

FG5-X Absolute Gravimeter User's Manual



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Applicable Products

Micro-g LaCoste: FG5-X Absolute Gravimeter

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1. INTRODUCTION

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History

A ballistic absolute gravimeter works by dropping an object in a vacuum and measuring the time it takes to fall a specified distance. Galileo recognized that the acceleration of a freely falling body is independent of its mass, and legend has it that he demonstrated this by dropping objects of different weight from the leaning tower of Pisa (though this may be apocryphal). Newton's theory of gravitation also required that the acceleration of a falling body in an external gravity field did not depend on its size, shape, or mass. Thus, measuring the acceleration of a freely falling object is equivalent to measuring gravity. This freefall acceleration is given the special symbol, g , to remind us that gravity is responsible.

The FG5-X represents the latest generation of ballistic absolute gravimeters and is based on technology developed over the last forty 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-X were the 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.

The FG5-X is now a firmly established industry standard in the fields of geophysics and metrology. As of 2010, over fifty instruments have been constructed and are employed throughout the world.

FG5-X Absolute Gravimeter

The FG5-X absolute gravimeter is the latest version of the high precision, high accuracy, transportable instrument that measures the vertical acceleration of gravity. The operation of the FG5-X 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 20 cm. A laser interferometer is used to determine the position of the test mass as a function

of time during its freefall. The acceleration of the test mass is calculated directly from the measured trajectory.

The interferometer generates an optical interference fringe each time the test mass falls $\frac{1}{2}$ the wavelength of the laser light. These fringes are counted and timed with an atomic clock to obtain precise time and distance pairs. A least-squares fit to these data are used to determine the value of g . This method of measuring gravity is absolute because the determination is purely metrological and relies solely 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 accurate time scale. The value of gravity obtained with the FG5-X can be used without the loop reductions and drift corrections normally required when using relative instrumentation. With the FG5-X, the absolute gravity value is determined and reported immediately.

Figure 1-1 shows the direct measurement of the acceleration due to gravity, g , using the FG5-X. As the optical fringes go through zero, the precise time is recorded by an atomic clock. A least-squares fit to the time and distance pairs is used to determine g .

A test body, containing a corner cube retro-reflector, is dropped from the top of the dropping chamber. Laser light is split to reflect off this falling corner cube and another fixed corner cube which serves as a reference. The mass accelerates to the bottom of the chamber, and the raw optical fringe signal is detected by the photodiode as the dropped object falls. The optical fringes in the raw fringe signal are timed to create calibrated time and distance pairs. The lower part of the figure demonstrates the increase in the fringe signal frequency as the test body accelerates.

