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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.
- The system controller has been updated to a 486-type 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.
- Improvements to the electronics reflect new technology and make the instrument smaller and easier to use.
- A user-friendly full-featured real-time software program takes interferometer data and environmental data. This software provides an immediate value for the local gravity in real-time.
- A user-friendly full-featured post-processing software program that allows complete ability to vary data analysis procedures and to vary environmental corrections.
- This absolute gravimeter is designed to work with a new rugged iodine-stabilized laser system (WEO model 100) traceable to the BIPM.

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.

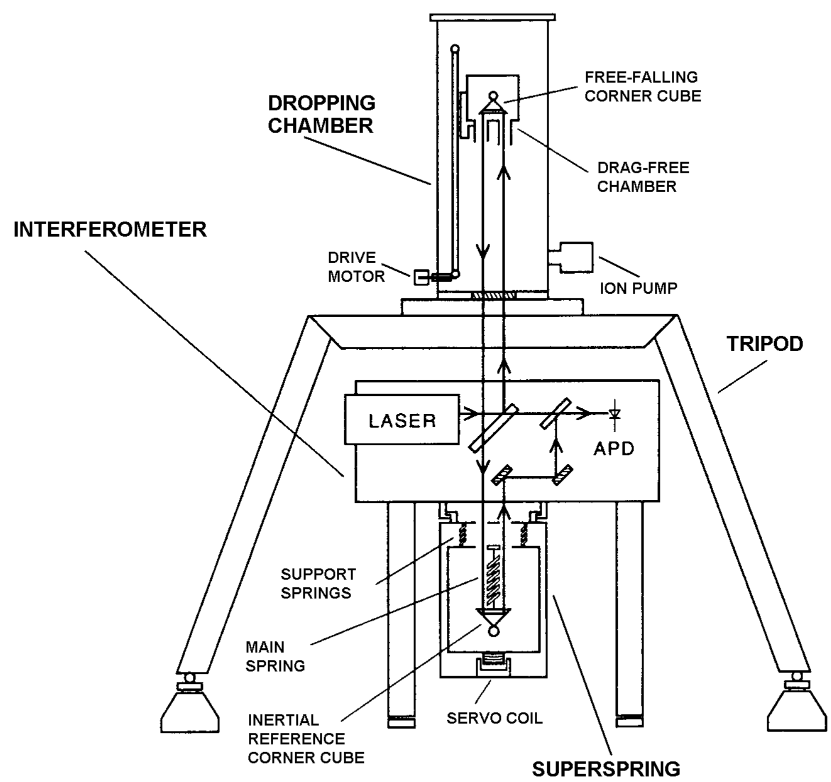

Figure 2-1 **The FG5 System**

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.

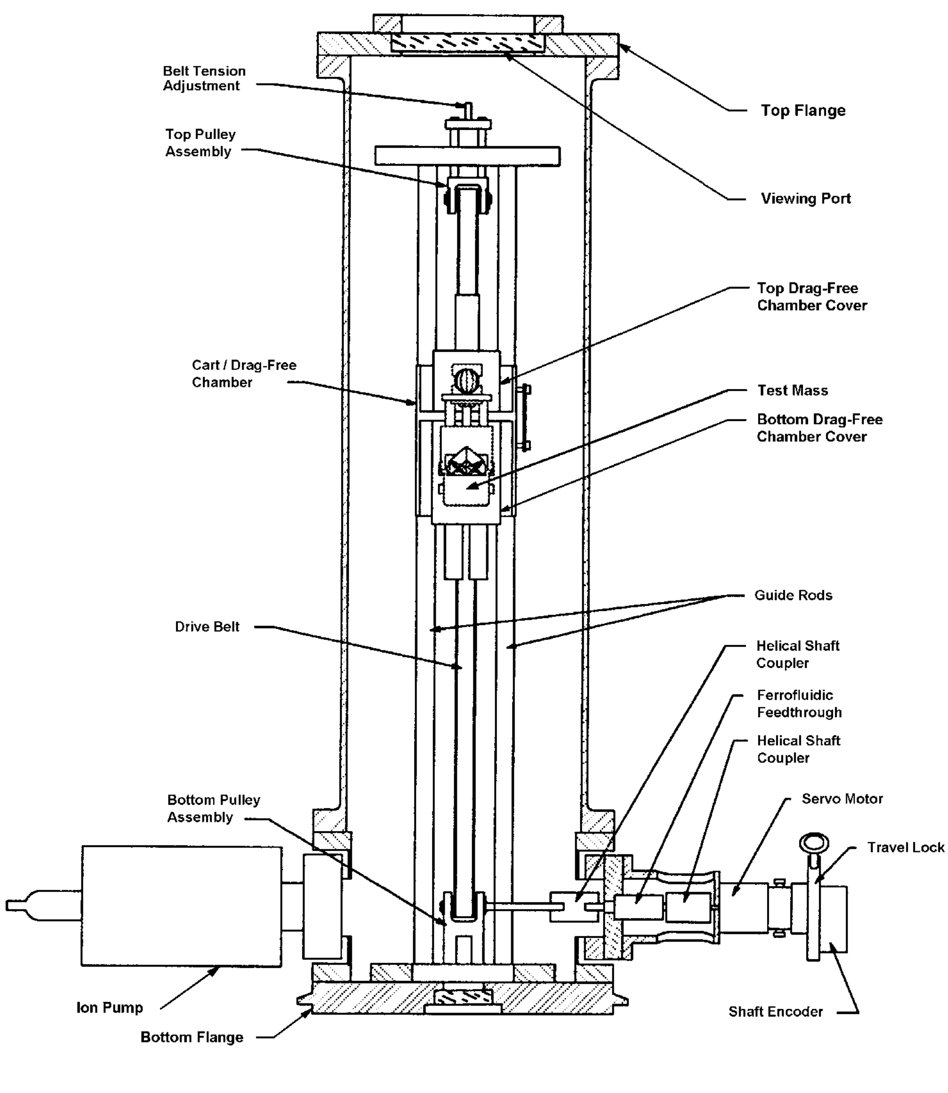

Figure 2-2 **Front view of the dropping chamber**

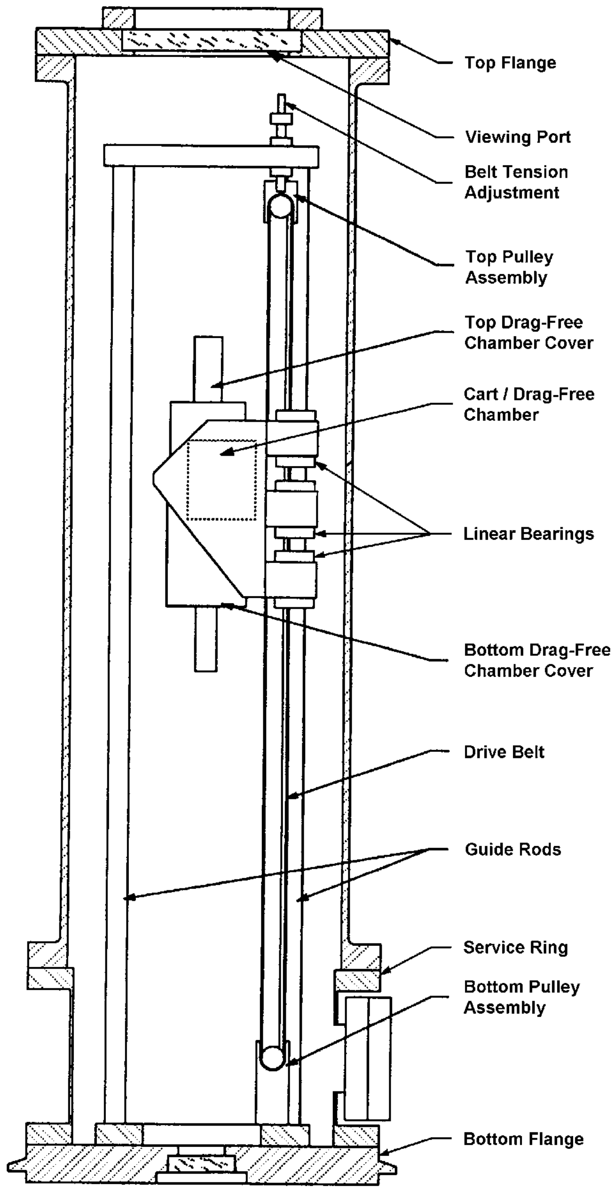

Figure 2-3 **Side view of the dropping chamber**

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.

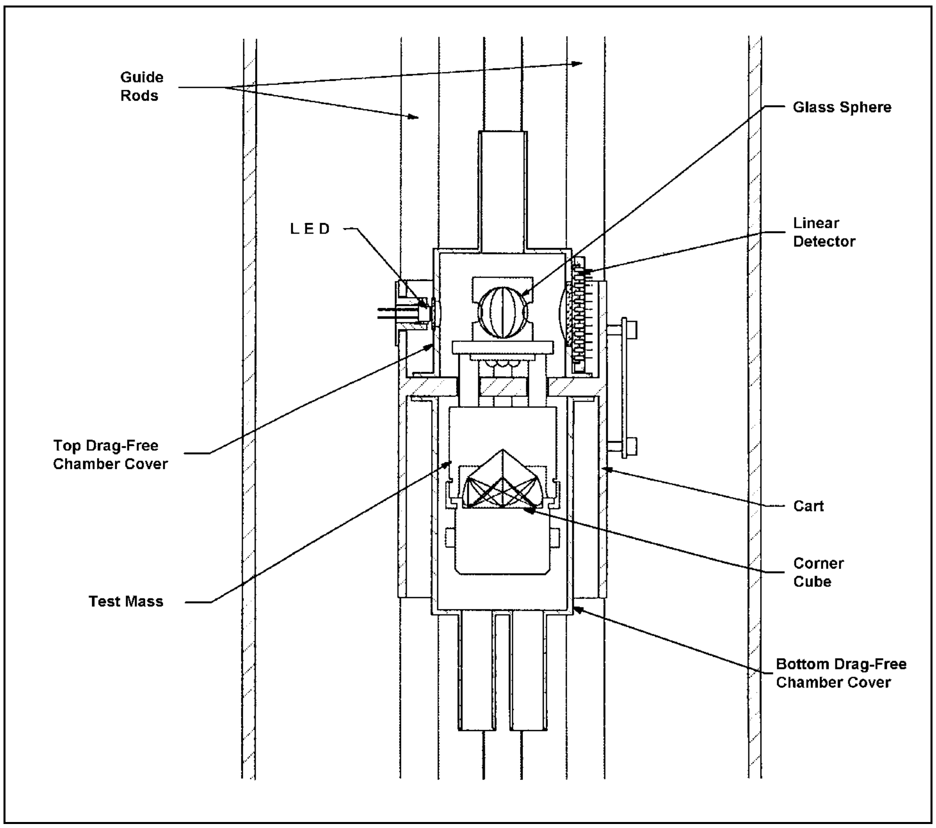

Figure 2-4 **Front view of the cart/drag-free chamber**

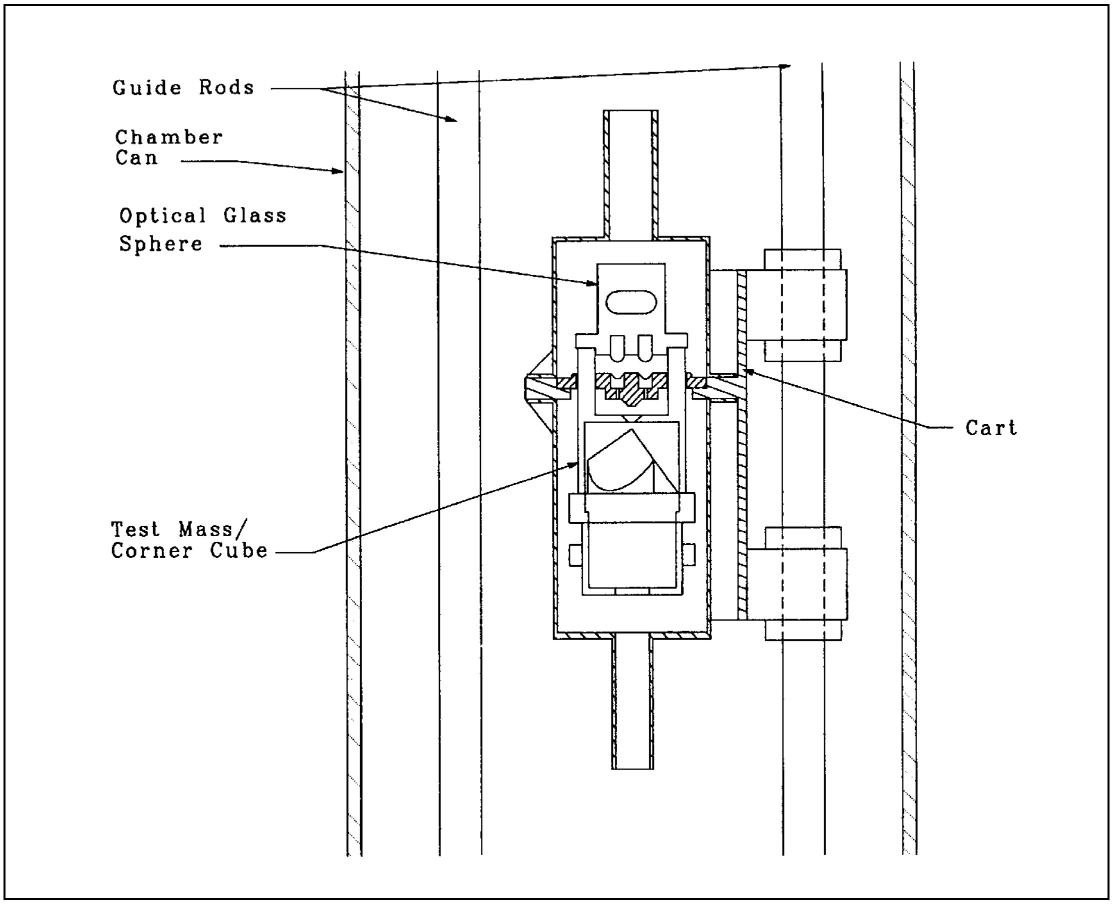

Figure 2-5 Side view of the cart/drag-free chamber

2.1.1.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)

2.1.2.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.

