specified height in the dropping chamber using a rotary shaft encoder, or to a specific velocity, again using the shaft encoder. The controller can also direct the motor to track the test mass during free-fall using the sphere detector system.

The dropper controller board uses an EPROM to allow control over the motor drive signal sources (the shaft encoder and the sphere detector), as well as programmable offsets (command voltages) for each servo mode. This EPROM also controls the state-machine clock source, clearing the state-machine counter, and clearing the shaft encoder.

A second EPROM holds a programmable comparator level used for the setting of trigger and hold points within the dropping chamber. One bit of the second EPROM is also used to control the time-out circuitry (a safe-guard that protects the motor and the test apparatus).

Eight bits address the two EPROM's, giving a total of 256 programmable states. One bit is reserved for a fail/standby state, reducing the system to 128 non-standby states. These remaining states are subdivided into modes defined using three bits of latched data (a total possibility of eight modes). Each mode can have an associated four-bit state-machine cycle (sixteen possible states). A counter which can be clocked by an external signal (the computer), by a window comparator level, or by a programmable reference level in the dropping chamber controls the latter four bits. These clock choices are stored in the first EPROM.

This architecture allows flexibility to program many different modes of operation. Each mode can be associated with a programmable cyclic state-machine. The circuitry also allows programmable digital set points for critical positions such as launch points or hold points. The set points are well-controlled against environmental variables.

The controller circuit board currently supports four different modes of operation: STANDBY, MANUAL, OSCILLATE and DROP.

4.5.1.DROPPER CONTROL MODES

4.5.1.1.STANDBY

4.5.1.1.1.To Select

This mode is chosen upon power-up, when the front panel RESET button is pressed, or when a time-out has occurred (usually indicating failure).

4.5.1.1.2.Function

The controller is in standby. The motor is turned off.

4.5.1.1.3.To Deselect

Press the front panel INIT button.

(Note: The initialize function can also be executed remotely through the INIT BNC connector.)

! WARNING: IT IS DANGEROUS TO ALLOW THE COMPUTER REPEATED INITIALIZE CAPABILITY. THE SYSTEM CAN ENTER THIS STATE THROUGH TIME-OUT, WHICH MAY INDICATE SYSTEM FAILURE.

4.5.1.2.MANUAL

4.5.1.2.1.To Select:

THIS MODE SHOULD NOT NORMALLY BE NEEDED BY THE USER AND SHOULD NOT BE USED WITHOUT FULL UNDERSTANDING OF THE CONTROLLER!

This mode is selected by turning the front panel selector switch to MANUAL and pressing the INIT button.

4.5.1.2.2.Function:

The front panel potentiometer controls a servo position for the cart. The cart servo will not initiate until the trimpot is within a predefined window of the actual cart position. This will time out after 20-30 seconds if the time out is enabled (default).

IF THE TIME OUT IS DISABLED, BE CAREFUL TO NOT BURN OUT THE MOTOR BY DRIVING IT INTO THE STOPS AT THE TOP OR BOTTOM.

4.5.1.3.DROP

4.5.1.3.1.To Select:

Set the selector to AUTO. Press the INIT button to initiate the drop mode.

4.5.1.3.2.Function:

The DROP mode has six states:

1. Standby: The motor is off and the system waits for a trigger signal from the computer or from the internal timer (selected on front panel).
2. Lift: The cart servos to a constant lift velocity until the cart comes within the window of the hold position.
3. Hold: The cart servos to a constant hold position.
4. Track: The cart servos to track the test mass with a separation of about 3 mm. This is adjustable.
5. Soft-catch: The cart tracks the test mass with a very slight separation.
6. Catch: The cart servos to a decreasing ramp velocity servo until about 5 mm. At this point the state-machine returns to the standby mode (1).

4.5.1.4.OSCILLATE

4.5.1.4.1.To Select:

Press INIT while the selector switch is set to OSC.

4.5.1.4.2.Function:

This mode causes the cart to move up and down smoothly (with a constant velocity) in the dropping chamber. It is very useful for generating fringes. DO NOT LEAVE IN OSC MODE UNATTENDED! Cumulative belt slip can cause the cart to drive into the bottom or top of the dropping chamber and burn out the motor.

4.5.2.Analog Servo

The analog servo has three different sections. They are: Cart-position, Cart-velocity, and Sphere-position. The cart servos use the rotary shaft encoder as a position/velocity sensor. The sphere servo uses the optical sensor mounted on the cart.

4.5.2.1. Cart-Position

The cart position is given by an optical shaft encoder that is mounted on the motor shaft. The base resolution is 500 counts per revolution. The outputs are two quadrature signals which give information about the amount and direction of shaft rotation.

The shaft encoder quadrature outputs are preconditioned by a custom programmed gate array logic (GAL) chip called the AXQD2X. The outputs of the AXQD2X are glitch-free clock pulses and an up/down bit. The resolution of the shaft encoder is multiplied by two, giving 1000 counts per revolution. The AXQD2X also has logic that helps clear the counters and keeps them from an overflow or underflow condition.

The sixteen-bit counters feed a twelve-bit digital to analog chip (DAC) for use in the analog servo. The top seven bits are also fed to a comparator that is used for level settings that trigger different phases of the servo. The output of the DAC is available on the front panel BNC called CART position.

The DAC output has a programmable offset corresponding to either (1) the manual position controlled by the front panel knob, or (2) the hold position trimpot on the controller board. The servo adds in some derivative or damping that is set by the CART DAMP trimpot on the PC-board. The overall gain is set by the HOLD GAIN trimpot on the PC-board.

4.5.2.2. Cart Velocity

The servo takes the cart position derivative. A velocity lead trimpot on the PC-board adds phase margin which tends to speed up or damp the servo in the velocity mode. Servos that measure position and control velocity tend to have a slow exponential response without this precaution.

A programmable reference voltage is added to the velocity signal. The servo makes the actual cart velocity track these reference voltages. The four references are called: throw, lift, soft throw, and catch.

The throw and lift are constant offsets set by trim pots on the circuit board.

The soft throw and catch are both linear voltage ramps whose slopes are controlled with trim pots labeled SOFT THROW RAMP and CATCH RAMP. Each reference voltage also allows an offset to be added using the trim pots labeled THROW OFFSET and CATCH OFFSET. These ramps are used to accelerate the cart during the throw phase and decelerate the cart during the catch phase.

The gain for the velocity servo is set by the VELOCITY GAIN trimpot on the PC-board.

4.5.2.3. Sphere Servo

The sensor for this servo is an LED focused spot-sensor. The operational principle is a simple optical lever arrangement. An LED and linear detector are mounted on opposite sides of the cart. A spherical lens mounted on the test mass focuses the LED onto the linear detector, giving relative position between the cart and test mass. The signal is preconditioned by a preamplifier mounted on the cart. The position can be monitored on a front panel BNC labeled SPHERE.