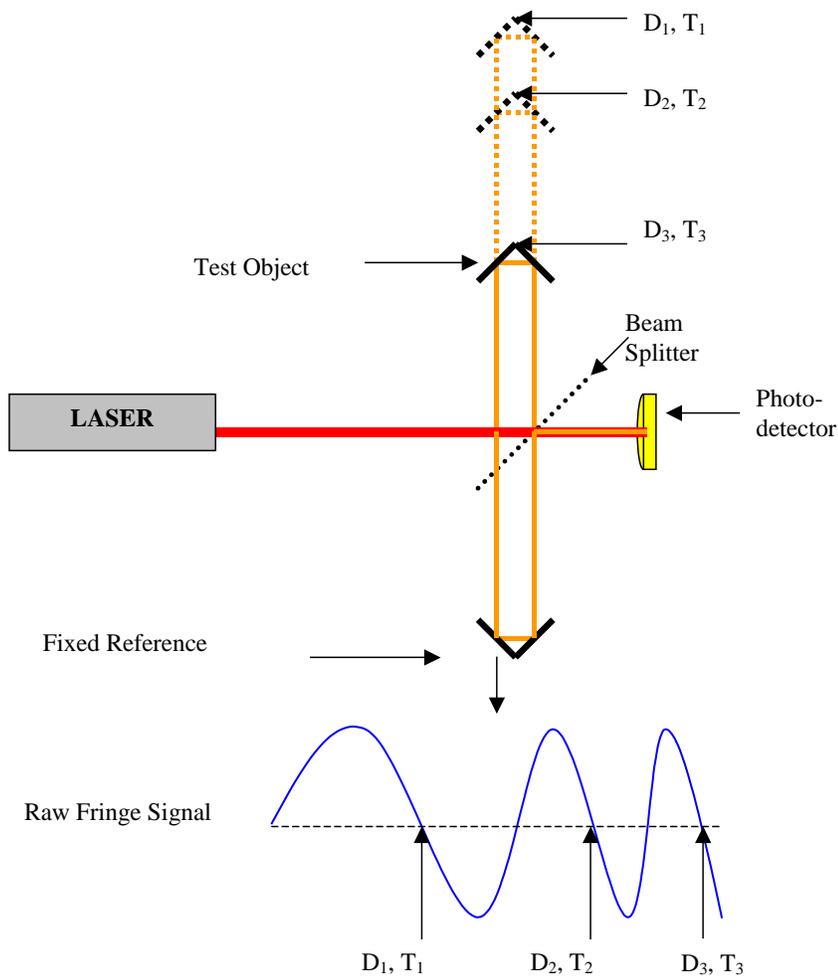


Figure 1-1 FG5-X Direct Measurement of Absolute g

Units In Gravitational Measurements

g is defined to be the magnitude of the acceleration experienced by a freely falling body at a specified point. As such, it is simply a scalar and is reported in units of distance per squared time interval. In the International System of Units (S.I), gravity is nominally about 9.8 m/s^2 .

For historical reasons, gravity is also commonly reported in the Centimetre gram second (CGS) system of units. This CGS unit of 1cm/s^2 is given the name Gal after the famous father of gravity, Galileo. Using these units, the nominal acceleration due to gravity is 980Gal.

Precision gravity measurements are often given in units of micro-gals: $1 \mu\text{Gal} = 10^{-6} \text{Gal}$. A measurement resolution of 1 micro-Gal (μGal) therefore requires a measurement of the earth's field with a precision of about 1 part in 10^9 (1part/billion).

$$1 \mu\text{Gal} = 10^{-6} \text{Gal}$$

The conversion between μGal and SI units is:

$$1 \mu\text{Gal} = 10^{-8} \text{m/s}^2.$$

Design Features

The FG5-X features an improved dropping chamber and an improved electronic interface.

Dropping Chamber

- Extended freefall length (33cm, 260 ms) in the original FG5 dropping chamber height.
 - 65% longer in distance.
 - 30% longer in time than a standard FG5.
- Redesigned drive system.
 - Counterweighted elevator to reduce mechanical recoil and air gap modulation.
 - Improved microprocessor servo controller, eliminating field tuning.
 - Increased motor power for better tracking.
 - Inline drive system to reduce horizontal accelerations (Coriolis) of test mass.
- New test mass design reduces decelerations caused by external magnetic fields.

Electronic Interface

The new System Interface Module (SIMx) provides smaller, lighter and more robust electronic control.

- Reduces size of total electronics by two full rack units.
- Includes Dropper Controller.
- Includes Superspring Controller.
- Includes System A/D interface eliminating need for National Instruments A/D card.
- Optional automatic system leveling control.

- Includes integrated, GPS based rubidium timing system.
- USB integration for communication with the new g-software Absolute Gravity Data Acquisition And Processing Software.
 - Provides user feedback if spring is out of range, dropper not in DROP MODE, and remote operation of FG5-X via internet connection.
 - Improved microprocessor servo controller eliminating field tuning.

Additional Features

- This absolute gravimeter is designed to work with iodine-stabilized laser systems (WEO models 100 and 200) traceable to the BIPM primary standards.
- The system controller is a standard, Intel-based laptop computer.
- The g-software Absolute Gravity Data Acquisition And Processing Software is a user-friendly, Windows® based, full-featured software program used for data acquisition.
 - This software provides an immediate value for the local gravity in real-time.
 - The program is also a full-featured post-processing software program that allows complete ability to vary data analysis procedures and to vary environmental corrections.
- An optional Tele-g/Remote Gravimeter Operation package is available that allows virtually complete remote control of the instrument and the software via an internet connection. Refer to the [Tele-g/Remote Gravimeter Operation User's Manual](#) for more information.

Documentation

Reference the following manuals for use with the FG5-X Absolute Gravimeter.