2.1.3.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

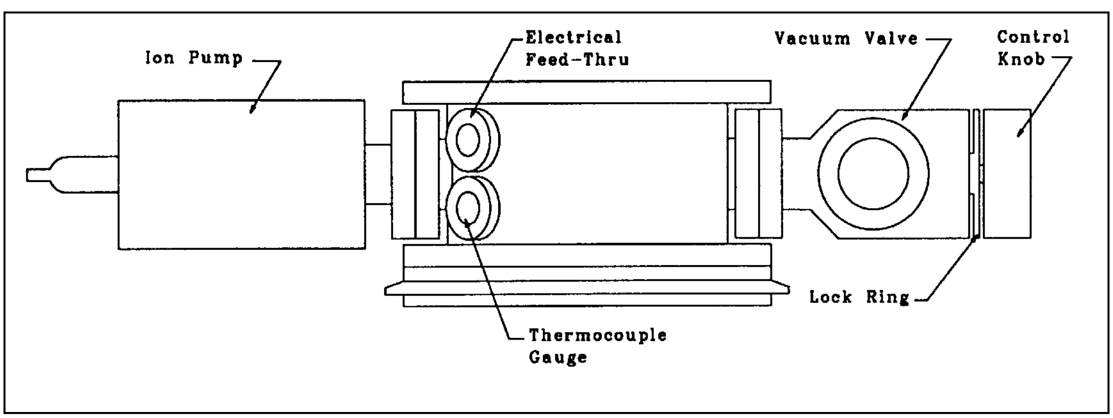

Figure 2-6. **Side view of the service ring.**

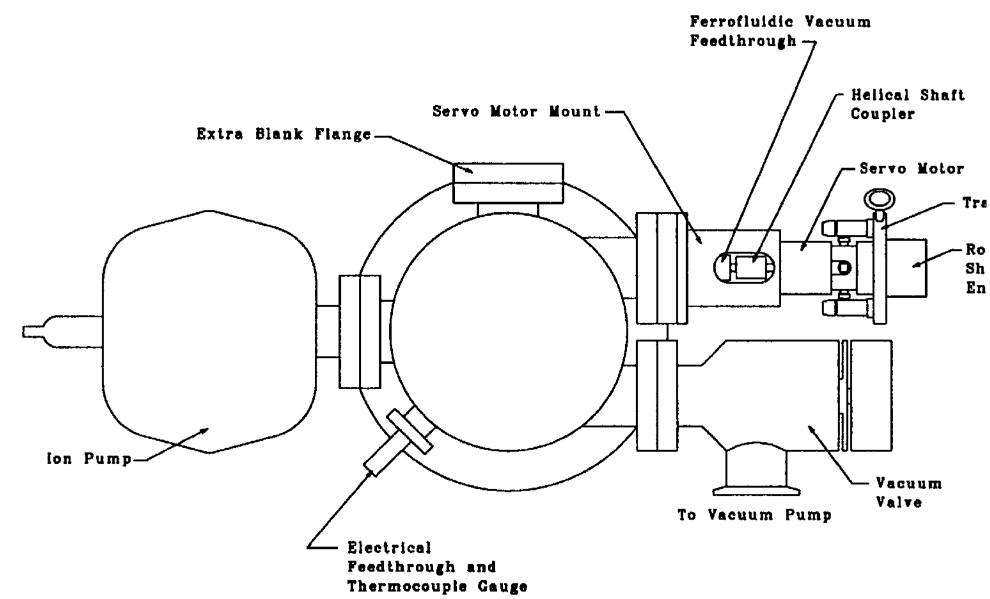

Figure 2-7 **Top view of the service ring.**

2.1.4.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.

2.1.5.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 2-12) 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 (typically 4000) which is set in the scaler-counter. A universal time interval counter (UTIC) 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

The interferometer is a massive, rigid cast aluminum housing which supports a **laser** and **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 AL-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

The laser beam (Figure 2-8 and Figure 2-9) is directed by **mirror #1** through the **isolator plate** to **mirror #2.** From there it passes through the **focusing optics** (microscope objective), and the **collimating lens**, where the beam is expanded. It is then directed to **beamsplitter #1** by **mirror #3** and **mirror #4**, 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)**. 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 beamsplitter #1 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 hits mirror #5, passes through the translator plate, hits mirror #6, and is recombined with the reference beam at beamsplitter #2.

This interferometer is a Mach-Zender interferometer with a fixed 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 reflected by mirror #7, and is focused by a lens. The focused beam strikes the detector (APD), and the interference fringes are converted to continuous wave (CW) signals and transmitted to the scaler counter.

The other recombined beam travels horizontally until it reaches the attenuator (or rattler) plate. 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 is deflected vertically by a mirror into the fringe viewer. The second and third beams exit the interferometer where a flag in front of mirror mount #7 blocks the second beam, allowing the third (dimmest) beam to enter 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.

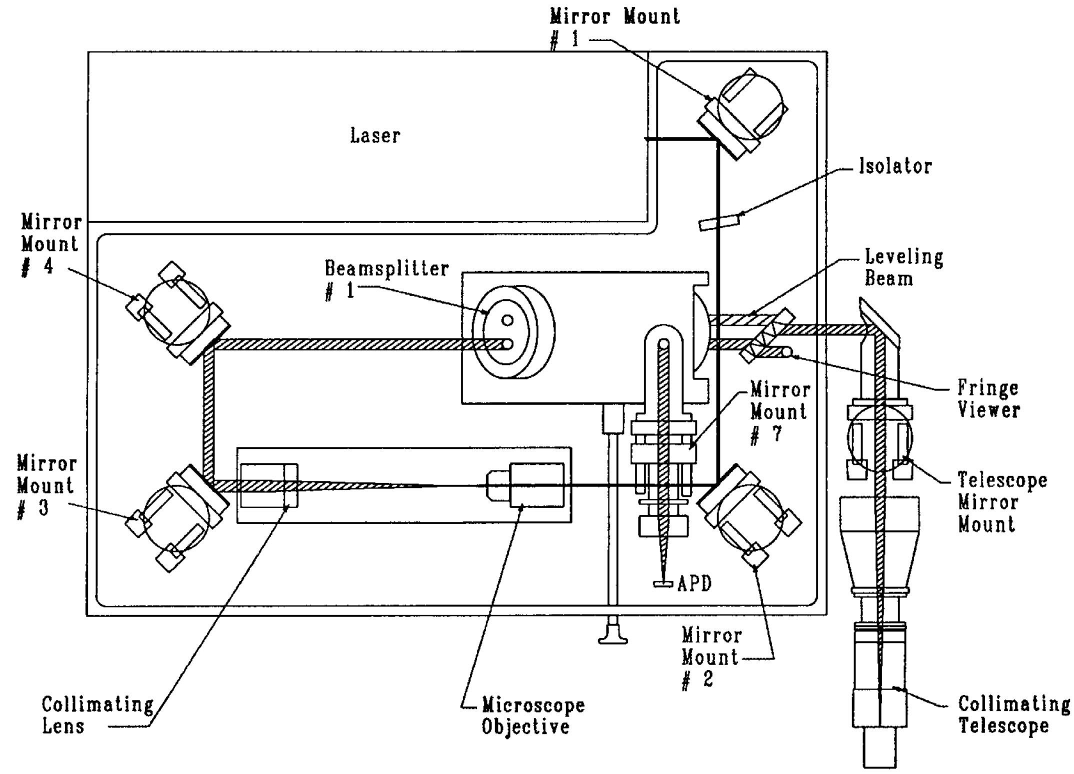

Figure 2-8 **Top view of interferometer optics and beam path**

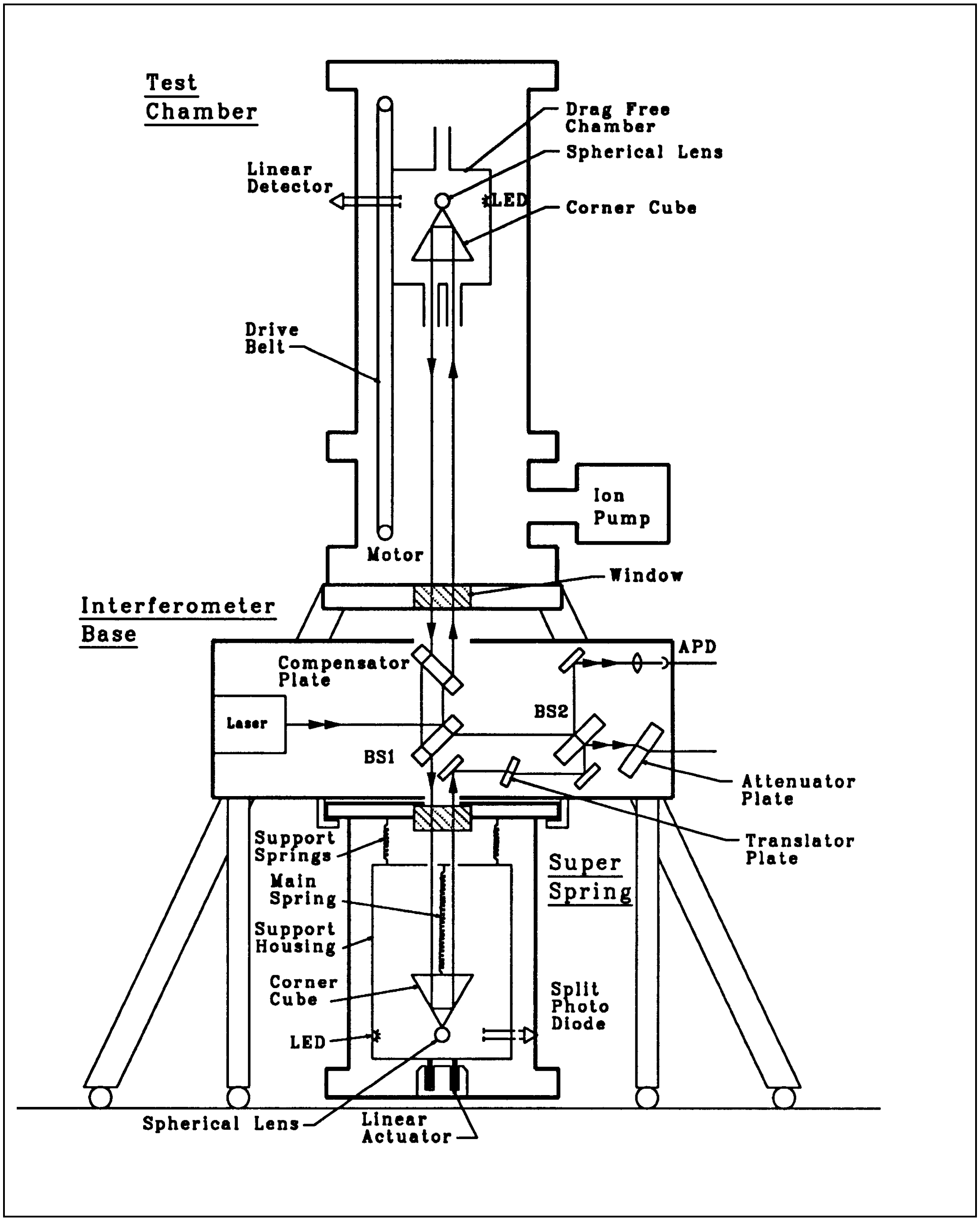

Figure 2-9 Side view of interferometer optics and beam path

2.3. The Superspring

The Superspring (Figure 2-10) 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 2-11) 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.