The servo consists of an active feedback servo and a passive feedforward servo. The feedforward provides the approximate correct motor voltage during the drop.. This reduces the demands on the feedback servo.

4.5.2.4. Active Sphere Servo

The sphere signal is added with an offset called height and another offset called hover height. The height offset is always added to provide a tracking difference between the cart and the test mass during free-fall. The hover height is switched in by the EPROM and gives an overall reduced offset which makes the cart track the test mass very close to the rest position. This is useful for catching the object near the bottom of the drop.

The sphere signal (sphere and offsets) servo uses a proportional and a first derivative term. The proportional term is controlled with a trimpot called

SPHERE GAIN. The derivative term is controlled with the trimpot called SPHERE DAMPING.

4.5.2.5. Feedforward Sphere Servo

This servo is made with a ramp waveform. The slope of the ramp is given by the trimpot called RAMP SLOPE. The zero point, which should be at the top of the drop or throw, is set by the ramp offset

4.6. Superspring Controller

The Superspring electronics comprise a system for locating the Superspring mass relative to the support housing, a motor-driven mechanical lever system for raising and lowering the mainspring, and an electromagnetic coil that enhances the natural frequency of the mainspring by 2000 to 3000 percent.

Inside the Superspring are an SE-3455 infrared LED, a photo detector, and a sphere signal preamplifier. An infrared beam from the LED shines through an optical glass sphere attached to the bottom of the Superspring mass, which is suspended from the end of mainspring. The sphere focuses the beam on the photo detector. The detector outputs a signal to the preamplifier that indicates the position of the Superspring mass in relation to the mainspring support system.

4.6.1.1. SUPERSPRING CONNECTIONS

Name	TYPE	Destination	Name
Front Panel:			
SPHERE OUT	BNC	BNC16	2H
COIL OUT	BNC	NC	
Back Panel:			
COMP OUT	BNC	NC	

NOISE INJECT	BNC	NC	

Table 4-2 Superspring Connections

The preamplifier relays the signal to the Superspring controller, which controls a motor. The motor drives a lever system that raises and lowers the mass and mainspring. Two micro-switches and diodes keep the motor from raising or lowering the mass beyond a specified range.

A linear actuator coil and magnet system pushes and pulls the mainspring support structure to track the Superspring mass.

The Superspring controller has six main parts:

1. LED driver
2. Sphere signal buffer
3. Window comparator
4. Motor driver
5. Active filter
6. Coil driver

The LED driver supplies a constant current to drive the LED in the Superspring can. This current can be adjusted internally using the potentiometer (pot).

The sphere signal buffer buffers the signal from the Superspring can so it can be routed to different parts of the board. The Sphere Detector Out BNC can be low pass filtered at 1.26 Hz (FILTER ON).

The window comparator checks the LP-filtered sphere signal to see if it is within the preset range. If the signal is within the window the Range Status will be "High;" if the signal is out of the window the Range Status will be "Low."

4.6.1.2. MOTOR DRIVE SELECTION

The motor driver circuit can be selected by an external switch with five positions: OFF, WINDOW, AUTO, REMOTE, and MANUAL. This controls a DC motor which can position the top of the main spring relative to the main bracket. The position may need to be adjusted as the main spring slowly stretches over time, or due to temperature or gravity changes. The DC motor can lift (lower) the test mass so that the sphere position becomes more positive (negative). This motor should only be used to position the mass but should not be activated during the Superspring operation as a long period isolation device.

4.6.1.2.1. OFF

This setting disables the DC motor that positions the top of the main spring. The Superspring should be left in this mode when the active servo is activated.

4.6.1.2.2. AUTO

The Superspring controller will try drive the DC motor using a feedback loop so that the sphere signal is zero.

4.6.1.2.3. WINDOW

The Superspring controller will activate the motor when the sphere voltage is out of range (larger than the window setting). The motor drives the sphere voltage to zero and then is turned off. In principal the Superspring can be left in this mode but it could re-zero during a measurement causing excess noise.

4.6.1.2.4. REMOTE

The Superspring can be made to zero using an external TTL signal.

4.6.1.2.5. MANUAL

In manual mode, the spring motor is controlled by the potentiometer (pot) on the front panel. A setting greater than 5 will move the spring up less than 5 will lower the spring. Moving the spring up will case the BNC Sphere out to move in a positive direction while down will move voltage output in a negative direction.

4.6.1.3. Active Servo

The filter is a band pass accomplished with a high pass (HP) and then a low pass (LP) filter. The Q-value and frequency of each filter is adjustable via the on-board trim pots. The phase lead and lag and the servo gain are also adjustable.[2]

[2] Nelson P.G., *An Active Vibration Isolation System for Inertial Reference and Precision Measurement*, Rev. Sci. Instrum., 1991, **62**, 2069-2075.

4.6.1.4. Coil Drive (Current Driver)

The filter section feeds the coil driver which produces a current for the coil using a high power op amp. The signal feeding the coil driver can be viewed at COMP OUT. The signal returning from the coil can be monitored at COIL. The coil driver can be engaged with the COIL switch. You can also insert a signal to the coil at the Noise Inject BNC on the back panel.

4.6.2. Maintenance Schedule

To keep the instrument at its optimum performance level proper maintenance procedures should be periodically performed.

4.6.2.1. Annually

Inspect, replace, and adjust the cart drive belt.

Inspect, replace, and lubricate the drive system bearings.

Inspect and replace the tungsten support contacts on the test mass and cart.

Reassemble the vacuum system and test for leaks. Pump down and bake out the vacuum system.

Test and adjust the system electronics.

Clean and align the optics.

4.6.2.2. Semi-annually

Calibrate the ML-1 He-Ne laser to an iodine standard.

Calibrate the rubidium oscillator frequency.

5. Troubleshooting

This section is intended as a rough guide to identification of system problems based on observed symptoms. There will be cases where the observed symptom is not described here and other times where the correct cause is not listed in this chapter because of the complexity of the mechanical, electrical, optical, and software relationships. In these cases, please contact Micro-g for a better diagnosis. Also any new symptoms/causes that are observed should be reported so that future versions of this manual can be updated.

5.1. The FG5 System

The FG5 absolute gravimeter is an extremely sensitive instrument which must be set up and operated with the utmost care to achieve optimum results. It is especially important to maintain a system check log during set up and observation. Conscientious recording of system information (e.g. laser power, ambient temperature and atmospheric pressure, Superspring position, ion pump current, fringe signal amplitude, dropping chamber and Superspring level positions, etc.) can be extremely helpful in diagnosing problems. The Micro-g Solutions Environmental Sensor Package is highly recommended for monitoring system status, because it automatically records ambient temperature and local atmospheric pressure during observations. It is also helpful to maintain a log of operating hours for the system. This will assist the operators in performing preventative maintenance (e.g. cleaning laser or interferometer optics, replacing the ion pump, etc.)