- g-software Absolute Gravity Data Acquisition And Processing Software User's Manual
- System Interface Module (SIMx) User's Manual
- Tele-g/Remote Gravimeter Operation User's Manual
- ML-1 Polarization Stabilizer Laser Operator's Manual (Or the appropriate laser manual for your system)

Documentation Conventions

Dialog box menus, commands, dialog box titles, labels and options are bolded text in the user instructions. WARNING and IMPORTANT notes are highlighted in red.



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g Determination

The FG5-X determines the acceleration of gravity, g , by using an interferometer to accurately track a test mass during freefall in a vacuum. (Refer to [Section 01](#) for introductory background.) The photo detector circuit at the output of the interferometer produces a pulse each time this interference signal crosses zero, and the times of these pulses are measured precisely using a rubidium clock. In the simplest example, these time and distance pairs are used to find a least-squares solution to the following equation:

$$x_i = x_0 + v_0 + \frac{1}{2} g_0 t_i^2$$

Where:

x_0 , v_0 , and g_0 are free parameters providing the best estimates for the initial position, velocity, and gravity, respectively.

g (gravity) is the parameter of most interest. In practice however, the situation is a bit more complicated. The finite value of the Earth's vertical gravity gradient, γ (approximately $-3 \mu\text{Gal}/\text{cm}$), causes a measurable change in g over the small length of the drop, and complicates this "standard" equation:

$$x_i = x_0 + v_0 + \frac{1}{2} g_0 t_i^2 + \frac{\gamma x_0 t_i^2}{2} + \frac{\gamma v_0 t_i^3}{6} + \frac{\gamma g_0 t_i^4}{24} .$$

In principle, the gradient should be a free parameter as well, but the short length of the drop provides little sensitivity in its determination. In practice, the gradient at the measurement location is either estimated or measured separately and entered into the software. Refer to the [g-software Absolute Gravity Data Acquisition And Processing Software User's Manual](#) for details. For reference, the "free air" value of the gradient is $- 3.086 \mu\text{Gal}/\text{cm}$.

Finally, because the arm of the interferometer that reflects off the test mass gets shorter during the drop, and because the speed of light is not infinite, the fringes at the bottom of the drop arrive earlier than they should. Therefore the equation has to be further modified as:

$$x_i = x_0 + v_0 + \frac{1}{2} g_0 \tilde{t}_i^2 + \frac{\gamma x_0 \tilde{t}_i^2}{2} + \frac{\gamma v_0 \tilde{t}_i^3}{6} + \frac{\gamma g_0 \tilde{t}_i^4}{24} ,$$

where:

\tilde{t} is the retarded time given by,

$$\tilde{t}_i = t_0 - \frac{(x_i - x_0)}{c} .$$

The gravity value determined from a least squares fit to the above equation becomes the best estimate for the absolute value of g at the beginning (top) of this particular measurement (or “drop”). Usually this number is recalculated at a more convenient height (perhaps for future comparison), and corrections are made for earth tide, ocean loading, polar motion, current changes in barometric pressure. These corrections and their applications are discussed in the [g-software Absolute Gravity Data Acquisition And Processing Software User’s Manual](#).

Design: Hardware Components And Function

Table 2-1 describes the FG5-X System components which are discussed in detail below.

Table 2-1 FG5-X System Components

Component	Description
Dropping (or Vacuum) Chamber	The test mass is allowed to free-fall inside the evacuated Dropping Chamber.
Interferometer Base (IB)	The Interferometer Base is used to split the laser beam to monitor the position of the freely-falling test mass and to provide the interference signal to the system controller.
Superspring	The Superspring is an active long-period isolation device used to provide an inertial reference for the gravity measurement.
Laser	The Laser is a stabilized helium-neon laser providing an accurate and stable wavelength used in the interferometric measurement system.
System Controller	The System Controller (computer) provides a flexible user interface, controls the system, acquires data, analyzes data, and stores the results
Electronics	The Electronics provides communication between the operator, hardware and software.

Dropping Chamber Theory

The Dropping Chamber

The Dropping Chamber is an evacuated chamber that contains a drag-free cart which, houses the test-mass/corner-cube and two recoil compensation carts. Refer to Figure 2-1 and Figure 2-2.