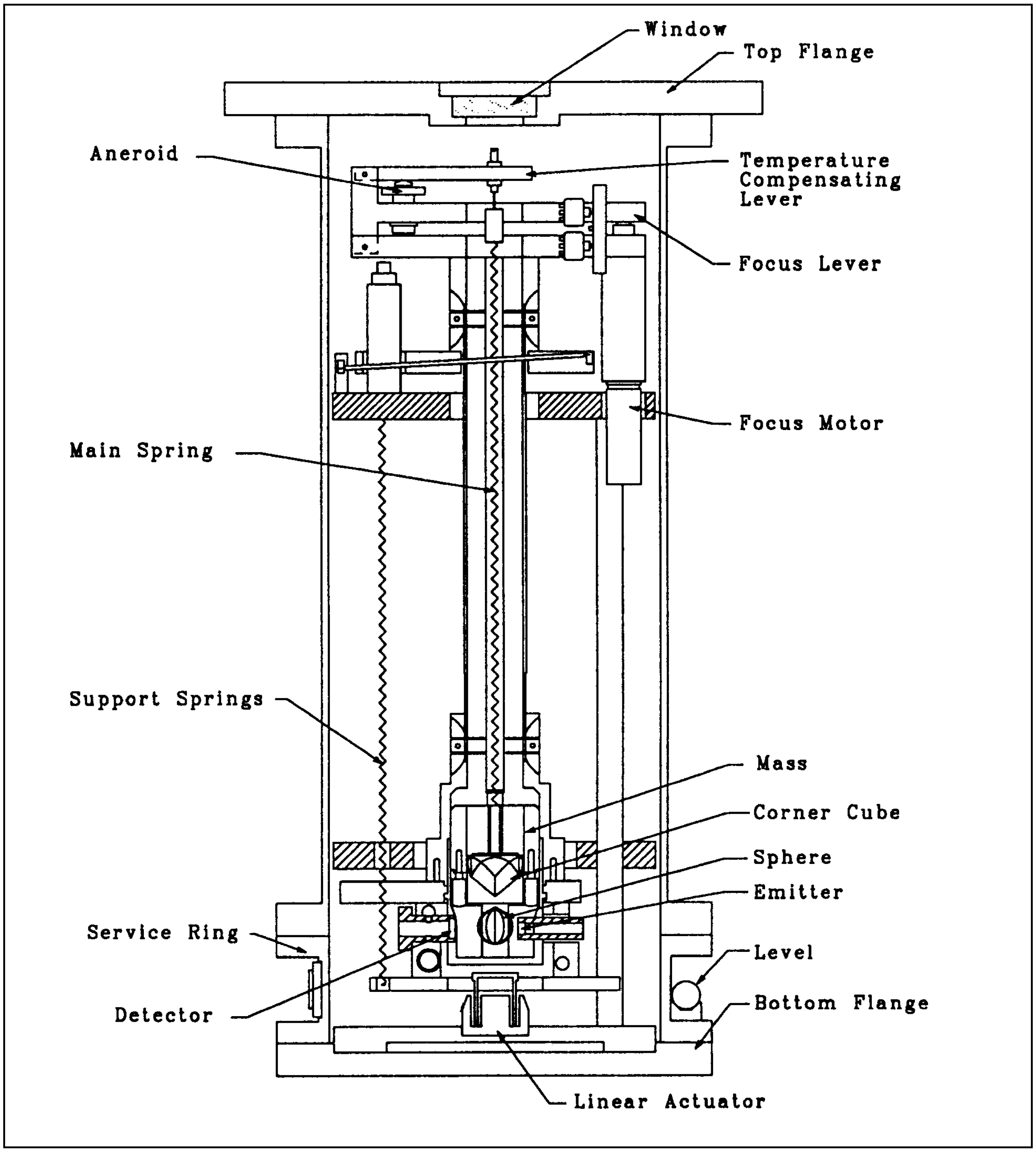

Figure 2-10 **The Superspring.**

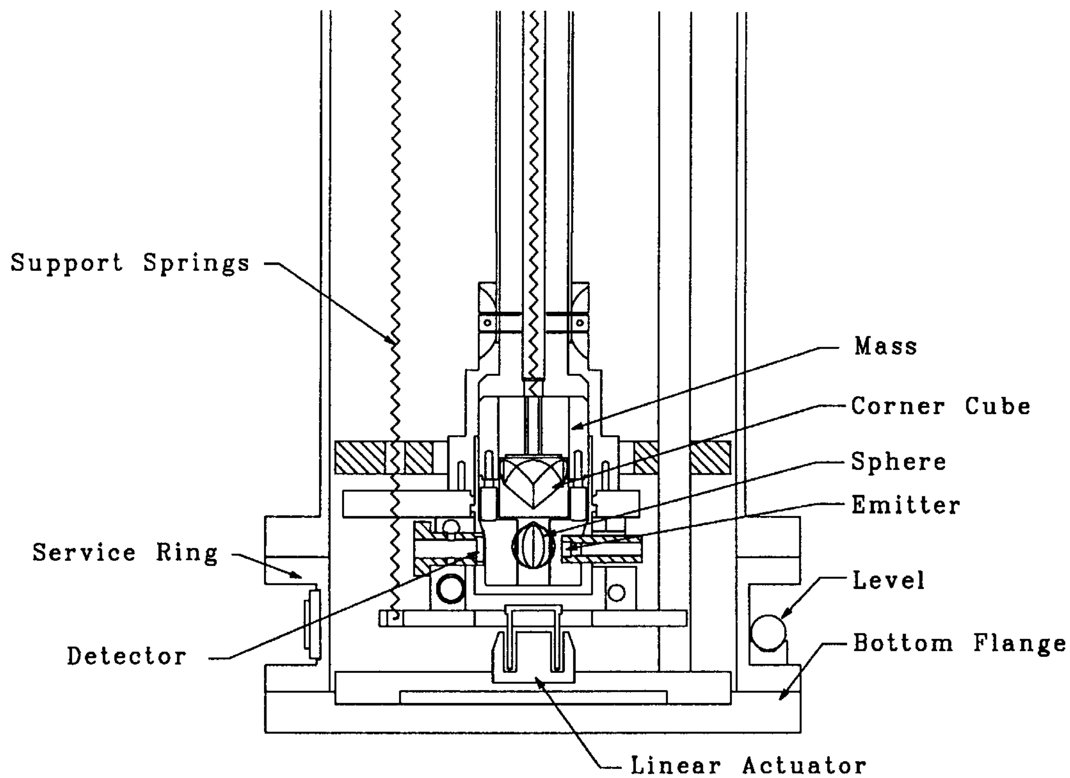

Figure 2-11 **The Superspring sphere detection system**

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 2-10).

2.4. The System Controller

The system controller is an IBM-compatible notebook PC with docking station 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 386 or better PC with a VGA display and math coprocessor

- Memory: 640 Kb RAM
- Hard Drive: 100 Mb or larger recommended for high density data storage
- IEEE 488 interface board
- Keithley/Metrabyte PIO-12 parallel digital interface board (set to address 380 hex)

2.4.2.OPTIONAL HARDWARE

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

2.4.3.SOFTWARE

The FG5 software consists of a bundled set of DOS-based applications. 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 program (OLIVIA) and the post-processing program (REPLAY).

The post-processing program (REPLAY) , allows complete reconfiguration of the data processing for data that has already been acquired and stored by OLIVIA. Both real-time and post-processing programs can be configured to select the raw data used for analysis as well as vary the parameters that affect gravity corrections.

The diagnostic routines are designed to help the user trouble-shoot I/O problems in the field.

The software is written in a combination of Microsoft FORTRAN 5.0 and Microsoft Assembly Language MASM 6.0. It is controlled by ASCII input data files that can be configured by the user for complete flexibility. The executable programs are compiled as DOS-based applications.

OLIVIA is a real-time data acquisition program that must have complete control over the system processor and is not compatible with multi-user or multi-tasking operating systems such as Windows® or OS2®. OLIVIA is also incompatible with most background TSR's and disk caching programs. These restrictions do not apply to the post-processing program (REPLAY), since it is not a real-time application. See the FG5 Software Manual for additional information.

2.5. Electronics

2.5.1. TIMING SYSTEM

The timing system (Figure 2-12) consists of four main components:

- Avalanche Photo Diode (APD)
- Rubidium Oscillator
- Universal Time Interval Counter (UTIC)
- Scaler Counter

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 Universal Time Interval Counter (UTIC) measures the time interval between the occurrence of each scaled fringe and the next scaled clock pulse. Using this information, the system controller computes the absolute time of occurrence of the scaled fringes.

The Scaler Counter uses a zero-crossing discriminator to transform the sinusoidal signals from the rubidium oscillator to square wave (TTL) pulses. It keeps track of the number of fringes that have passed by counting the TTL signals from the APD. It also scales (divides) the fringes and the 10 MHz TTL clock pulses by user-defined scale factors. Nominal scale factors are 4000 for fringes and 2000 for clock pulses. Both scale factors are "hard set" by switches on the scaler counter circuit board.

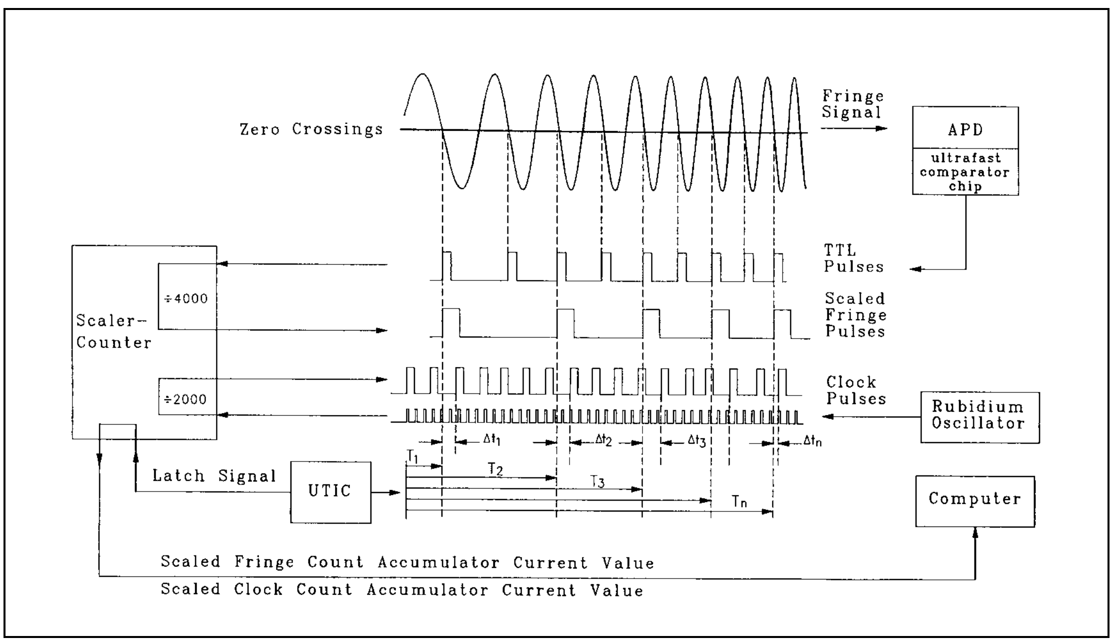

Figure 2-12 **Timing diagram**

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 acts to effectively weaken 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 AL-1 frequency/intensity stabilized laser. See Chapter 3 for setup and operation.

2.5.5.POWER SUPPLIES

The electronics case contains all the power supplies which are required to operate the FG5. They consist of two primary units:

The Micro-g Solutions Model 125 Portable Ion Pump Power Supply is located in the front of the electronics case. It supplies power to the ion pump for both AC and DC operation. See the Model 125 manual for operating instructions.

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.

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:

- **A/D Converter:** A 16-bit, 100 kHz IEEE488 A/D converter is mounted on the front of the electronics case. It is used to convert all analog signals which are monitored and logged by the system controller.
- **BNC Signal Connection Box:** A signal connection box is mounted at the rear of the electronics case. It provides the proper termination and connections for BNC cables which are used for the Environmental Sensors Package.
- **Temperature Sensor:** A thermocouple is used to sense temperature. It is normally mounted on the tripod tray, and connected to a temperature probe which is attached to the dropping chamber cover.
- **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.

2.5.6.2.ROTATION MONITOR

The rotation monitor (Figure 2-13) 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.

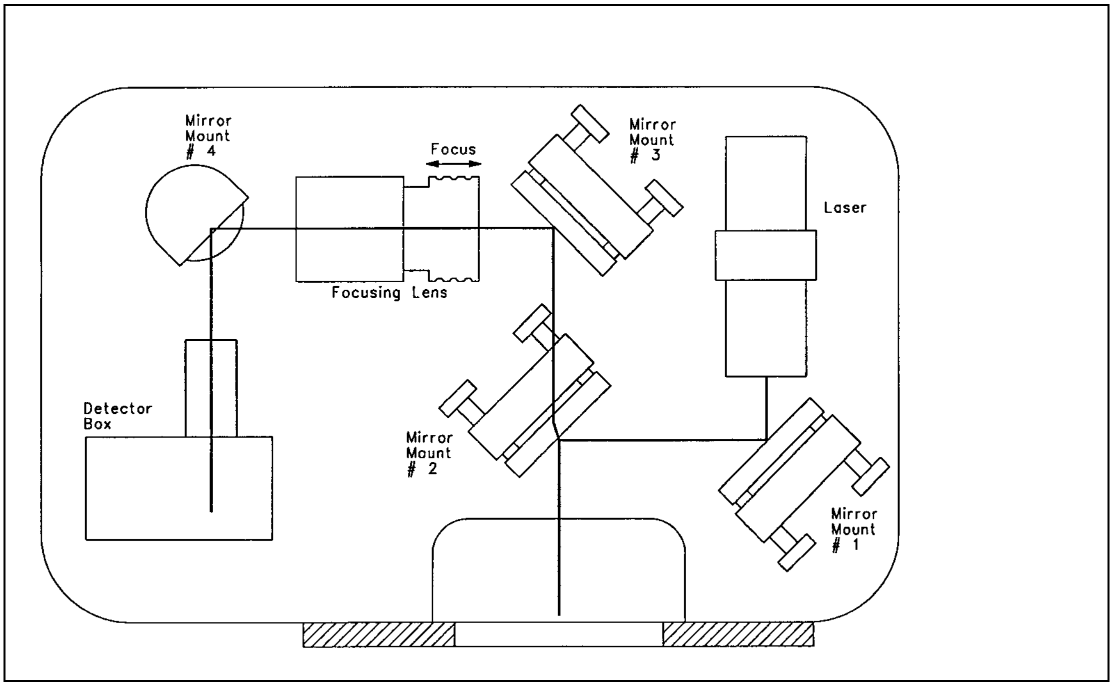

Figure 2-13 **Rotation Monitor**

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, page 9-4.