5.2. System Problems

5.2.1.DROPPING CHAMBER

It is extremely important that all dropping chamber systems (dropper servo, vacuum, etc.) operate properly to achieve the best results possible. Table 5-1 lists problems related to the dropping along with possible solutions.

Problem	Solution
Dropping chamber will not drop	Travel lock engaged Controller not initiated
Current at portable ion pump power increases after each drop.	Ferrofluidic rotary feedthrough needs to be replaced.
Vacuum level (ion pump current) consistently high.	This can be caused by a small leak in the dropping chamber (usually at an O-ring seal). Also, the ion pump may need to be replaced. Leak check the dropping chamber. If no leaks are found, replace the ion pump. The life of the Ion Pump is rated as 20,000 hours at 1×10^{-6} torr (continuous operation). However, ion pump life is usually much less if the pump is shut off and restarted often.
OSC mode does not operate continuously, and cart drives into lower spring	Velocity servo needs to be adjusted
Noisy catch.	Catch offset and ramp need to be adjusted

Hum at the top of the drop.	Hold servo gain needs to be reduced. Shaft encoder is dirty and needs to be blown clean with high pressure air.
Upward or downward trend in gravity values (time series plot).	Ion pump is not turned on. Time or date on PC controller have been set incorrectly. Tide correction flag has not been set in the Process | Setup | Control. Latitude or longitude have been entered incorrectly in Process | Setup | Information. Set up on non-rigid floor and verticality of the beam is drifting.
Single clicking sound during lift and drop.	Drive belt developing fracture and needs to be replaced.
Stops after one drop and resets itself	Drive belt could be loose and may need to be tightened.
Multiple clicking sounds during lift and drop.	Drive bearing needs to be replaced.
Cart drives to the top very fast	No shaft encoder signal. Check cable connection. Check that the cart voltage changes as you manually lift the mass (using a hex wrench).
Very bad sound during drop	Sphere signal is not present because of the cable is not connected or a there is a bad cable/connector. Look for a sphere signal that changes as the mass is travel locked.

Sharp spikes (faster than 1ms) on the sphere signal during drop with a bad sound during drop	Bad cable/connector
Many bad drops occur with extremely high residuals. [High number of drop-outs]	The cart travel is not aligned with the vertical. The bubble levels on the tripod need to be reset or the dropping chamber is not sitting in the tripod tray correctly. Dropper guide rods are not straight. Can be due to snubbers tightened asymmetrically or because of stress from bad alignment of rods in the top ring.

Table 5-1 Dropping Chamber Problems and Solutions

5.2.2.INTERFEROMETER AND LASER

To achieve the best possible results, the interferometer optics must be clean and correctly aligned. In some cases, it is possible to detect alignment problems during setup. The operator should always be extremely observant while leveling the interferometer, and adjusting beam coincidence and verticality so any problems in misalignment can be detected and corrected before observations begin. Table 5-2 gives a list of problems and possible solutions which are related to the interferometer.

Problem	Solution
WEO laser not producing beam	Check cable connections. If the front panel show no sign of power check the fuse and power switches.
WEO laser power too low	Laser optics need cleaning. Alignment of back laser mirror should be adjusted. Iodine cell needs rotation adjustment to maximize beam. Laser tube needs to be replaced. Fiber alignment needs to be optimized
WEO laser will not lock	Ambient temperature too high (30C) Laser not warmed up Laser sweep turned on Incorrect toroid voltage setting
Large systematic signal in the least-squares residual plot.	Interferometer base and dropper tripod are mechanically coupled. The top interferometer plates are not fastened.

Beam spot viewed in T2-telescope is larger than normal	T2-telescope infinity focus needs calibration. Beam expander is not set correctly for collimation. Optics in beam path need cleaning. Alcohol pool dirty. Shake pool or replace alcohol.
Test beam viewed in periscope has flat side (not circular).	Dropper not aligned properly with interferometer. Superspring not leveled or not aligned properly with interferometer.
Cannot obtain >200mv amplitude on analog fringe output with alignment optimized.	Rotate $\lambda/4$plate lens in front of faraday isolator to increase beam intensity.
Analog fringe output clipped with alignment optimized.	Intentionally mis-align the input into the fiber optic. Set fringes at about 340 mV
Larger than expected single drop distributions or multi-node histogram on computer display or simply too large of a scatter at a quiet site (100μGal)	This can be due to the software incorrectly detecting a peak hop. Rerunning the data without the peak detect should solve the problem in replay. The problem could be due to the 1f signal is not hooked up correctly or the time constant is set to FLAT. The time constant should be set to 1s.
Data drop-outs	Laser not locked (possibly due to mechanical vibrations, air flow on instrument, or optical feedback)

Large residual amplitude	Check parameter file, do not fit past point 170 Bad cables, especially PIO ribbon cable Bad grounding of fringe signal
10nm residual frequency swept	Wrong laser type selected Incorrect laser modulation frequency entered in the fg5param.dat file
No fringes at all	No power to APD. One/both beam blockers are pushed in Very bad alignment of the test/reference beams. Look into the telescope and make sure that the test and reference beams are overlapped. Also make sure that the beams are overlapped in the fringe viewer with the twiddler
Fringe amplitude varies as the cart is moved up or down.	The iodine-stabilized laser is running multi-mode. This can indicate the laser servo gain being set too high.

Table 5-2 Interferometer Problems and Solutions

5.2.3.SUPERSPRING

A Superspring problem usually results in gravity data with a large drop-to-drop scatter. A chart recorder 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. 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. Also, if the change in gravity from one site to the next is very large, it is common for the test mass to be out of range (as indicated by an LED on the front panel of the Superspring controller). If the change in gravity from the most recent station to the present one is positive and the sphere is out of range, the spring will be low and should be driven up into range. If the change in gravity is negative, the spring should be driven down into range. 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. See Chapter 3, paragraph 53-54 for more details. Table 5-3 lists possible problems and solutions pertaining to the Superspring.

Problem	Solution
Test mass can be driven in one direction but cannot be adjusted in the other direction.	Limit switch is limiting the motion. The solution is either to widen the range for the limit switch or adjust the coarse position of the main spring using the nut on the top of the flexure.
Sphere shows no oscillations when unlocked and cannot be driven into range.	Upper flexure on main spring is broken and needs replacement or a delta rod bent.
Spring sphere signal looks quiet but the gravity data is still noisy as if the Superspring is not isolating.	The mass is not in range of the detector. The Superspring is still locked.

Spring damps suddenly after unlocking.	Spring is off level, check bubble levels for proper level. Spring is out of range and is hitting upper or lower physical limit of the spring. Horizontal flexure (delta rod)has been damaged and needs replacement. The lock on the controller is locked.
Gravity is extremely noisy (mGal)	It is possible that there is an earthquake event occurring somewhere on earth. The Superspring is very sensitive to earthquakes no matter where they occur. The gravity will continue to be noisy for hours or even days when the earthquake event is close to the gravimeter location.