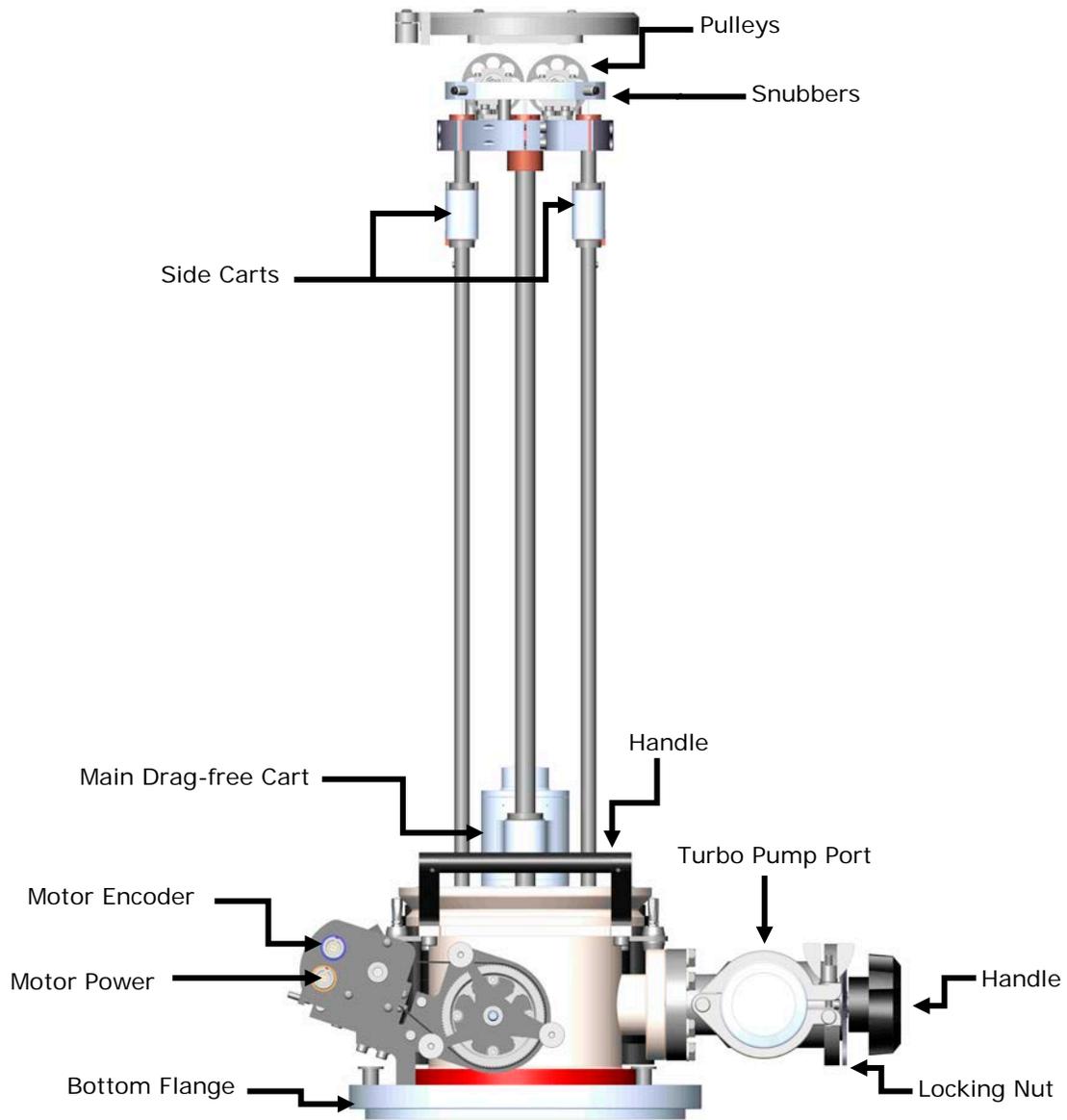


Figure 2-1 Front View Of The Dropping Chamber

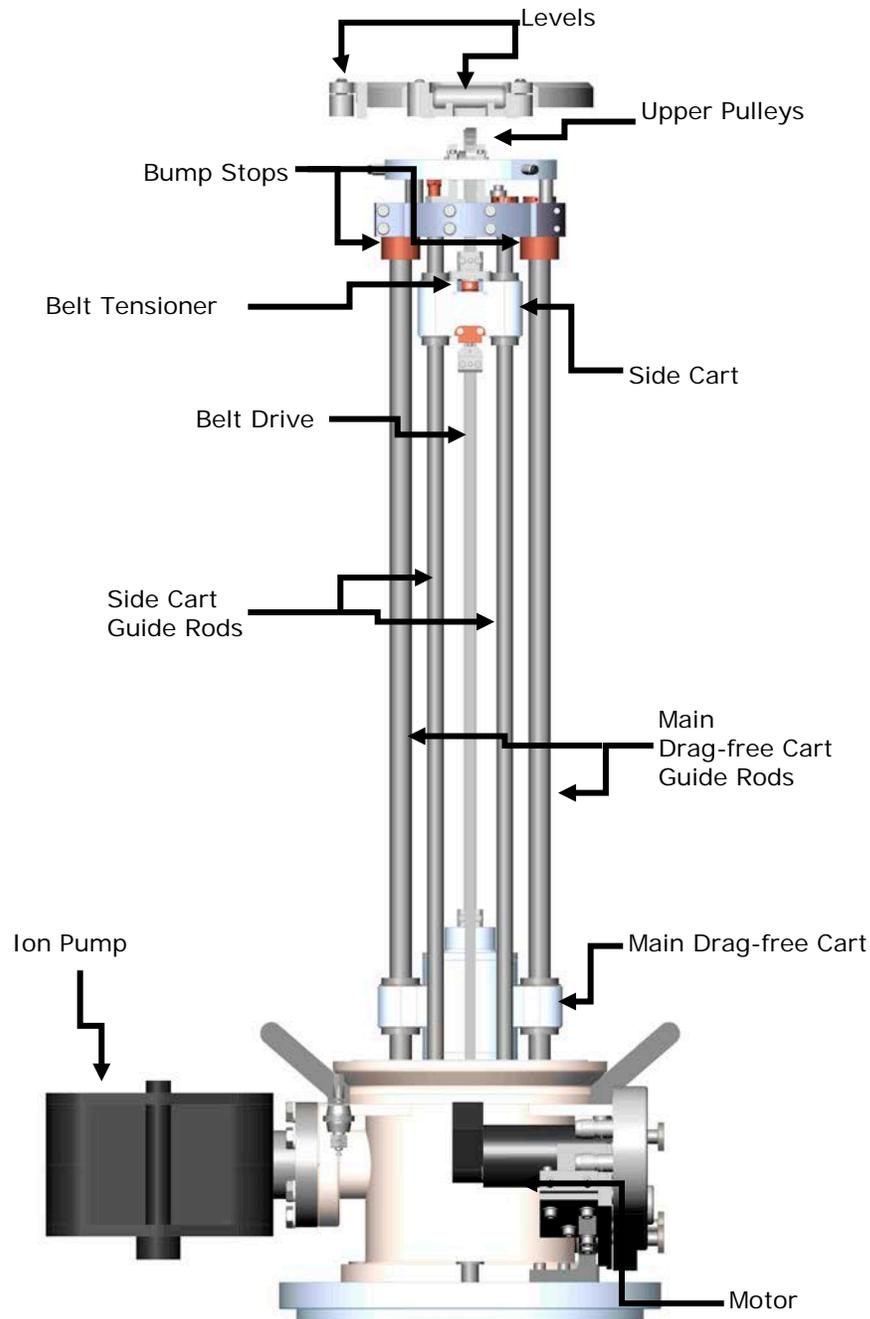


Figure 2-2 Side View Of The Dropping Chamber

A drive mechanism is used to drop, track, and catch the test mass inside the drag-free cart. Laser light passes through a window in the bottom of the Dropping Chamber to the corner cube (inside the test mass), and is then reflected back down through the window to the interferometer.

Drag-free Cart

The main drag-free cart (Figure 2-3 and Figure 2-4) is used to lift, drop, and catch the test mass. The term “drag-free” refers to the fact that though the chamber is evacuated, there are still some residual air molecules. The cart effectively pushes these molecules out of the way of the test mass, which is falling inside the cart. In addition to reducing drag, the cart also reduces magnetic and electrostatic forces on the test mass.