3.1.1.INTERFEROMETER

1. 1. Locate and mark a reference point on the floor where gravity will be measured.
2. Lift the interferometer out of its shipping case by the handles on the sides of the base. **!** DO NOT USE THE LASER AS A HANDLE TO LIFT THE INTERFEROMETER.
3. Lay the interferometer end with the telescope mount on the foam case insert, and attach the three legs. It is best to use two people so one can steady the interferometer while the other is attaching the legs. Carefully raise the interferometer to its upright position and place on the floor. Tighten each leg by sliding the steel rod through the hole in the leg and turning until the legs are snug. There is no need to over-tighten the legs since they experience no shock during the drop.
4. Remove the two dust caps from the top and telescope mount end of the interferometer.
5. Position the interferometer over the reference mark by sighting down through the beam splitter to the mark on the floor. Orient the interferometer with the laser tube in a north-south direction, if possible, to minimize Coriolis errors. Rotate the brass V-blocks at the bottom of the interferometer legs so the V's in the leveling feet all point to the reference mark on the floor. ! 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!

3.1.2.ELECTRONICS CASE

6. Place the electronics case in a convenient location within two meters of the interferometer. It is helpful (if the site permits) to place the rack adjacent to the connector end of the laser head with the front side of the rack facing in the same direction as the beam blocker controls on the interferometer. Place the computer/system controller on top of the electronics case.
7. Remove the front and rear covers of the electronics case. Remove the cables from the pouch on the inside of the rear cover.
8. 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 how to change the voltage selection..
9. Make sure the following switches are **off**:
   - Main AC power (rear)
   - Main DC power (rear)
   - Laser power (main AC power and key switch)
   - Universal Time Interval Counter
   - Superspring coil
   - Portable ion pump power supply (AC, BAT, and HV)
10. Connect the main AC power cable from the mains power input (rear of electronics case) to the AC power receptacle.
11. Remove the laser control cable (#7) and laser HV cable (#6) from the electronics case and connect them to the laser head.
12. Turn on the main AC and DC power switches on (rear of electronics case).
13. Turn on power to the laser. Consult the instructions below for the proper laser.

3.1.2.1. Model AL-1 Laser:

3.1.2.1.1. Warm Up

- Set the LOOP switch to the OPEN position.
- Turn the switch on the laser controller to MANUAL.
- DO NOT ADJUST THE COARSE GAIN KNOB.
- Turn on the main power switch and the key switch for the laser tube HV. Both lights on the laser controller panel should come on.
- Set the heater current to 0.3 using the front panel monitor to view current..
- Allow the laser to warm up for at least half an hour before locking.

3.1.2.1.2. Operation

- After the laser is warm, the LOOP switch should be closed.
- The control switch should be set to REMOTE so that the computer can control the red/blue side-lock choice.

3.1.2.2. WEO Model 100 Laser

- Turn on the power (main power and HV key switches).
- Select the proper iodine peak.
- 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	OFF

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.

3.1.3. DROPPING CHAMBER TRIPOD

14. Remove the tripod tray from the Superspring case and place it carefully upside down on the floor.
15. Remove the three tripod legs from the dropping chamber case and attach them to the tray.
16. Turn the tripod upright and tighten the legs by turning the large 3-lobe knobs clockwise.

At this point the interferometer will be used to support the dropping chamber tripod.

! MAKE SURE THE HANDLES ON THE INTERFEROMETER ARE IN THE UP POSITION AND THE TOP DUST CAP HAS BEEN REMOVED.

17. Slide each of the three horizontal alignment pins on the top of the interferometer radially outward by pulling the 5-lobe knobs until they stop. Carefully position the tripod on top of the interferometer using the single locating pin and the three horizontal alignment pins on the top of the interferometer as a guide. The three brass V-posts in the bottom of the tripod tray should fit over the pins on the interferometer. The handles on the interferometer should be up and not touching the legs on the tripod.
18. Open the three dropping chamber clamps on the tripod tray by turning the three 5-lobe knobs fully counterclockwise. The clamps must be outside the mounting pocket so the dropping chamber can be placed on the tripod.
19. 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 on the side of the interferometer which is opposite the laser head, directly above the beam blocker controls on the interferometer.
20. 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. Make sure the laser beam coming out of the dropper hits the floor on the reference mark.
21. 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 rest in the lock. Gently release the wrench or ball driver from the motor shaft

3.1.4.ION PUMP

22. Recheck the AC,BAT, and HV switches on the ion pump power supply, and make sure they are off.
23. 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. Tie both cables to a tripod leg with a velcro strap.
24. 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.
25. 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

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

3.1.5.ROUGH LEVELING INTERFEROMETER

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

27. Adjust the interferometer base legs until the bubble levels mounted on the tripod base are centered. For this step, and following steps concerning leveling, be sure to center the cross level first, then the long level. The cross level is the one which is perpendicular to the laser head axis and the long level is parallel to the laser head axis. 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.

28. Remove the blue pads and brass tripod feet from the Superspring case. Make sure the pads are clean.

29. Place a tripod foot under each leg of the tripod. Raise each foot and slide a blue pad under the foot.

30. 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 feet and the tripod leg because it will cause the dropping chamber to shift sideways when it is lifted. It is helpful to rotate the foot slightly (while it is in contact with the nylon ball) to release any horizontal tension.

3.1.6.DROPPER VERTICALITY

31. After each foot is in contact with the tripod leg, rotate each tripod foot leveling screw **exactly one revolution** (counterclockwise), using the mark on the top of the adjustment screw as a reference. This raises the tripod off the interferometer just enough to take the weight of the tripod and dropping chamber off the alignment pins.

32. Level the tripod tray by adjusting the tripod feet (not the interferometer base legs. Be sure to adjust the cross level first, then the long level (see step 27 for explanation). It is best to adjust the levels by *raising* the proper adjustment foot. This will prevent the dropping chamber from contacting the interferometer.

33. Gently slide each alignment pin in until it reaches its stop. If any of the three alignment pins do not slide freely, the tripod is still in contact with the interferometer. **If this happens, slide the alignment pins out, and lower the tripod leveling feet (turning clockwise) until the cones are no longer in contact with the tripod leg balls. Return to step 30 and repeat steps 30-33 to raise the tripod.**

! 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.

3.1.7.BEAM VERTICALITY

34. Make sure the plug in the side of the interferometer base has been removed. Remove the collimating telescope from the Superspring case and take off the lens cap. Slide the telescope onto the dovetail at the end of the interferometer base until it reaches its stop and tighten the three screws on the bottom of the mount.

35. With both beam blockers pushed in, look through the telescope and focus the crosshairs with the telescope by rotating the eyepiece. It may be helpful to place a white card in front of the telescope to see the crosshairs better.

! DO NOT ADJUST THE *INFINITY FOCUS* OF THE COLLIMATING TELESCOPE (adjust only the eyepiece). THE OPERATOR WHO FOCUSES THE CROSSHAIRS SHOULD ALSO PERFORM THE REMAINING ALIGNMENT STEPS (36-39).

36. Pull out the reference beam blocker and adjust the mirror mount in front of the telescope to center the reference beam on the crosshairs.

3.1.8.VERTICAL ADJUSTMENT OF THE TEST BEAM

37. Pull out the test beam blocker to view both the test and reference beams in the telescope.
38. Perform a rough vertical adjustment of the test beam by turning the adjustment screws at the bottom of the interferometer legs until the two points are coincident in the telescope. This is most easily done by first adjusting the interferometer leg nearest the telescope eyepiece (moving the spot diagonally) until the test beam spot is on the vertical crosshair which passes through the reference beam spot, either above or below it. Then adjust the single leg on the side of the interferometer opposite the telescope to move the test beam spot vertically up or down into coincidence with the reference beam spot (centered on the crosshairs).
39. Align the test and reference beams precisely by blocking the reference beam blocker and adjusting the interferometer legs until the test beam is centered in the crosshairs of the telescope. Alternately block the test and reference beams to verify that **both beams** are centered on the crosshairs, then return both beam blockers to their out position.
40. Snap the top bellows ring off of its retainer and lower the bellows ring so it rests on the Superspring mounting plate. This allows access to the underside of the interferometer.

3.1.9.REFERENCE HEIGHT

41. Hang the measuring scale from the Superspring mounting ring under the interferometer base. Loosen the clamp and slide the scale down until it touches the floor, then clamp it in place. Make sure the scale is straight. Read the value at the bottom side of the clamp (Figure 3-1). This value is nominally 495 to 510 mm. Record the value (cm) for later entry in the system check log.

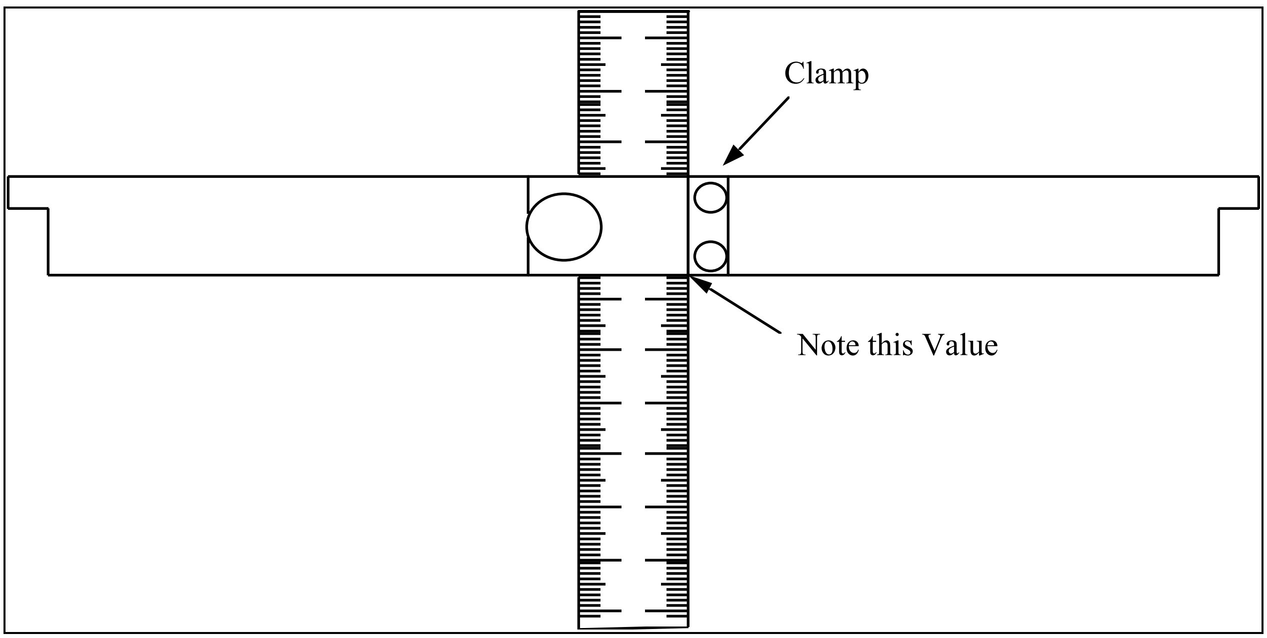

Figure 3-1 Measuring Scale

42. The brass V-posts on the bottom of the tripod are marked with concentric rings 1 mm apart, the red ring being 0 (see Figure 3-2). Estimate the distance the tripod has moved upward (+) or downward (-) and add this to the value read with the scale. If our setup procedure has been followed correctly, the dropping chamber will be 1 ring (1 mm) above the zero position. Record this value (the Superspring reference height added to the vertical distance indicated by the brass V-posts in cm) in the system check log as the reference height. It must be entered in the FG5COMND.DAT file before beginning observations. Consult the FG5 Software Manual for instructions.