Table 5-3 Superspring Problems and Solutions

5.2.4.SYSTEM CONTROLLER

Since the system controller performs real time gravity computations/corrections, records data, and initiates the dropping sequence, a failure of this component results in a catastrophic system failure. Table 5-4 gives a list of problems and possible solutions for the system controller. The primary source of all problems encountered with the controller units have been with poor cable connections or poor internal connections of the cards to the computer.

Problem	Solution
"g" responds with "Time Out: Check Trigger, Fringe Amplitude, TTL Cable" message.	General message indicating no fringe data arrived at the computer. Check for alcohol pool in the I.B., beam blocker pushed in, TTL cable to computer, TRIG cable from dropper controller to computer. Check that the fringe amplitude is >250 mV. Check that the dropper is functioning in the DROP mode.
Gravity value is wrong	Check all gravity corrections especially vertical transfer to the specified height. Check latitude/longitude and date/time. Check laser peak lock hardware/software

Table 5-4 System Controller Problems and Solutions

5.2.5.ELECTRONICS

The system electronics consists of the timing system, controllers for primary subsystems, and power supplies for most components in the FG5. Some of the electronic subsystems are manufactured by Micro-g Solutions, while others are "off-the-shelf" components from other commercial vendors. Electronics problems can range from catastrophic system failures to subtle, intermittent problems which are extremely difficult to detect and diagnose. Table 5-5 gives a list of possible electronic problems and solutions. As with the system controller, the majority of problems encountered with this system have been poor or missing connections during setup.

Table 5-5 Electronics Problems and Solutions

Problem	Solution
A systematic gravity shift is observed	The rubidium clock has lost its calibration. Check its frequency against a standard Cesium reference. Beam verticality is off Beam is not collimated High rotation/translation of test mass Wrong laser lock or the laser hopped a peak.
Sinusoidally varying gravity value	Rubidium standard is warming up or will not lock. VCXO trim may need adjustment.
Large noise (often looks like a Superspring problem)	Poor system grounding. Sometimes it is necessary to ground the system electronics rack to an earth ground (like a water pipe) in the laboratory.

5.2.6.ENVIRONMENTAL SENSORS PACKAGE

The environmental sensors package is an optional system for the FG5. Therefore, if there is a major failure, it is possible to continue observations. Occasionally, the operator can obtain temperature and pressure data from an alternate source. If the pressure data is accurate enough (± 1 mb or better), local barometric pressure attraction corrections accurate to better than one µGal can still be computed and applied during post processing. Possible problems and solutions pertaining to the environmental sensors package are shown in Table 5-6.

Problem	Solution
Gravity is 300µGal too high	The system is not reading the barometer. Make sure the barometer is hooked up correctly. Also make sure that the voltage range for the analog input (Process | Setup | System | A2D Card) is set to Unipolar, 10 V, with an offset of 537.5 and a multiplier of 1.25.

Table 5-6 Environmental Sensors Package Problems and Solutions

5.2.7.ROTATION MONITOR

The rotation monitor is an optional system for the FG5, so it is possible to operate the FG5 without it. The rotation monitor is a diagnostic tool which is used to determine if there is excessive rotation of the test mass about a horizontal axis (i.e. if the balls and/or v-grooves are worn, and need to be replaced). Possible problems and solutions are shown in Table 5-7.

Problem	Solution
Excessive Rotation (>10mrad/sec)	Alignment of the dropper is not correct. Ball/Vee contacts for the test mass need to be replaced.

Table 5-7 Rotation Monitor Problems and Solutions

5.3. Gravity Site Selection

5.3.1.GEOLOGIC STABILITY

To achieve best results, a site should be located in a geologically stable area. Generally, it may be necessary to measure gravity at a particular site for a number of different reasons, and geologic stability cannot be considered. However, when selecting a primary base station, geological stability is important in minimizing long term variations in gravity resulting from groundwater changes, and subsidence or rebound of the earth's crust.

5.3.2.SITE STABILITY

It is always best to select a site in the lowest level of a building to reduce vibrations as much as possible. A basement with a thick concrete floor is usually best. Avoid floors with composition materials, if possible, and set up the instrument on a solid tile or concrete floor.

5.3.3.ENVIRONMENTAL NOISE

Heavy heating or cooling equipment, as well as bipedal or vehicular traffic, can cause vibrations which tend to increase the drop-to-drop scatter of the observations. This can usually be seen as a large, systematic change in the drop-to-drop scatter between day and night observations. A remote, environmentally quiet site usually minimizes these changes.

5.3.4.TEMPERATURE STABILITY

Although the FG5 will operate properly over a wide temperature range, it is important to have a site with good temperature stability to minimize possible problems with temperature sensitive components (e.g. laser and Superspring).

5.4. AC POWER

Problems with AC power are not uncommon, especially in remote field environments. Make sure that ground is available before plugging in system. It is always best to use voltage stabilizers and/or uninterruptible power supplies to minimize problems with unreliable line voltage. Some system components (especially the WEO Model 100 iodine laser and system computer) are more sensitive to line voltage fluctuations than others, so it is always best to stabilize line voltage well enough to satisfy the requirements of the most sensitive component.

6. SWITCHING THE AC POWER

Switching between 100-115 VAC and 220-240 VAC

NOTE: Check the manuals for each component to determine the proper fuse for the line voltage being used. Components not listed in these instructions are configured to automatically switch between 100-115 VAC and 220-240 VAC.

6.1. LASER

6.1.1.WEO Model 100 Laser

Possible voltage selection positions (50-60Hz): 100, 115, 220, and 240 VAC

1. Remove AC power cord from the power entry module on the rear panel of the laser controller.
2. Open the power entry module and remove drum voltage selector. IT IS VERY IMPORTANT TO REMOVE THE DRUM - DO NOT ROTATE THE DRUM IN PLACE. THIS CAN CAUSE DAMAGE TO THE TRANSFORMER INSIDE THE LASER CONTROLLER.
3. Rotate the drum voltage selector until the proper line voltage is visible (make sure the drum is removed from the power entry module).
4. Replace the drum voltage selector (making sure the proper line voltage is visible) and plug the AC power cord into the power entry module.

6.1.2.ML-1 Laser

1. The ML-1 is compatible with AC voltages of: 110 and 240 VAC (50-60Hz). No manual switching is necessary.

6.2. Portable Ion Pump Power Supply

2. The Model 125 Portable Ion Pump Power Supply is compatible with AC voltages of: 110 and 240 VAC (50-60Hz). No manual switching is necessary.

6.3. Computer

Computer models are prone to change as newer technology is introduced. The computers are usually very easy to switch voltages by flipping a selector switch near the AC power cord. Some models use a universal power supply, so switching is not required. Please check the computer manual supplied with the FG5 for complete details.

7. Pumping/Baking the Chamber

7.1. Choosing the Pumping Method

A 70 l/s turbo pumping station (turbo pump, backing pump, and controller/power supply) is currently included with each FG5, and is used to evacuate the dropping chamber when necessary. It is possible to use a turbo pump as small as 40 l/s, if necessary, with good results. There are two pumping methods which are commonly used.