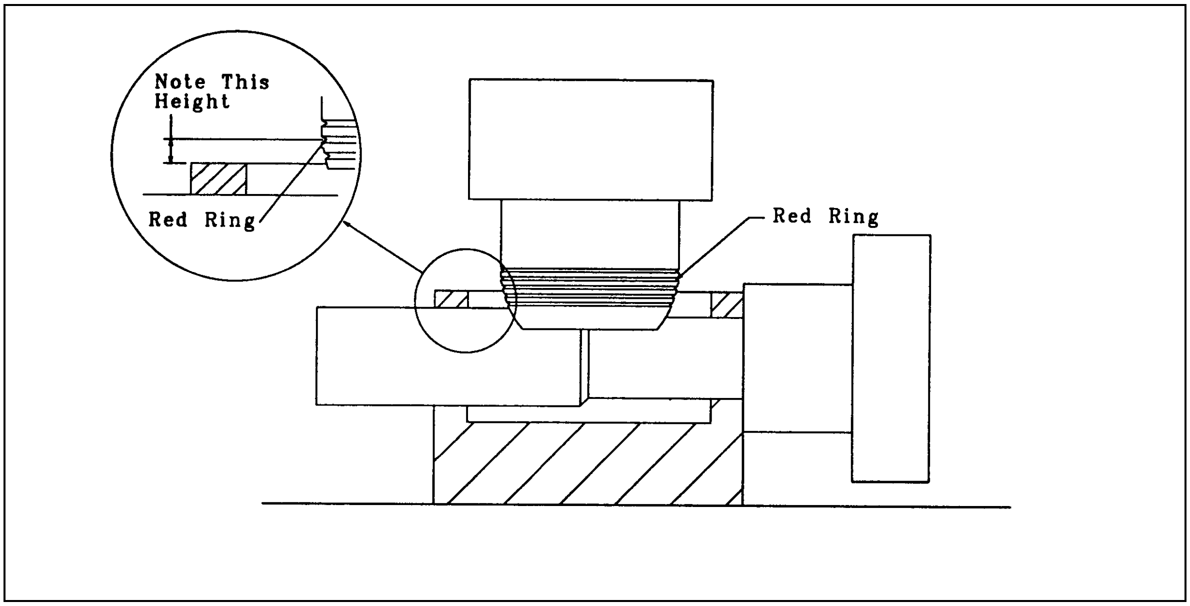

Figure 3-2 V-Post

3.1.10.THE SUPERSPRING

43. Remove the dust cap from the top window of the Superspring. Make sure the Superspring locking mechanism is engaged. Then carefully slide the Superspring under the interferometer base. The top Superspring flange has three “ears”. Note that the ear which is directly above the travel lock is larger than the other two to ensure correct orientation of the Superspring. The Superspring mounting plate has openings for the ears (one larger than the other two) to ensure proper orientation of the Superspring. The large ear is oriented toward the leg of the interferometer which is farther from the telescope. Gently lift the Superspring until the top flange is above the mounting plate. Rotate the Superspring until the ears are directly above the nearest leveling screws, then gently lower the Superspring into place so the v-grooves on the underside of the ears are resting on the leveling screws.

! VERIFY THAT THE THREE V-GROOVES IN THE SUPERSPRING TOP FLANGE ARE CORRECTLY SEATED ON THE ADJUSTMENT SCREWS. CHECK THAT EACH V-GROOVE IS ENGAGED IN EACH LEVELLING SCREW. IT IS VERY EASY FOR ONE LEVELLING SCREW TO RIDE UP ON THE SIDE OF ITS V-GROOVE.

44. Make sure the COIL switch on the Superspring controller is OFF. Connect the Superspring control cable (#15) from the rear (power supply panel) on the electronics rack (yellow washer) to the connector on the base of the Superspring.

! DO NOT ATTACH CABLE 15 WHILE THE WHEN THE COIL SWITCH IS ON.

45. Adjust the three leveling screws to level the Superspring with the two precision level vials on the base. The levels should be nearly centered. If they are not, recheck the v-grooves, and make sure they are properly seated on the adjustment screws.

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

3.1.11.TRAVEL LOCK

46. 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 (190°). Slowly release the lock knob. The arrow on the lock knob points down when it is locked (up when it is unlocked).
47. If necessary, one can use the travel lock knob dampen 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.

3.1.12.CONNECT REMAINING SYSTEM CABLES

48. Attach the rest of the system cables as described below. Both ends of all cables are labeled with the proper location for each connector. When connecting cables to the computer, make sure the power is off.

- MAKE SURE THE DROPPING CHAMBER IS IN STANDBY (HIT RESET BUTTON TO FORCE THE DROPPING CHAMBER CONTROLLER INTO STANDBY). Connect the dropping chamber signal cable (cable #14, **white** Lemo connector) from the rear (power supply panel) of the electronics rack to the electrical feedthrough on the service ring.
- Connect the rotary shaft encoder cable (cable #13, **blue** Lemo connector) from the rear (power supply panel) of the electronics rack to the blue Lemo connector on the motor drive assembly.

- Connect the DC motor power cable (cable #12, **orange** Lemo connector) from the rear (power supply panel) of the electronics rack to the orange Lemo connector on the motor drive assembly.
- Connect the APD power cable to the interferometer base and the power supply.
- Connect the APD fringe cable to the interferometer TTL and the SCALER COUNTER Input Fringes.
- Connect the 37 pin PIO cable to computer
- Connect the IEEE cable to computer
- If the FG5 is equipped with the environmental sensors package, connect the 9 pin barometer cable to computer.
- Connect the temperature cable from the temperature probe to the BNC 16 (1F).

49. Recheck the verticality of the interferometer by placing the alcohol pool on the top of the Superspring. Level the interferometer, if necessary, by adjusting the tripod feet.
50. If adjustments were made in step 51, recheck the alignment pins to assure that there is no contact between the dropping chamber and the interferometer.

3.1.13.SUPERSPRING ZERO-POSITIONING

51. Allow the spring to settle for at least two minutes before setting the zero-position of the mainspring. Use the d.c. 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. It is preferable to set the zero-position between 0 mV and +20 mV since long term drift will normally be downward (negative).

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 d.c. motor that can be varied with a front panel mounted trimpot labeled MOTOR. The middle of the trimpot (marked 5) applies no voltage. Numbers above the middle (5-10) cause the motor to lift the mass (increasing positive voltage on the sphere BNC) and numbers below the middle (0-5) lower 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 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 will move 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 above 5 if the SPHERE voltage is negative or below 5 if the SPHERE voltage is positive.

52. Once the desired zero-position is reached, (SPHERE output between 0-20mV) 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.

3.1.14.FRINGE OPTIMIZING

53. To optimize the fringe signal, the test and reference beams must be made perfectly coincident. 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 #6 of the interferometer.
54. Adjust mirror #6, if necessary, until the beams are coincident in the telescope. Then, move the translator plate (twiddler) until they are

coincident in the viewing periscope. Adjustment of the translator plate does not affect the appearance of the beams in the telescope.

55. If the two beams can be overlapped using the twiddler, skip to step 58. If the translator plate does not have enough range to make both beams coincident, there are two methods of adjustment. The simplest adjustment is made using mirror #6 to translate the test beam horizontally. If a vertical adjustment is needed, the Superspring position must be adjusted by loosening and translating the interface plate between the interferometer base and the Superspring. These adjustments are not normally required, and may indicate a problem.

56. Vertical coarse adjustment of the test beam in the fringe viewer: Move the translator plate (twiddler) to the center of its travel so that the glass is normal to the test beam. Adjust all three screws of mirror mount #6 equally in or out to move the beam left or right in the periscope. View the two spots in the telescope while adjusting the screws. Adjust the screws individually until the beams are coincident in the telescope, then adjust the beam translator until both beams are coincident in the periscope. Note: Only the horizontal axis in the periscope can be made coincident using mirror mount 6. Vertical coincidence must be accomplished with the translator plate or using step 57 for a coarse adjustment.

57. Horizontal coarse adjustment of the test beam in the fringe viewer: If the twiddler is not sufficient to move the test beam vertically to overlap with the reference beam in the fringe viewer the Superspring location relative to the interferometer base must be adjusted. This is accomplished by translating the interface plate which is attached to the interferometer base and supports the Superspring. First, loosen (but do not remove) the bolts that fasten the interface plate to the interferometer. It is usually sufficient to loosen each bolt by ¼ turn. Then suspend and level the Superspring. Unlock the Superspring and translate the interface plate so that the test beam and reference beams overlap in the fringe viewer. Make sure that the twiddler is set so that the glass is normal to the laser beam. After the beams are overlapped, tighten the bolts that fasten the interface plate to the interferometer plate.

58. Connect the ANALOG output on the interferometer (near the beam blockers) to an oscilloscope, with the following settings:

Scale = 50 mV/div

Sweep = 2 μsec/div

AC coupled input

59. Make sure the laser is locked. Set the dropper to OSC mode and press RESET, then 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 #6.
60. Adjust mirror #6 until the peak-to-peak signal is maximized on the oscilloscope. Also adjust the twiddler for maximum signal. Record this amplitude in the system check log.

3.1.15.Dropper Controller

61. OSC mode can be terminated by hitting RESET on the dropping chamber controller. This turns off the motor and lets the cart drop to the bottom. It is preferable to wait until the cart is near the bottom before hitting RESET. Make sure the cart is resting at its bottom position, and the red STANDBY light is on. Set the trigger source switch to EXT, and turn the rotary knob to AUTO. Press RESET, then INIT. The dropper is now waiting for an external signal from the computer to initiate a drop.

3.2. Running the FG5

The FG5 begins observations when the realtime data program, **OLIVIA**, is executed. 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 SETUP

1. Make sure the time and date are correctly set to UT. This is done by entering TIME and DATE at the DOS prompt.
2. Edit the FG5COMND.DAT file and make the following entries:
   - Site name (C01) and site code (C02)
   - Site coordinates (C03 and C04) and elevation (C07)
   - Measured reference height (C05)
   - Nominal air pressure (C08)
   - Gravity gradient (C10)
   - Polar motion X and Y components (C12)
   - Session scenario (C14-C19)
   - Output control codes and filenames (C56-C61)

3. Check the FG5PARAM.DAT file, and make changes, if necessary.
4. If peak detection is enabled (P32), check the 1f signals and correct, if necessary.

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 signal monitor connector on the laser controller and channel 4H of the IO/TECH BNC 16.

3.2.2.PROGRAM SETUP

5. Begin observations by executing the **OLIVIA** program. Refer to the FG5 Software Manual for instructions.

3.3. Shutting Down the FG5

3.3.1.COMPUTER

1. Backup the data.
2. Shut off computer power.

3.3.2.SUPERSPRING

3. Set the switch on the front panel of the Superspring controller to OPEN.
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 AL-1 Laser.

6.

a) Set the switch on the front panel of the laser controller to MANUAL.
b) Turn the fine gain control off (fully counterclockwise).
c) Set LOOP switch to OPEN.
d) Turn the key switch off. The green indicator light should turn off.
e) 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 the UTIC and any other devices that are still on.
11. Turn off the AC and DC power (rear of electronics rack).

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:

Unplug cables from the electronics rack and components.

1. APD power cable
2. TTL fringe BNC cable
3. Laser signal cable
4. Laser HV BNC cable
5. Temperature monitor BNC cable
6. AC Mains power cord
7. AC computer power cord

The following cables may be disconnected from exterior components and remain connected to the electronics case. They are rolled up and stored inside the electronic case during shipment.

8. Ion pump HV supply cable
9. Ion pump supply safety ground cable
10. GPIB cable to computer
11. PIO cable to computer
12. Put the remaining cables in the zippered pouch which is attached to the inside of the rear electronics case lid.

3.4.2.SYSTEM CONTROLLER

13. Unplug power cords and printer cable from the computer and printer and place in the system controller case.
14. Close computer lid and place computer/docking station in the system controller case.
15. Close the system controller case and secure all latches.

3.4.3.ROTATION MONITOR (IF INCLUDED)

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

3.4.4.DROPPING CHAMBER

21. Lock the cart by turning the locking hub counterclockwise using a 4 mm Allen wrench or ball driver until the cart stops moving.
22. Pull and rotate travel lock knob 90°, allowing the pin to drop onto the hub, then rotate the lock clockwise until the pin engages the hub.
23. Open the three dropping chamber clamps by turning the
24. 5-lobe knobs fully counterclockwise so the clamps are outside the bottom flange of the dropping chamber.
25. Lift the chamber off the tripod and set it in its case.

3.4.5.TRIPOD

26. Carefully remove the tripod from the interferometer base. Remove the legs from the tripod. Place the legs in the dropping chamber case and the tripod tray in the Superspring case (large 3-lobe knobs toward the outside of the case).
27. Place the brass tripod feet in the Superspring case and the blue pads in the dropping chamber case.
28. Close dropping chamber case and secure all latches.

3.4.6.SUPERSPRING

29. Pull out the travel lock brass knob until it engages the locking mechanism, and rotate the lock 190° clockwise to lock it in place. The arrow on the lock knob points **down** when it is **locked** and *up* when it is *unlocked.*
30. Remove the Superspring from the interferometer base. Insert the plug in the top of the Superspring and set the Superspring in its case.

3.4.7.INTERFEROMETER

31. Loosen the three locking screws of the telescope rail assembly. Slide the assembly off the interferometer base and place it in the Superspring case. Make sure the lens cap of the telescope is in place.
32. Close Superspring case and secure all latches.
33. Insert plugs into the top and side of the interferometer base.
34. Remove the legs from the interferometer. This is best done by two people. Gently place the interferometer on the telescope end (legs horizontal) on the bottom part of the interferometer case or another padded surface. One person should steady the interferometer while the other person unscrews the legs.
35. Place the legs in bottom of the interferometer case and cover with the foam pad provided.
36. Gently place interferometer base in the case above the legs.
37. Fold the handles down on the interferometer base.
38. Close interferometer case and secure all latches.

3.4.8.TURBO PUMP (IF USED)

39. Make sure the blank flange is in place on the turbo pump intake flange.
40. Make sure all covers are in place on the flexible tube and turbo pump exhaust flange.
41. Unplug the power cord from the turbo pump.
42. Store the power cord and flexible tube in the base of the turbo pump case.
43. Place the turbo pump in the turbo pump case.
44. 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.