7.1.1.Cold Pumping the Chamber

Cold pumping (no bakeout) can be used when the ion pump has been off power for a period of one week or less, and the dropping chamber HAS NOT BEEN OPENED. For this method, the turbo pump is connected to the dropping chamber and allowed to pump for a period of time before the ion pump is started. The required pumping time is determined by the time the ion pump has been off power, and the temperature at which the dropping chamber has been stored. If the ion pump has been off for less than one week, a pumping time of 1 hour (or less) is usually sufficient to start the ion pump. When the ion pump has been off for several weeks, it is usually best to pump the chamber overnight (12-14 hours). It may be necessary to bake out the chamber while pumping. See the section on baking out the chamber for instructions.

7.1.2.Baking Out the Chamber

The dropping chamber must be baked whenever it has been opened, and it often helps to bake a chamber that has been off power for a long period of time. This requires that the dropping chamber and ion pump be heated to help "evaporate" the interior of the chamber. This decreases the pumping time by speeding out-gassing within the chamber. **Note that the ion pump must be turned off during the bakeout.**

7.2. Connecting the Turbo Pump to the Dropping Chamber

Remove the turbo pump from its shipping case and make sure it is set for the proper AC line voltage (see appendix A). Place the lid of the turbo pump case on the floor near the dropping chamber and interferometer. Orient the turbo pump so its intake flange is facing the vacuum valve intake flange (on the service ring) and the turbo pump is close enough to the dropping chamber so the flexible stainless steel hose will easily reach from the vacuum valve flange to the turbo pump intake flange. Remove the blank flanges from the vacuum valve on the dropping chamber service ring and the turbo pump intake. Connect the flexible stainless steel hose to the turbo pump intake and the bellows valve using the quick connect vacuum fittings. The vacuum fittings have an O-ring that fits between the two flanges. A clamp holds the two vacuum flanges and O-ring assemble together. Make sure that there is no dirt or hair on the vacuum flanges or O-ring, and take care not to touch the inside of the rings or hose. Sometimes it is helpful to use a little high vacuum grease (such as Apiezon) on the O-ring to ensure a good seal.

There are two different circumstances which dictate whether the bellows valve is to be open or shut when starting the turbo pump.

If the chamber is under partial vacuum, DO NOT open the valve until the turbo pump has evacuated the air inside the flexible hose. When the hose is evacuated, slowly open the valve. This prevents the contamination of the dropping chamber by air or moisture inside the hose.

If the chamber has been open to the air make sure that you open the bellows valve before starting the turbo pump. Venting the dropping chamber to the turbo pump when it is at full speed can cause damage to the turbo pump.

Make sure the small relief valve on the turbo pump is closed, and turn on the turbo-pump.

The turbo-pump should reach normal operational speed in a few minutes. If the pump fails to reach full speed for an extended period it indicates that there is a leak in the system.

While the turbo-pump is pumping down the system it is best that the AC power not be interrupted. However, if the power is interrupted, the newer, Varian Turbo Dry 70 turbo pumps are self-sealing. That is, they do not vent to atmospheric pressure, and they do not contaminate the chamber vacuum. If the power goes out, just continue pumping down as before.

7.3. Heating the Chamber

After the turbo pump has evacuated the chamber, remove the magnet package from the ion pump and wrap separate heat tape around the dropping chamber and the ion pump. The chamber temperature should be maintained at 70° C (or less). This is done by connecting the heat tape to a variable transformer to control the temperature. Monitor the bakeout temperature using the type F thermocouple cables which are attached to the dropping chamber. Make sure that the temperature probe is contacting both the heat tape and the chamber. This insures that the hottest part of the chamber does not exceed the maximum temperature. Bake the chamber for at least 8 hours, with the turbo pump running. It is very important to have the test mass locked down during bake-out and cool-down. This allows a good thermal contact between the dropping chamber and test-mass.

! DO NOT ALLOW THE TEMPERATURE OF THE CHAMBER TO EXCEED 80° C. EXCESSIVE HEAT MAY DAMAGE THE FERROFLUIDIC VACUUM FEEDTHROUGH OR OPTICAL SENSORS INSIDE THE DROPPING CHAMBER

Turn off the heat tapes and allow the turbo pump to continue pumping the chamber for at least 16 hours. Make sure that the test-mass remains locked until the chamber is completely cool. When the chamber has returned to ambient temperature, remove the heat tapes and reinstall the ion pump magnet package.

7.4. Starting the Ion Pump

Install the magnets on the turbo pump. Check the AC, BAT, and HV switches on the ion pump power supply, and make sure that they are off. Connect the ion pump HV cable (#9) to the ceramic connector on the pump. Connect the small green safety ground umbilical of the HV cable to one of the banana jacks located on the base of the dropping chamber near one of the handles. Connect the safety HV ground cable (#10) to the other banana jack on the base of the dropper. Set the meter select knob on the ion pump controller to PUMP VOLTAGE (KV). Start the ion pump by turning on the AC, BAT, and HV switches on the ion pump controller. Leave the turbo pump running and connected to the dropping chamber until the ion pump starts. After turning on the ion pump, check the meter on the ion pump power supply. The voltage should be at least 2 KV within five minutes after turning on the ion pump. At operating pressure, nominal voltage is 4 KV (on AC), and 3 KV (on battery). If the ion pump has not started within five minutes, turn off the power and continue pumping with the turbo pump for at least one hour before trying the ion pump again. Leaving the ion-pump on with excessive current (> 10^{-5} Torr) shortens the lifetime of the pump dramatically. Once the ion pump is at a stable 4 kV and the current (monitored by switching to the 10^{-3} μA scale), is starting to slowly decrease, the ion pump has "started". Slowly close the bellows valve on the chamber. It is normal for the current to rise again, but after five minutes or so, it should once again start to decrease. Once the ion pump has started with the bellows valve closed, it is now safe to turn off the turbo pump. Turn off the turbo pump power switch, and once the turbo pump has come to a stop, vent it by slowly opening the small relief valve. The flexible hose should relax, and it is now safe to remove the flexible hose and replace the blank flanges on the vacuum valve and turbo pump intake.

8. THE ROTATION MONITOR

8.1. INSTALLATION

Remove two opposing M6x25 screws holding the test chamber top flange. Attach the attitude monitor to the top flange using two M6x35 screws. There should be no washers underneath the screws holding the top lid or the rotation monitor will not set flat. It may be necessary to remove these washers if they are installed. Connect the power supply. Connect the x and y BNC connectors on the detector box to channels 1 and 2 of an oscilloscope. Set the scope to the x-y mode at 500 mV/ scale. Turn the laser on.

Remove the cap from the window on the top flange of the test chamber. With the test mass in its bottom position, adjust mirror mounts 1 and 2 until the laser beam is centered in the mirror on top of the test mass.

Raise the test mass as far as possible without losing sight of the test mass mirror. Use the travel lock pin to lock the mass in this position. Adjust <u>only</u> mirror mount 1 so as to put the laser beam back in the center of the test mass mirror. Lower the test mass to the bottom and adjust <u>only</u> the beam-splitter on mirror mount 2 to put the spot back in the center of the test mass mirror. The first mirror is used to translate the beam onto the mirror at the top position and the beamsplitter is used to adjust the angle of the beam so that it hits the mirror on the bottom position.

Repeatedly raise and lower the test mass, adjusting mirror mounts 1 and 2 until the laser beam is centered in the test mass mirror at both the top and bottom.

After the laser beam has been aligned to the travel of the test mass, use mirror mount 3 to steer the beam through the center of the lens and down the center of the tube on the x/y detector. Adjust mirror mount 3 until the spot on the scope is at the zero position. Disconnect the x and y cables from the scope. Verify that there is good sensitivity to motion of beam using mirror mount #3. Sometimes an extra reflection from the glass viewport will interfere with the measurement. Any extraneous reflections can be blocked with a piece of paper or tape.

9. Checklists and Logs

It is helpful to use checklists to assure that critical tasks associated with operation of the FG5 are done correctly. Logs are strongly recommended so the operators can easily record the status of the system and document any information (e.g. weather, site conditions, system status) which is noteworthy. This information is invaluable in documenting observations, performing data analysis/post processing, and troubleshooting the system. This appendix consists of several checklists and logs which are helpful. In many cases, the user may develop additional or modified procedures which are "tailored" to their own survey methodology.

9.1. Switching the AC Power

Switching the AC Power Checklist	
	Determine and use proper fuse for each component.
	WEO 100 Laser: Use drum in power entry module. Remove drum from power entry module before rotating.
	Computer: Select proper input voltage using switch near power entry module. Some models may automatically switch for proper line voltage. Consult computer manual.

Table 9-1 Switching the AC Power

9.2. FG5 Setup

FG5 Setup Checklist	
	Locate the reference mark.
	Place the electronics case in a convenient location.
	Check AC line voltage. Connect main AC power cable.
	Turn on main AC and DC power switches.
	Turn on laser power.
	Place superspring tripod over reference mark.
	Rough level superspring tripod.
	Measure and record lower reference height.
	Place superspring on tripod and clamp in position.
	Level superspring using precision level vials.
	Remove superspring dust cover and place interferometer on superspring. Tighten four knobs to lock interferometer to superspring.
	Remove dust cover from interferometer base.

	Assemble dropper tripod and place on interferometer base.
	Place dropping chamber on tripod and lock in place.
	Release the dropper travel lock.
	If necessary, connect cables to ion pump and power up. Rough pump the chamber, if necessary.
	Check superspring levels and adjust, if necessary.
	Place blue pads and tripod feet under dropping chamber tripod.
	Raise each foot until it contacts nylon ball on tripod leg. Raise dropper (two revolutions of each tripod foot).
	Level dropper (cross level first, then long level).
	Check superspring levels and adjust, if necessary.
	Measure and record upper reference height.
	Place computer/system controller on electronics case.
	Connect computer power cable to power supply panel.
	Connect ribbon cable from patch panel to computer.

	Connect "TTL" BNC cable from interferometer to computer time interval card.
	Connect "10 MHz" BNC cable from power supply to computer time interval card.
	Connect trigger BNC cable from dropper controller TRIG OUT to computer time interval card.
	Connect barometer cable from power supply to patch panel Channel 4.
	Connect BNC cable from laser controller output to Channel 3 on patch panel (WEO Model 100 Laser only).
	Connect BNC cable from "sphere out" on superspring controller to Channel 1 on patch panel.
	Connect BNC cable from "meter monitor" on ion pump power supply to Channel 2 on patch panel.
	Connect BNC cable from "trigger out" on patch panel to "Trigger EXT IN" on dropper controller.
	Make sure dropper controller is on STANDBY. Connect dropper signal cable (white Lemo connector) from power supply to dropper.
	Connect shaft encoder cable (blue Lemo connector) from power supply panel to motor drive assembly.
	Connect motor power cable (orange Lemo connector) from power supply panel to motor drive assembly.

	supply panel to motor drive assembly.
	Connect APD power cable (green Lemo connector) from power supply panel to interferometer base "power" connector.
	Make sure COIL switch on superspring controller is off. Connect superspring cable (yellow Lemo connector) from power supply panel to superspring.
	Check superspring levels and release travel lock.
	Adjust superspring position (0 – 20 mV) and turn coil switch on.
	Adjust beam verticality and optimize fringe signal.
	Check/set computer time. Edit fields in Process | Setup. Set dropper controller to AUTO and initiate.

Table 9-2 FG5 Setup

9.3. Dropping Chamber Pump Down and Bake-Out

Dropping Chamber Pump Down and Bake-Out	
	Set turbo pump for proper line voltage (see appendix A).
	Place turbo pump on case lid and connect pump to dropper with flexible stainless steel tube.
	Remove plastic cap from exhaust mist collector. If the dropper is under vacuum, keep the bellows valve shut. If the dropper has

	been open to air, open the bellows valve.
	Plug in turbo pump power cord and turn on pump.(keep bellows valve closed).
	Wait to see that turbo-pump has reached normal operation. Open bellows valve if necessary. (after evacuating air in flexible tube).
	Remove magnet package from ion pump (if heating is required).
	Connect heat tape and temperature sensors to dropper and ion pump (if heating is required).
	Lock test mass.
	Monitor dropper and ion pump temperatures (dropper < 80° C).
	Bake dropper and ion pump for at least 8 hours.
	Turn off heat tapes. Allow dropper to cool at least 16 hours.
	Unlock test mass.
	Reinstall ion pump magnet package.
	Connect HV and ground cables between ion pump controller and ion pump.
	Turn on ion pump controller to start ion pump.

	Monitor voltage at ion pump controller (should be 2 KV within 5 minutes and rising).

Table 9-3 FG5 Pump Down and Bake Out

9.4. Dropping Chamber Maintenance

9.4.1.Removing Dropping Chamber Cover

Removing Dropping Chamber Cover Checklist	
	Remove blank flange from vacuum valve.
	Unlock valve locking ring and slowly open valve. Vent with dry nitrogen, if possible
	Remove top flange.
	Loosen snubber lock nuts and screws.
	Remove chamber cover from service ring. Keep bottom flange clean and protect O-ring surface.

Table 9-4 Removing Dropping Chamber Cover

9.4.2.Replacing Dropping Chamber Cover

Replacing Dropping Chamber Cover Checklist	
	Inspect chamber O-ring and sealing surfaces. Lubricate O-ring, if necessary.
	Lower chamber cover over dropping mechanism.

	Tighten mounting screws in star pattern.
	Adjust snubber screws and tighten lock nuts.
	Inspect top flange O-ring and sealing surfaces. Lubricate O-ring, if necessary.
	After installing dropper, adjust level bubbles on tripod tray.