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, 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). Tighten the set screw until the belt slips on the pulley at a minimum of 6 inch-lb. 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. If possible, use dry nitrogen to vent the chamber.

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.

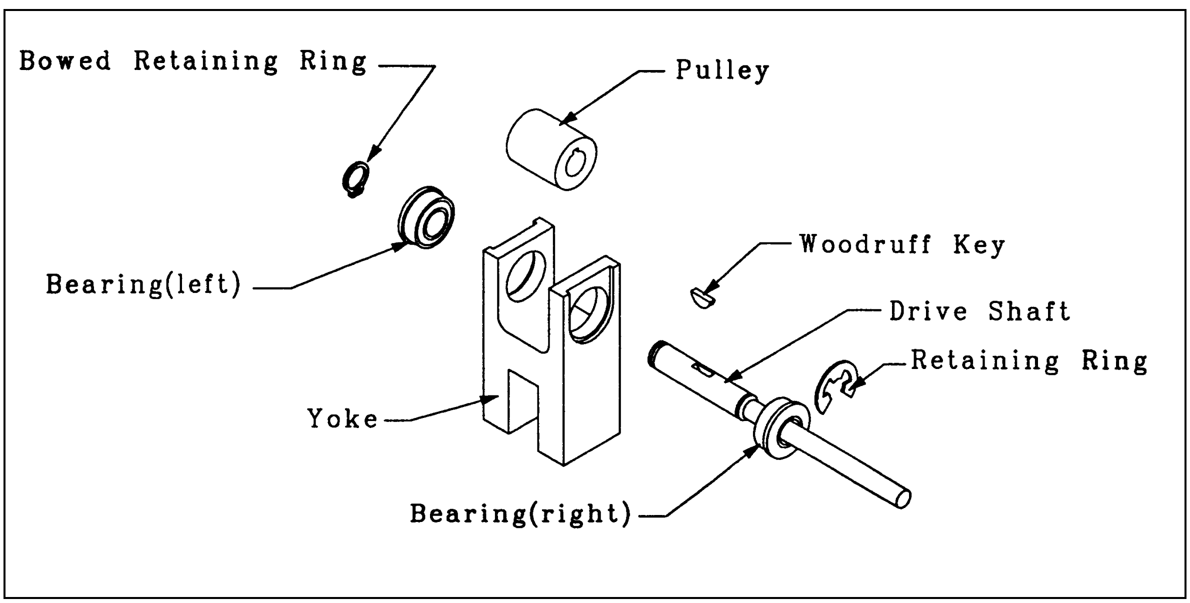

Figure 4-1 **Drive Pulley Assembly**

!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. TROUBLESHOOTING THE BEAM PATH

Periodic adjustments of the beam path can be made with the mirrors. (For a detailed description of the beam path, see Chapter 2). Adjustments of the beam path through the beam expander and the beam splitter assemblies are performed separately.

The beam should pass through the center of the isolator without being clipped by mirror mounts 1 or 2. The beam should pass through the center of both the microscope objective and the collimating lens. After it exits the collimating lens, the beam should be collimated approximately 5-7 mm in diameter. On a card or paper placed in its path, it should make a round uniform spot..

The beam should hit the center of mirrors 3 and 4 without being clipped by the button-head screws. It should then pass through both the dropping chamber and the Superspring and return intact. The recombined beam should be centered in the fringe viewer. It should also be focused and steered onto the center of the APD.

4.2.2. ALIGNMENT

4.2.2.1. Laser

The AL-1 laser mounts to the interferometer base with four 1/4-20 socket head screws. The WEO iodine-stabilized laser mounts using four M6 socket head screws. Tightening or loosening the front lower screw requires use of a short Allen socket wrench.

4.2.2.2. Standard Optical Isolator

The standard optical isolator is attached to the interferometer base by two screws in the bottom. The optical element has a preferred orientation with the linear polarizer first. This can be tested by rotating the optical isolator. You should notice that you can change the light level from very bright to very dim by rotating the isolator. Normally you should rotate this until the feedback into the laser is minimal.

4.2.2.3./2-Faraday Isolator combination

These elements are mounted to the interferometer base by two screws on the bottom (identical to that with the standard isolator). These M4 screws have an M3 socket head. The $\lambda/2$ plate is mounted in front of the Faraday isolator and is used to rotate the linear polarized laser beam to match the polarizer in the Faraday isolator. The $\lambda/2$ plate should be turned until the light going through the Faraday isolator is maximized. The base of this mount has two screws on the bottom with oversized through holes to allow a height and tilt adjustment of the polar angle. There are also 2 screws on the top plate of the mount with oversized through holes to allow adjustment of the azimuthal angle. These are M3 screws which require a M2.5 socket head hex wrench. Note that there is a 1.6 mm horizontal translation of the beam through the Faraday isolator.

4.2.2.4.Optical Isolator Replacement

To replace the standard isolator with the $\lambda/2$-Faraday Isolator, remove the five M5 screws (with M4 hex socket heads) which secure the Superspring interface plate to the underside of the interferometer base. This allows access to the two screws which secure the isolator mounting block to the interferometer base.

4.2.2.5.Adjusting mirrors 1 and 2-The first two mirrors

Remove the focus lens sleeve and collimating lens sleeve from the spatial filter assembly. Insert the alignment pinholes into the two lens mounts in the spatial filter (see Figure 4-2). The sleeves are held in by M4 screws with a M3 socket head. Steer the beam through the two alignment pinholes. This is easiest if you use the first mirror (#1) to adjust the translation of the beam to pass through the first pinhole and then use the second mirror (#2) to adjust the beam angle so that it passes through the second (furthest) pinhole. This procedure may require several iterations to get the alignment perfect.

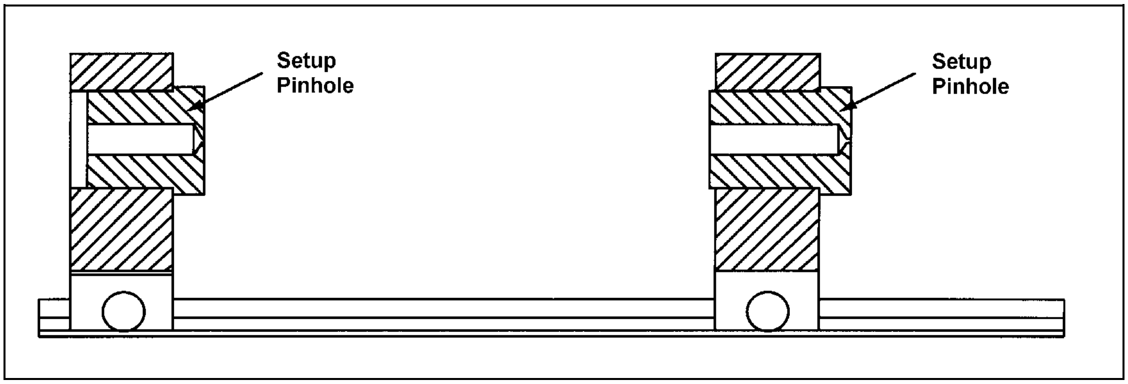

Figure 4-2 **Beam expander with alignment pinholes mounted**

4.2.2.6. Beam Expander

4.2.2.6.1. Focusing lens:

Remove the alignment pinholes and put the focusing lens (25.4 mm focal length) into the first lens holder. The lens should be inserted so that curved surface is towards the input beam (Figure 4-3).

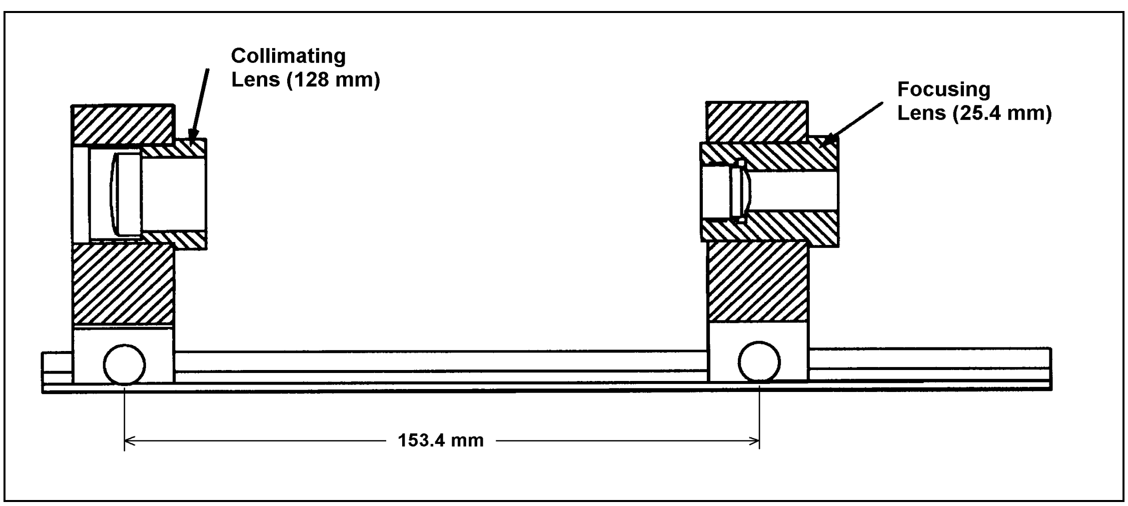

Figure 4-3 **Beam expander**

4.2.2.6.2.Collimating lens:

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

4.2.2.7.Leveling the Tripod Tray

Now that the beam has been steered through the optical isolator and beam expander, it remains to use mirrors #3 and #4 to steer the beam vertically off of beamsplitter #1 through the dropping chamber. This adjustment will be made assuming that the interferometer is referenced to the bubble levels in the tripod tray. First, we must verify or set the tripod bubble levels so that they are aligned with the cart travel inside the dropping chamber.

First re-install the top middle cover on the interferometer base (leave the two end plates removed for access). Pull the alignment pins out and make sure that the interferometer base handles are in the upright position. Put the tripod tray onto the interferometer base without the feet. Place the dropping chamber onto the tripod tray and clamp it down.

4.2.2.8.Making the test beam vertical using the alcohol reference surface

To make the test beam vertical, one must place a dish of alcohol on the floor below the interferometer base (with the Superspring removed). It is good to use a dish with enclosed sidewalls to reduce wind vibrations and enough width (at least 50mm) to avoid a severe meniscus. Looking through the telescope one can see the reference beam and the return beam from the alcohol surface. The beam is traveling vertically when these two beams overlap in the telescope. Level the beam by adjusting the legs of the interferometer base so that the test and reference beam are coincident in the telescope. Note that this procedure does not rely on the dropper being vertical. At this point the bubble levels are not necessarily leveled, but this not a problem since the following procedures will serve to define the correct level of the tripod tray. Now put the feet under the tripod tray and lift all three until they just barely make contact with the nylon balls on the tripod legs. Then lift all three feet one revolution so that the tripod is not making contact with the interferometer base. You may now level the dropping chamber using the bubble levels (if you believe they are correct). If the bubble levels are not believed to be correct, you can ignore them for the moment. In any case, the test beam is vertical and now we must align the dropping chamber so that the cart travel is also vertical.

4.2.2.9. Leveling the Dropper

Make sure that the beam coming back from the dropping chamber is full and is not clipped or smeared on the edges. If the beam doesn't go through the dropper, you may have to adjust mirrors 3 & 4 (see the next section for this procedure) or you can alternatively translate the dropper. Then switch the dropper controller to OSC mode in order to make the dropper move smoothly up and down. Initiate the dropper in OSC mode by hitting RESET then INIT. The goal is to level the tripod so that the laser beam coming back from the dropper cornercube does not translate as the cart travels up and down. The laser spot can be monitored by eye, but is much better if monitored using a quadrant photodiode such as the translation detector supplied with the FG5. Put the translation detector on the floor and attach X and Y outputs to channels 1 and 2 on an oscilloscope. Set the scope on XY, 200 mV/div. Move the translation detector into the laser beam path so that the spot on the scope is near the origin. Throughout this procedure it is important that the spot stay near the origin since there are non-linear effects on the edges of the detector. Note the magnitude of movement of the spot on the scope as the cart raises and lowers. Adjust the tripod feet until the spot movement is minimized, moving the detector on the floor to keep the spot near the origin. Note which direction the beam moves as the cart raises: this is the direction the cart is moving as it is lifted. Raise the leg which is in the same direction as the movement of the cart as it moves upwards. When necessary, increase the sensitivity of the scope and again minimize the spot movement by adjusting the tripod feet. Repeat this procedure until the spot movement is below 50 mV in both axes. Make sure the tripod does not touch the interferometer and that the beam returns from the dropping chamber without being clipped.

Once this procedure is finished, the tripod is adjusted so that the cart is traveling vertically. Without changing anything the bubble levels should now be reset to indicate level.

4.2.2.10. Setting the Bubble Levels on the Tripod

Once the cart travel is vertical, the tripod bubble levels should be adjusted to show level. This step is necessary so the cart travel will be vertical when the bubbles are level. Adjust the levels by loosening the M3 screw with a 2.5M socket inside the outer brass screw and adjusting the brass screw, then locking the assembly using the internal screw (see Figure 4-4). The thread on the outer brass screw is delicate and can be damaged easily by turning the brass part when the internal screw is tight (locked). This procedure will ensure that the rods on which the cart travels are vertical when the bubbles-levels on the tripod are leveled. Having the cart travel vertically helps reduce damage to the test mass during the catch phase of the drop.

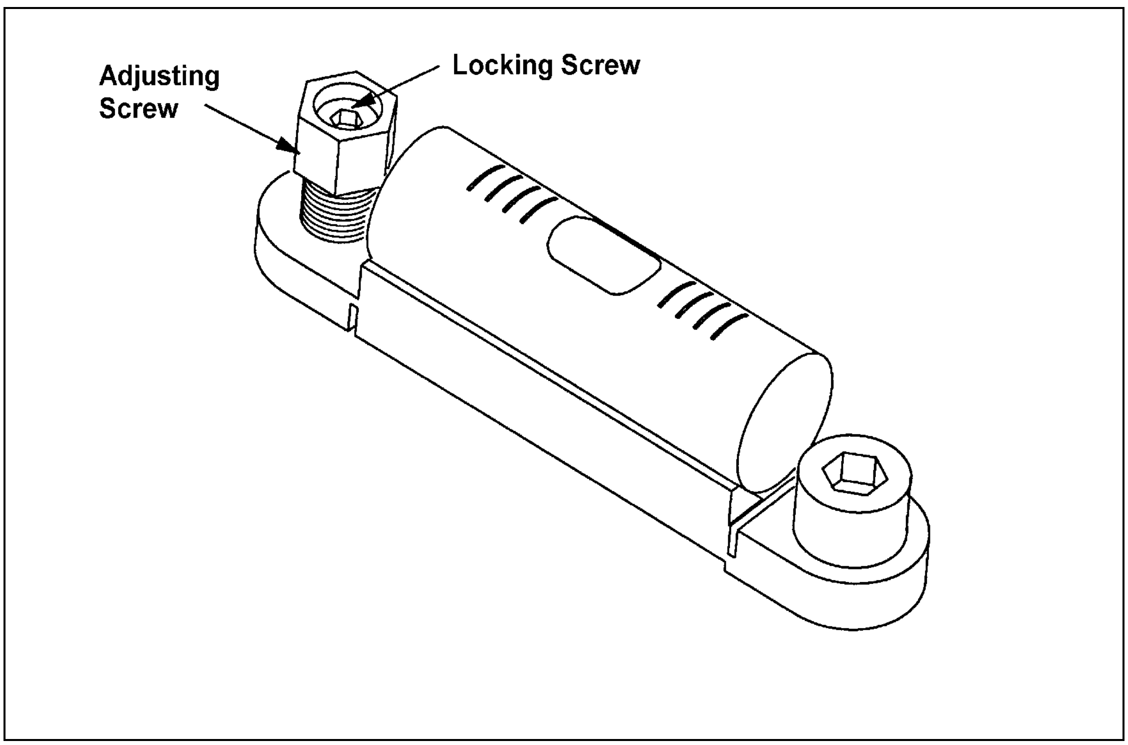

Figure 4-4 Tripod bubble level

4.2.2.11. Adjusting Mirrors 3 & 4 to steer beam through dropper and make beam vertical.

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

4.2.2.12. Adjusting the Superspring position and final adjustment mirror

The Superspring position must be set so that the test-beam returns cleanly after going into and out of the Superspring. In addition, it is important to get the reference and test beams to overlap in the fringe viewer when the translator plate underneath the interferometer base (twiddler) is in the mid-range position. It may be necessary to adjust the position of the Superspring interface plate (top mounting plate) that attaches to the bottom of the interferometer and supports the Superspring chamber. The five M5 screws should be loosened slightly and the Superspring leveled. These M5 screws have a M4 hex socket head. The Superspring should be unlocked mechanically to let free the reference test mass. The translator plate underneath the interferometer base (twiddler) should be put into its mid range position so that the glass surface is normal to the beam. The top mounting plate can be translated so that the beam travels cleanly through the Superspring. Ideally, the test beam should overlap the reference beam in the fringe viewer. Sometimes there is not enough range on the plate to get the beams overlapped totally in the fringe viewer in the horizontal direction but you should be able to get the two beams to have the same vertical position in the fringe viewer. Finally, tighten the screws on the top mounting plate and relevel the Superspring. Recheck the alignment after screws have been tightened.

4.2.2.13. Final Mirror Translation-Getting Beams Overlapped In Fringe Viewer

To move the test beam horizontally to overlap in the fringe viewer with the reference beam it is sometimes necessary to translate the final adjustment mirror underneath the interferometer base. Before doing so look through the telescope and adjust the mirror until the two spots are coincident in the telescope. This will ensure that the angle of the reference and test beams are the same even though they may not yet be coaxial. Then you can turn all three screws on the mirror mount in the same direction to translate the test beam relative to the reference beam. Always watch the beam in the telescope and make sure that you end up with the two beams overlapped in the telescope. Once the reference and test beams overlap in the fringe viewer and in the telescope they two beams are coincident and will produce good fringes.

4.2.2.14. Adjusting the APD signal detector

Preparations and Electrical hookups: Remove the dropper and tripod from the interferometer base (IB) and remove the center section of the IB top cover and the IB top cover containing the fringe viewer. Monitor the DC light level from the avalanche photodiode (APD). It is usually best to do this using a scope. The DC light level is available on the Analog Out port on the interferometer base.

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

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

4.2.2.15. Adjusting The Fringe Amplitude

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

4.2.2.16. Replace all covers 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 scaler-counter board, the rubidium oscillator and the universal time interval counter (UTIC). Data are taken by two different interface cards inside an IBM-compatible 386 (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 scaler-counter keeps track of how many fringes have gone by and measures the absolute time of occurrence of these fringes. The scaler-counter scales (divides) the fringes by a number which can be set on the scaler-counter board (typically preset to 4000).

The 10-MHz signal from the rubidium oscillator is also divided by a preset factor in the scaler-counter (usually 2000). The time interval between the occurrence of each scaled fringe and the next scaled clock pulse from the rubidium oscillator is measured with the UTIC. The computer records each time interval, the number of clock signals, and the number of scaled fringes since the last time interval measurement. This information is used to construct the absolute time of occurrence of the scaled fringes.

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 scaler-counter board. 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-voltage bias is zener-limited to 600 volts (on-board). Two potentiometers are used to set the temperature coefficient and 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. Scaler-Counter Printed Circuit Board

The scaler-counter board has several major functional blocks:

1. Clock discriminator
2. Clock scaling
3. Scaled clock count accumulator
4. Fringe scaling
5. Scaled fringe accumulator
6. Accumulator/computer data latching
7. Miscellaneous I/O interface circuitry

The incoming clock signal is converted to TTL levels (1), and then scaled (2) according to a three-digit hexadecimal value selected with three PCB hex switches. The scaled clock output of this circuit increments the 10-bit clock accumulator (3) and is also sent to the UTIC via a BNC connector on the front panel. Except that it does not need a TTL discriminator, the fringe scaling circuit (4) is identical to that of the clock scaler. The scaled fringes are counted by a 4-bit accumulator (5), and are passed on to the UTIC via a front panel BNC connector.

The leading edge of the latch pulse from the UTIC latches (6) the current values of the scaled clock and fringe accumulators into buffers, along with the states of the "data_valid" and "up/down" status lines. The accumulators themselves are then cleared by the trailing edge of the delayed latch. To indicate data available for reading, an extended latch pulse is sent to the computer.

A control line from the computer, /DIS, disables the fringe output to the UTIC so that an incoming fringe cannot retrigger the UTIC until after the computer has finished its current data read operation.

Several other signals are routed to and from the computer through the scaler-counter board. They are specified in Table 4-2.

SCALER-COUNTER SIGNALS	
BNC INPUTS	**DESCRIPTION**
Clock In	50-Ω terminated input from 10-MHz Rubidium Oscillator
Latch In	TTL pulse from UTIC that latches count data for reading by the computer
Input Fringes	50-Ω terminated TTL prediscriminated fringe signal from APD board
Valid Data	TTL signal from controller indicating object in free-fall
Up/Down Status	TTL signal from controller indicating object is in the ascending/descending phase of throw trajectory
Spring Status	TTL signal from Superspring indicating proper operation (not implemented)
Laser Status	TTL signal from the Laser indicating lock status
Stat 1	undedicated TTL-compatible status inputs to computer
BNC OUTPUTS	**DESCRIPTION**
Spring Zero	TTL signal telling the Superspring to re-zero itself (not implemented)
Scaled Fringes	TTL output to UTIC
Scaled Clock	TTL output to UTIC

Throw Init	TTL control line to controller used to initiate a throw cycle
Laser Control	TTL signal to laser controller used to indicate which mode to lock (red or blue)

Table 4-2 Scaler Counter Signals

DB-37 CONNECTOR SIGNALS TO COMPUTER			
PIN	**NAME**	**TYPE**	**DESCRIPTION**
3	FL3	output	latched fringe count, bit 3
4	FL2	output	latched fringe count, bit 2
5	FL1	output	latched fringe count, bit 1
6	FL0	output	latched fringe count, bit 0
7	VALIDL	output	latched "data valid" status bit
8	U/D_L	output	latched "up/down" status bit
9	DL9	output	latched clock count, bit 9
10	DL8	output	latched clock count, bit 8
17	GND	power	ground connection
19	GND	power	ground connection
21	GND	power	ground connection
22	CTL1	input	laser control signal
23	CTL0	input	spring zero signal
24	/DIS	input	fringe output inhibit
25	INIT	input	throw init signal; also clears clock and fringe count accumulators
26	STAT2	output	undedicated "status input 2" bit
27	laser stat	output	undedicated "status input 1" bit
28	SPRINSTAT	output	spring status bit

29	LATCH	output	(extended) "latch" signal to computer
30	DL7	output	latched clock count, bit 7
31	DL6	output	latched clock count, bit 6
32	DL5	output	latched clock count, bit 5
33	DL4	output	latched clock count, bit 4
34	DL3	output	latched clock count, bit 3
35	DL2	output	latched clock count, bit 2
36	DL1	output	latched clock count, bit 1
37	DL0	output	latched clock count, bit 0

Table 4-3 DB37 Connector

4.4.1.4. 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 UTIC and scaler-counter to provide accurate time information. The oscillator is split by a 50 Ω POWER splitter. From there, the clock is sent into the 10-MHz IN BNC on the back of the UTIC and also into the Clock In BNC on the back of the scaler counter.

4.4.1.5. Universal Time Interval Counter

To measure the time between a scaled fringe and the next scaled clock, the FG5 uses a Universal Time Interval Counter (UTIC). The scaler-counter SCALED FRINGES signal is connected to the front A input of the UTIC, while SCALED CLOCKS signal is connected to the B input. After each time interval is measured, the UTIC generates a LATCH signal from a rear BNC. The LATCH signal is connected to the Scaler/Counter where it is used to latch the clock and fringe number onto the output pins of the parallel I/O port of the Scaler/Counter. The UTIC is controlled and read by the computer through an IEEE-488 cable.

UNIVERSAL TIME INTERVAL COUNTER SIGNALS			
Front Panel:			
Name	**Type**	**Destination**	**Name**
B	BNC	Scaler/Counter	SCALED CLOCK
A	BNC	Scaler/Counter	SCALED FRINGES
Back Panel:			
LATCH	BNC	Scaler/Counter	LATCH IN
10-MHz IN	BNC	Rb oscillator	
STD PORT	IEEE	computer	

Table 4-4 UTIC Signals

The proper set-up of the UTIC is accomplished automatically in the software. The OLIVIA program sets the A and B inputs to be 50-Ω terminated, the clock reference to be external, and the clock frequency to be 10 MHz. The UTIC is set to measure positive mean time intervals only. The trigger levels for A and B are set at 1.8 V.

4.4.2.DATA ACQUISITION

4.4.2.1.Computer Interface Cards

The computer running the system is a 386 DX machine (or better). To interface the computer to the scaler-counter the FG5 uses a Metrabyte PIO-12 (SET TO 380 HEX). This card provides 24 bits of I/O. It is configured for 20 input lines and 4 output lines. The PIO-12 card has a 37-Pin D connector that runs to the back of the SCALER COUNTER. The UTIC interface is a Metrabyte DV-488 card (an IEEE-488). The IEEE-488 cable runs from the back of the scaler-counter to the back of the UTIC.

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

4.5.3. 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.

4.5.3.1.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 4-5 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."

4.5.3.2.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.

4.5.3.2.1.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.

4.5.3.2.2.AUTO

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

4.5.3.2.3.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.

4.5.3.2.4. REMOTE

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

4.5.3.2.5. 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.

4.5.3.3. 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]

4.5.3.4. 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.

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

4.5.4. Maintenance Schedule

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

4.5.4.1. 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.

4.5.4.2. Semi-annually

Calibrate the He-Ne laser to an iodine standard.

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 FG5COMND.DAT file. Latitude or longitude have been entered incorrectly in the FG5COMND.DAT file. 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 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.
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.	Rotate quarter-wave plate lens in front of faraday isolator to decrease beam intensity.
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.

	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 the computer to docking station connection and lock in.

Problem	Solution
Olivia locks and the status line displays reading barometer or getting environmental.	Turn of the computer and disconnect and reconnect the serial cable. Use the GETBAR program to test the barometer.
Olivia ends with the: Error Number => 00308 Original Command => OUTPUT 16 …	The UTIC is not connected to the system or it is turned off.
Olivia ends with the: Error Number => 00308 Original Command => OUTPUT 14 …	The IOtech ADC 16A is not connected to the system or is not turned on.
OLIVIA locks and the UTIC displays BINARY DATA.	No Fringe signal is hooked up or one of the beam blockers is inserted. The condition can be cleared by manually forcing a drop using the internal trigger for the dropping controller.
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.