Table 9-5 Replacing Dropping Chamber Cover

9.4.3.Replacing Drive Belt

Replacing Drive Belt Checklist	
	Remove dropping chamber cover.
	Loosen belt tension.
	Remove belt clamp from cart.
	Remove belt.
	Clean drive and top pulleys and wipe new drive belt.
	Thread new belt around top and drive pulleys.
	Place belt ends over dowel pin and install belt clamp (do not tighten clamp).

	Tension belt (while moving cart up and down).
	Allow belt to locate natural position.
	Tighten belt clamp.

Table 9-6 Replacing Drive Belt

9.4.4.Adjusting Belt Tension

Adjusting Belt Tension Checklist	
	Tighten belt adjustment screw until belt is straight.
	Tension belt by tightening adjustment screw three turns (until tension spring is just short of coil bind). or tension belt using torque wrench.

Table 9-7 Adjusting Belt Tension

9.4.5.Replacing Ferrofluidic Vacuum Feedthrough

Replacing Ferrofluidic Vacuum Feedthrough Checklist	
	Remove dropping chamber cover.
	Loosen 4-40 screws on Helical coupling (between motor and feedthrough).
	Remove ¼-28 screws which attach motor to Conflat flange.

	Remove motor mount assembly (motor, Helical coupling, travel lock plate, and shaft encoder) from Conflat flange.
	Loosen screw on Helical coupling (where it attaches to drive pulley shaft).
	Remove Conflat mounting screws.
	Remove Conflat (with feedthrough attached).
	Remove Helical coupling from feedthrough.
	Unscrew feedthrough from Conflat flange.
	Lubricate O-ring on new feedthrough. Gently tighten new feedthrough to Conflat flange (use pliers with padded jaws).

Table 9-8 Replacing Ferrofluidic Feedthrough

9.4.6.Replacing V-plate

Replacing V-plate Checklist	
	Remove dropping chamber cover.
	Remove bottom drag-free cover from cart.
	Detach LED bracket from cart and pull out of the way (be careful not to damage wires).
	Observe position of the threaded post attaching top drag-free cover to cart.

	Remove top drag-free cover from cart and pull out of the way (do not detach or damage wires connected to it).
	Note orientation of top part of test mass to V-plate.
	Remove top part of test mass from posts which pass through V-plate.
	Lower bottom part of test mass through V-plate.
	Remove old V-plate and replace with new one.
	Reverse procedure to reassemble.

Table 9-9 Replacing V-Plate

9.4.7.Replacing the Linear Bearings

Replacing Linear Bearings Checklist	
	Remove dropping chamber cover.
	Remove drive belt.
	Remove top rod ring.
	Remove upper bumper stop assembly.
	Remove ribbon cable wires and clamp from cart.
	Lift cart off guide rods.

	Remove two retaining rings for each linear bearing (wind off end of bearing).
	Slide linear bearings out of the cart.
	Make sure new linear bearings have venting holes.
	Make sure new linear bearings have been cleaned and lubricated with Krytox 143AC low vapor pressure oil.
	Insert new linear bearings in cart and insert retaining rings.
	Reverse above procedure to replace cart.

Table 9-10 Replacing Linear Bearings

9.4.8. Replacing Shaft Bearings (Drive Pulley)

Replacing Shaft Bearings (Drive Pulley) Checklist	
	Remove dropping chamber cover.
	Remove drive belt.
	Disconnect Helical coupling between pulley shaft and Ferrofluidic feedthrough.
	Remove screws holding bottom rod ring to bottom flange.
	Rotate guide rod structure so shaft clears service ring.
	Remove guide rod structure.
	Remove pulley yoke from bottom rod ring.
	Remove bowed retaining ring from short end of pulley shaft (note orientation).
	Remove retaining ring from other end of shaft (don't lose Woodruff Key).
	Remove pulley from bearing mounting yoke.
	Push bearings out of yoke.

	Make sure new bearings are cleaned and lubricated with Krytox LVP low vacuum grease.
	Reassemble in reverse order (make sure bowed snap ring is oriented correctly and fully seated in groove).

Table 9-11 Replacing Shaft Bearings (Drive Pulley)

9.4.9.Replacing Shaft Bearings (Top Pulley)

Replacing Shaft Bearings (Top Pulley)	
	Remove dropping chamber cover.
	Remove drive belt.
	Remove snap rings on upper bump stop and slide down shaft.
	Remove retaining rings on top of upper pulley yoke.
	Remove pulley (slide down).
	Remove bowed retaining ring from short end of pulley shaft (note orientation).
	Remove retaining ring from other end of shaft.
	Remove pulley from bearing mounting yoke.
	Push bearings out of yoke.
	Make sure new bearings are cleaned and lubricated with Krytox LVP low vacuum grease.

	Reassemble in reverse order (make sure bowed snap ring is oriented correctly and fully seated in groove).

Table 9-12 Replacing Shaft Bearings (Top Pulley)

9.4.10.Replacing Rotary Shaft Encoder

Replacing Rotary Shaft Encoder Checklist	
	Loosen set screw holding disk to shaft.
	Pry encoder housing off back plate (plate remains attached to travel lock plate).
	Snap new encoder over back plate.
	Tighten set screw holding disk to shaft.
	Rotate shaft to assure encoder disk rotates freely.

Table 9-13 Replacing Rotary Shaft Encoder

9.5. Interferometer Alignment

Interferometer Alignment Checklist	
	Set up superspring. Attach interferometer base and level superspring.
	Turn on laser and slide out fiber/collimating assembly from the interferometer base.
	Roughly collimate laser beam on ceiling or target.
	Precisely collimate laser beam by adjusting slide to minimize spot diameter in telescope. Tighten slide locking screw.
	Remove dust plug from interferometer base. Place dropping chamber and tripod on interferometer base.
	Loosen two set screws above fiber optic input and block test beam.
	Center beam in fringe viewer by translating fiber optic input. Tighten set screws.
	Focus telescope crosshairs and center beam in telescope viewfinder by adjusting mirror # 3.
	Open side access door and place alcohol container inside interferometer base.
	Pull out both beam blockers and align test and reference beams using mirror mount screws on fiber optic mounting plate.
	Make sure reference beam is centered in fringe viewer.

	Place superspring alignment fixture on top superspring window.
	Verify beam alignment through superspring and adjust, if necessary.
	Adjust mirror # 2 to align test and reference beams in telescope.
	Adjust twiddler to align test and reference beams in fringe viewer.
	Remove dropping chamber and tripod from interferometer base.
	Block test beam and remove top plate of interferometer base.
	Adjust APD X-Y stage to maximize voltage at “analog” BNC connector on interferometer base (largest negative voltage).
	Replace top lid of interferometer base and tighten all screws.

Table 9-14 Interferometer Alignment

9.6. Superspring Maintenance

9.6.1.Removing Superspring Cover

Removing Superspring Cover Checklist	
	Remove Superspring cover (including top flange) from service ring. Do not remove top flange !
	Lift cover straight up over Superspring mechanism.

Table 9-15 Removing Superspring Cover

9.6.2.Replacing Superspring Cover

Replacing Superspring Cover Checklist	
	Check O-ring seat and lubricate O-ring, if necessary.
	Gently lower Superspring cover (including top flange) over mechanism.
	Tighten screws holding Superspring cover to service ring.

Table 9-16 Replacing Superspring Cover

9.6.3.Removing Superspring Service Ring

Removing Superspring Service Ring Checklist	
	Unplug in-line connector (on electrical feedthrough) closest to bulkhead.
	Remove electrical feedthrough from service ring (note color coding on connector).
	Remove travel lock knob.
	Remove travel lock assembly from service ring.
	Remove service ring and bottom flange as a unit.

Table 9-17 Removing Superspring Service Ring

9.6.4.Replacing Superspring Coil

Replacing Superspring Coil Checklist	
	Remove service ring.
	Remove base plate.
	Lift rod assembly off bottom plate.
	Remove travel lock fork from main rod.
	Unhook support springs from O-rings.
	Remove lower triangular spring plate (do not damage O-rings).

	Remove emitter-detector block (note orientation).
	Remove permanent magnet assembly from base plate.
	Remove coil from emitter-detector block.
	Reverse procedure for reassembly.

Table 9-18 Replacing Superspring Coil

9.6.5.Replacing Superspring Flexures

Replacing Superspring Flexures Checklist	
	Remove Superspring cover.
	Put dust cover over top main tube.
	Remove service ring.
	Place hard foam or rubber shim between top rod ring and top triangular plate.
	Fasten plates together with cable tie.
	Loosen clamps holding rods to bottom plate.
	Disconnect wires from pre amp circuit board.
	Lift rod assembly off bottom plate.

	Remove travel lock fork from main rod.
	Unhook support springs from O-rings.
	Remove lower triangular spring plate (do not damage O-rings).
	Remove emitter-detector block (including test mass, spring, and flexure). Note orientation of emitter-detector block.
	Wear plastic gloves when handling test mass.
	Remove spring from test mass (count number of spring turns holding upper anchor to main spring).
	Put lower lock nut on new flexure assembly.
	Remove broken flexure-anchor.
	Screw new flexure-anchor into spring (to original position).
	Thread pulling tool through one nut, top lever, and down center tube.
	Thread tool into top of flexure (coarse adjustment screw of main spring assembly).
	Pull tool up until spring hangs.
	Thread test mass onto lower main spring anchor.

	Tighten lower anchor.
	Pull tool to lift test mass and guide coarse adjustment tool through top lever.
	Screw on top nut (to center of coarse adjustment tool).
	Remove pulling tool.
	Align beam holes in top lever and test mass.

Table 9-19 Replacing Superspring Flexures

9.6.6.Assembling Superspring

Assembling Superspring Checklist	
	Replace emitter-detector block in original orientation (below lever pivots).
	Replace lower triangular spring plate.
	Attach support springs.
	Install travel lock fork assembly on shaft.
	Replace spring assembly into lower plate (don't damage coil).
	Make sure rods are seated flush with bottom of lower plate.
	Tighten barrel clamps.

	Check movement of center tube (so it doesn't rub).
	Remove cable tie and foam or rubber shim.
	Recheck center tube for free movement.
	Make sure test mass is centered in cage and wires do not rub.
	Replace spring assembly in service ring (don't tighten screws).
	Replace travel lock assembly.
	Rotate main spring assembly to equalize travel lock fork clearance.
	Tighten screws holding spring assembly to service ring.
	Install electrical feedthrough.
	Connect all wires (match color coding).
	Place Superspring on leveling table.
	Adjust table to center test mass in cage.
	Make sure top of test mass is about 1.5 mm below cage assembly.
	Connect Superspring controller to Superspring.
	Drive zero-positioning motor (ZPM) until sphere voltage is zero.

	Measure gap between two levers near ZPM.

	Adjust coarse adjustment screw so motor will be in center of travel position (6 ± 0.5 mm gap between lever arms).
	Make sure sphere voltage goes +/- to assure true center position.
	Carefully align beam holes in top lever with holes in test mass.
	Recheck centering of test mass in cage and adjust bubble levels.

Table 9-20 Assembling Superspring

9.6.7.Replacing Superspring Focus Lever Motor

Replacing Superspring Focus Lever Motor Checklist	
	Remove nut on focus adjustment screw.
	Lower focus lever motor assembly off fulcrum lever.
	Loosen set screw holding hex bushing to motor shaft.
	Raise bushing out of the way.
	Remove screws holding motor to motor mount.
	Reverse procedure to reinstall motor.

Table 9-21 Replacing Superspring Focus Lever Motor

9.6.8. Adjusting Superspring Micro-Switches

Adjusting Superspring Micro-Switches Checklist	
	Adjust trip positions by changing position of set screws in actuator arms.
	Adjust so limit switches shut off ZPM when gap between focus lever and fulcrum plate is 4-8 mm.

Table 9-22 Adjusting Superspring Micro-Switches

9.7. Packing the FG5

Packing the FG5 Checklist	
	Unplug cables from electronics rack and components.
	If leaving the chamber under ion pump control, leave ion pump cables attached from power supply to dropping chamber.
	Put remaining cables in zippered pouch (inside of rear electronics case lid).
	Secure lids to electronics case.
	Unplug power cords and printer cable from computer.

	Rotation Monitor (if applicable). Otherwise, skip to dropping chamber.
	Unplug all cables and store in rotation monitor case.
	Secure lids to electronics case.
	Remove rotation monitor from dropper and place in its case. Close case and secure all latches.
	Replace two M6X35 screws in top dropper flange. Replace viewing port cover.
	Dropping Chamber
	Engage cart travel lock.
	Remove dropping chamber from tripod and place in dropping chamber case. Place ion pump controller and cables in dropping chamber case too.
	Lift tripod from interferometer base. Remove legs and store in dropping chamber tripod case.
	Place brass feet in superspring case and blue pads in dropper tripod case.
	Place tripod tray in dropping chamber tripod case.
	Close dropping chamber tripod d secure latches.

	Insert dust plug in top of interferometer base.
	Remove interferometer base and place in its shipping case along with laser. Take care not to stress fiber optic.
	Engage Superspring travel lock.
	Insert dust plug in top of superspring.
	Remove superspring from tripod and place in superspring case.
	Close superspring case and secure all latches.
	Place superspring tripod in its case.
	Close interferometer case and secure latches.
	Make sure all blank flanges and covers are in place on turbo pump and flexible tube. Store flexible tube and power cord in base of turbo pump case.
	Place turbo pump in its shipping case.
	Close turbo pump case and secure all latches.

Table 9-23 Packing the FG5

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