Problem	Solution
The Stanford Research Instruments (SRS) Model SR620 UTIC has momentary power outages and loses programmed configuration.	A voltage regulator is shorting out against the case. Call Micro-g for detailed instructions.
The SRS UTIC displays an error.	See UTIC manual
The SRS UTIC has excessive jitter	Make sure that the voltage selection is correct for the AC power. This unit will not operate correctly at 100VAC when set to 120VAC.
A systematic gravity shift is observed	The rubidium clock has lost its calibration. Check its frequency against a standard Cesium reference. This can easily be done by counting the frequency of the standard clock with the UTIC which is referenced to the FG5 system rubidium. It should read the correct frequency to better than 5 parts in 1010 for the error to be less than 1µGal. SRS UTIC not locked to the rubidium clock.

	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.

Table 5-5 Electronics Problems and Solutions

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
Room temperature reading incorrectly.	Change battery in thermocouple mounted on tripod tray. Turn on temperature probe Attach thermocouple to temperature probe Attach BNC between temperature probe and BNC16 channel 1H
Gravity is 300μGal too high	The system is not reading the barometer. Make sure the barometer is hooked up correctly.

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) 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 100-115VAC and 220-240 VAC

NOTE: Check the manuals for each component to determine the proper fuse for the line voltage being used.

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.AL-1 Laser

Possible voltage selection positions (50-60Hz): 115 and 220 VAC. SWITCHING IS NOT NECESSARY BETWEEN 100 ←→ 115 VAC OR BETWEEN 220 ←→ 240.

1. Remove AC plug
2. Remove card selector
3. Flip or Rotate card to correct voltage (the correct voltage will be visible on the left-hand side)
4. Reinsert the card selector and the AC power cord. Check to see if the correct voltage is visible before reconnecting to mains power.

6.2. UTIC

Stanford Research Systems SR 620 Time Interval Counter

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

1. Remove AC plug
2. Remove card selector with a paper clip or needle nose pliers.
3. Flip or Rotate card to correct voltage (the correct voltage will be visible on the left-hand side)
4. Reinsert the card selector and the AC power cord. Check to see if the correct voltage is visible before reconnecting to mains power.

6.3. MAIN POWER SUPPLY

Rear Mains Power Rack

Possible voltage selection positions (50-60Hz): 100, 115, 220, and 240 VAC. This power supply controls the dc power supplies, rubidium standard, barometer, dropping chamber, Superspring, scaler/counter, translation detector, printer voltage, and ac power strip.

1. Remove AC plug
2. Remove selector by pulling straight out
3. Flip or rotate selector to correct voltage
4. Reinsert the selector and the AC power cord. Check to see if the correct voltage is visible before reconnecting to mains power.

6.4. Portable Ion Pump Power Supply

Possible voltage selection positions (50-60Hz): 115 and 220 VAC. NO SWITCHING IS NECESSARY IF SWITCHING BETWEEN 100 ←→ 115 VAC OR IF SWITCHING BETWEEN 220 ←→ 240.

1. Remove AC plug
2. Open the power entry module and remove the drum voltage selector.
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.

6.5. 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 (such as the IBM ThinkPad) use a universal power supply, so switching is not required. Please check the computer manual supplied with the FG5 for complete details.

6.6. Docking Station

Select the proper line voltage (115 or 230 VAC) using the red switch located at the rear of the docking station.

6.7. IOtech ADC16

Possible voltage selection positions (50-60Hz): 115 and 220 VAC. NO SWITCHING IS NECESSARY IF SWITCHING BETWEEN 100 ←→ 115 VAC OR IF SWITCHING BETWEEN 220 ←→ 240.

1. Remove the unit from the electronics rack and remove the top lid of the box.
2. Flip the red selector switch between 110 or 220 VAC
3. Install the appropriate fuses.

6.8. Turbo pump

The Varian Model V-60 Turbo Pump was included with the FG5 prior to February, 1996. Since then, the Varian Model V-70 Turbo Pump has been used. Other than a slight increase in pumping speed, there is very little difference between the two pumps. The forepump (Varian SD-40) used in the turbo pumping station uses a special motor which is wired to run efficiently at both 50 and 60 Hz. Possible voltage settings are 100-115 and 220-240 VAC. NO SWITCHING IS NECESSARY IF SWITCHING BETWEEN 100 ←→ 115 VAC OR IF SWITCHING BETWEEN 220 ←→ 240.

1. To switch input power settings, make sure power cables are not connected to the turbo pump, then remove the access panel at the rear of the motor and use Table 6-1 to set for the proper input voltage.

High Voltage (220-240 VAC)		**Low Voltage (100-115 VAC)**	
Connector	Cable	Connector	Cable
L1	No Connections	L1	No Connections
3	Blue	3	Violet
4	Orange	4	Orange
5	Violet	5	No Connections
L2	Red	L2	Red and Blue

Table 6-1 Turbo Pump AC Voltage Select

2. To complete the voltage switching, it is necessary to select the proper input voltage for the turbo pump control unit. This is done by removing the access panel at the rear of the enclosure to access the back of the control unit, and orienting the input voltage selector to the desired position.

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 month 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 month, 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). In extreme cases, 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. 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. In some cases, when the ion pump has been off for several weeks, it may be helpful to bake out the chamber even though it has not been opened.

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. 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.

Remove the plastic cap from the exhaust mist collector/muffler and turn on the turbo-pump.

The turbo-pump should reach normal operational speed in a few minutes. If the pump indicates a high load 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 very important that the AC power is not interrupted. If the power is interrupted, the entire system will vent to air. This can cause back-streaming of oil which could cause damage to the turbo-pump or dropping chamber. This can be avoided by using a special SENTRY valve which closes the dropping chamber when the AC power is removed. This valve will automatically open when the vacuum is restored by the turbo-pump.

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 tapes around the dropping chamber and the ion pump. The chamber temperature should be maintained at 80° C (or less), and the ion pump at 100° C. This is done by connecting the heat tapes to a variable transformer to control the temperature. It is preferable to use separate transformers, if possible, to allow independent adjustment of the chamber and ion pump temperatures. Monitor the bakeout temperatures using the type F thermocouple cables which are attached to the dropping chamber and ion pump and a dual channel temperature sensing unit (or equivalent temperature sensing units). Bake the chamber for at least 12 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 4 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 red 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. After the ion pump has started, close the vacuum valve and turn off the turbo pump. Once the turbo pump has vented, 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 only 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 only 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.

8.2. THE DATA LOGGING SYSTEM

Connect the x, y, and sum jacks on the detector box to the IOtech patch panel connections as follows:

- X to 5H
- Y to 6H
- SUM to 7H

Connect the "Valid" and the "Trigger Out" signals of the DROPPER Controller to the IOtech patch panel connections as follows:

- Valid to 8H
- Trigger Out to Trigger

8.3. TAKING DATA

The program for taking data from the attitude monitor is turned on and off using line P22 of the FG5PARAM.DAT control file as follows:

Rotation detection:

- 1 for ON
- 0 for OFF

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 voltage 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.
	AL-1 Laser: Use card in power entry module.
	UTIC: Use card in power entry module.
	Rear Mains Power: Use card in power entry module.
	Ion Pump Power Supply: Use drum in power entry module. Remove drum from power entry module before rotating.
	Computer docking station: Flip red switch on rear panel to 115 or 230.
	IOtech ADC16: Remove unit and top cover. Flip red selector to 110 or 220.
	Turbo Pump: Remove motor access panel and connect cables to proper terminals (see owner's manual or table in appendix A).
	Turbo Pump: Remove access panel on turbo pump control unit. Set voltage selector to desired position.

Table 9-1 AC Voltage Select

9.2. FG5 Setup

FG5 SETUP CHECKLIST	
	Unpack and assemble interferometer.
	Position interferometer over reference mark. Orient so laser is in the north-south direction, if possible
	Set up electronics case and remove covers.
	Check AC line voltage. Connect main AC power cable.
	Connect signal, HV cables from electronics rack to laser head.
	Turn on main AC and DC power switches.
	Assemble dropping chamber tripod and place on interferometer.
	Place dropping chamber on tripod, ion pump away from laser head. Clamp dropping chamber to tripod.
	Release cart travel lock.
	Connect ion pump cables and start ion pump. Rough pump dropping chamber, if necessary.

	Rough level interferometer using bubble levels on tripod tray.
	Place tripod feet under tripod until they just contact nylon ball on tripod legs.
	Raise dropper above interferometer (1 turn for each foot).
	Make sure interferometer and dropper do not touch.
	Check levels on tripod tray and center, if necessary. If levels are adjusted, recheck to make sure interferometer and dropper do not touch.
	Mount telescope and focus crosshairs.
	Adjust verticality of test beam using interferometer legs.
	Measure and record reference height.
	Mount Superspring . Verify that all three v-mounts on Superspring lid are located properly.
	Connect Superspring cable (yellow Lemo)
	Level Superspring.
	Release Superspring travel lock.

	Connect three cables to the dropping chamber: Vacuum feedthrough (white Lemo), motor cable (orange Lemo), shaft encoder (blue Lemo).
	Connect BNC from temperature probe on tripod tray to BNC 16 1H.
	Connect Superspring cable.
	Connect APD power (green Lemo).
	Connect BNC fringe signal to interferometer TTL port and front panel of Scaler/Counter.
	Recheck beam verticality. Adjust if necessary.
	Adjust Superspring zero position.
	Record Superspring sphere voltage in system check log.
	Close Superspring servo loop (turn coil switch on).
	Put Dropper in OSC mode and hit RESET then INIT to make the dropper move smoothly up and down.
	Optimize fringe signal.

	Record fringe voltage in system check log.
	Make sure cart is at bottom position (STANDBY light on).
	Turn rotary knob to AUTO and select the internal trigger (INT) to automatically check that the dropping chamber is performing drops properly. Press RESET then INIT.
	Note cart position voltage at the top and bottom of the drop. Record these values in the system check log.
	When the cart is at the bottom of the drop set the trigger source to EXT.
	Press RESET, then INIT. Now it waits for the computer to initiate a drop.
	Check the laser output power and record this value in the system check log.
	Verify 1f signal of the WEO and put these values in the FG5param.dat file. Make sure that the time constant is set to 1f.
	Reconnect BNC from WEO 1f signal to BNC16 4H channel.
	Set up the software to run correctly at the site.

Table 9-2 FG5 Setup

9.3. Dropping Chamber Pump Down and Bake-Out

FG5 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 tapes 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 12 hours.
	Turn off heat tapes. Allow dropper to cool at least 4 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 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 Dropper 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 Dropper 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.Adjust 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.Replace 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 Replace 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 Replace 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 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 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 Replace Shaft Encoder

9.5. Interferometer Alignment

Interferometer Alignment Checklist	
	Adjust mirrors 1 and 2 (use alignment pinholes in spatial filter).
	Adjust optical isolator, if necessary.
	Reinsert 25.4 mm lens in spatial filter (curved surface toward input beam).
	Reinsert 128 mm collimating lens in spatial filter.
	Adjust collimating lens position by minimizing spot in telescope.
	Level the dropping chamber and adjust bubble levels.
	Adjust mirrors 3 and 4 to make the beam travel through dropping chamber vertically.
	Adjust Superspring position (top mounting plate).
	Adjust final mirror (overlap beams in fringe viewer).
	Steer beam onto the APD.
	Focus beam on APD.
	Adjust fringe amplitude with $\lambda/2$ plate.

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 Remove 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 Replace Superspring Cover

9.6.3.Removing Service Ring

Removing 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 Coil

Replacing 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 Flexures

Replacing 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 Focus Lever Motor

Replacing 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 Micro-Switches

Adjusting 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.
	Store ion pump, GPIB, and PIO cables in electronics case.
	Put remaining cables in zippered pouch (inside of rear electronics case lid).

	Unplug power cords and printer cable from system controller and printer. Store in system controller case.
	Close system controller lid and place controller/docking station in system controller case. Close case and secure latches.
	Unplug all BNC and power cables from rotation monitor (if used). Store in rotation monitor case.
	Remove rotation monitor from dropper and store in case. Close case and secure latches.
	Secure lids to electronics case.
	Replace screws and viewing port cover on top dropping chamber flange.
	Engage cart travel lock.
	Remove dropping chamber from tripod and place in dropping chamber case.
	Lift tripod from interferometer base and remove legs.
	Place tripod legs in dropping chamber case.
	Place tripod tray in Superspring case (3-lobe knobs toward the outside).

	Place brass tripod feet in Superspring case, and blue pads in dropper case.
	Close dropping chamber case and secure latches.
	Engage Superspring travel lock.
	Remove Superspring from interferometer and insert top plug.
	Place Superspring in Superspring case.
	Remove telescope assembly from interferometer base.
	Put lens cap on telescope and place assembly in Superspring case.
	Close Superspring case and secure latches.
	Insert top and side plugs in interferometer base.
	Remove interferometer legs.
	Place interferometer legs in interferometer case and cover with foam pad.
	Place interferometer base in interferometer case.
	Fold interferometer handles down.

	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.

Table 9-23 Packing the FG5

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