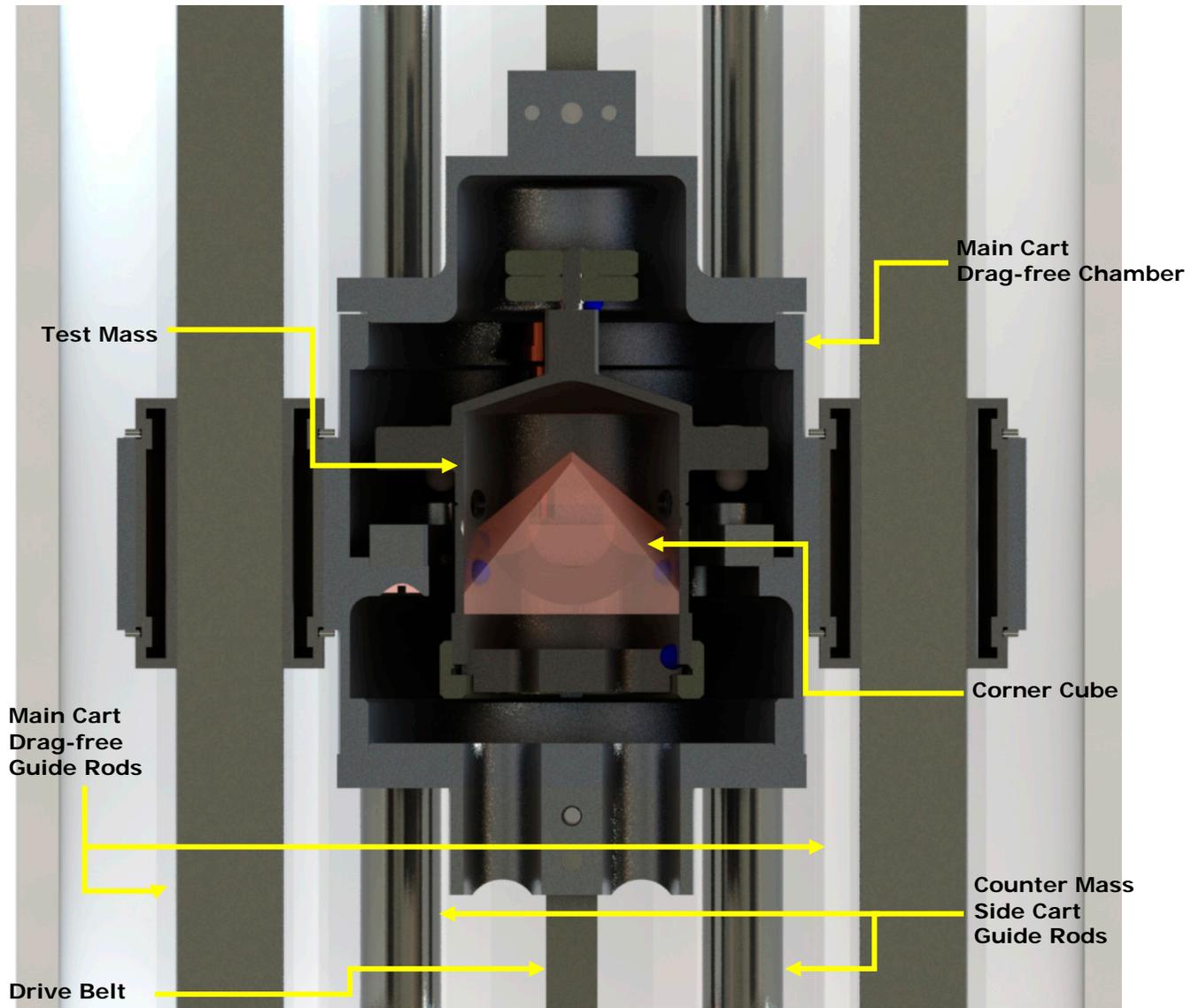


Figure 2-3 Main Cart/Drag-free Chamber, Front View

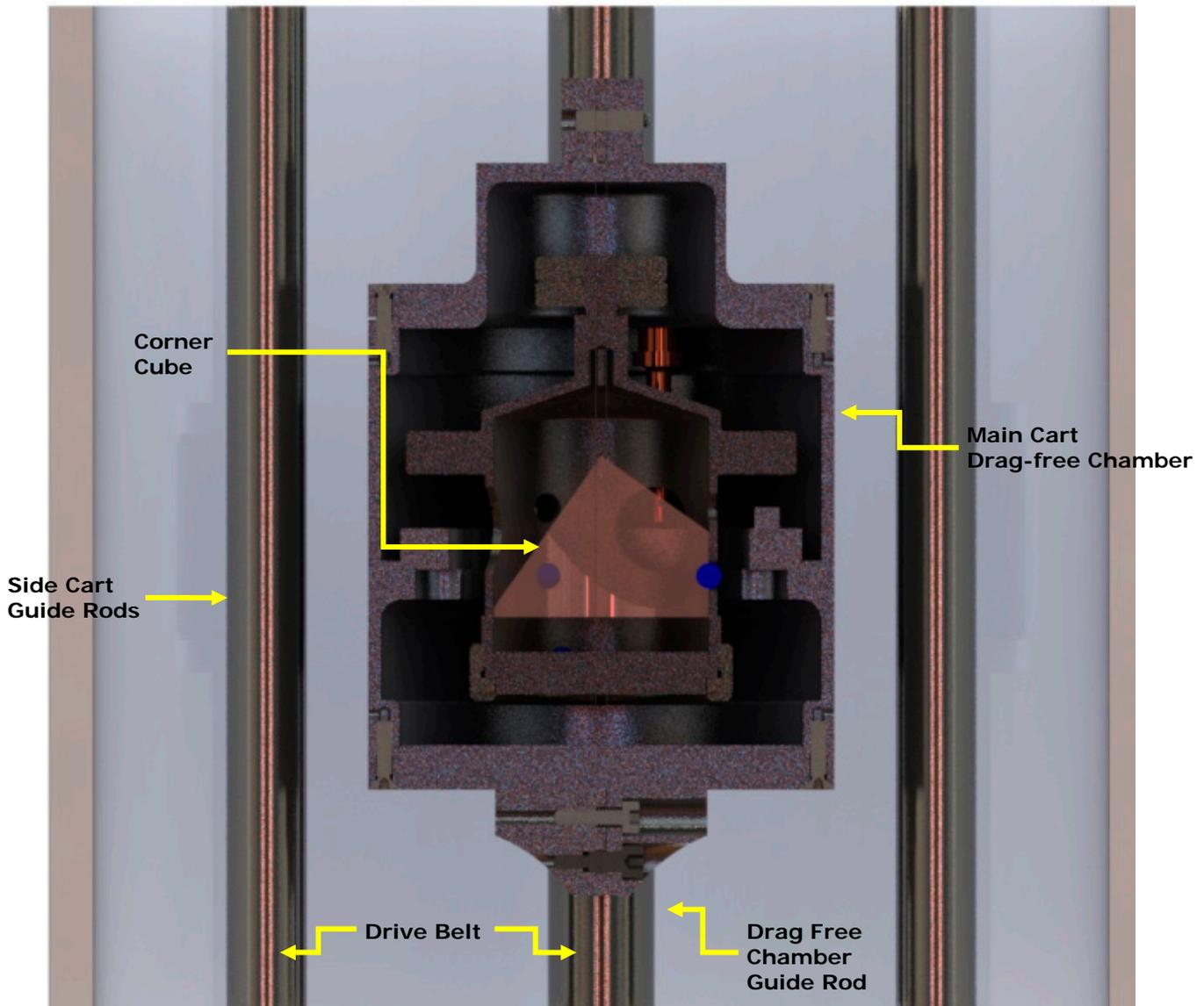


Figure 2-4 Main Cart/Drag-Free Chamber, Side View

Test Mass

The test mass contains a retro-reflective corner-cube surrounded by a support structure which is 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. When in contact with the

cart, the test mass is supported by three spherical feet (or “balls”) that fit and orient it to “vees” in the cart.

Recoil Compensation Carts

Two smaller carts move 180 degrees out of phase from the main cart to counterweight the main elevator. This reduces mechanical recoil and air gap modulation.

Drive Mechanism

The drive mechanism is a support structure inside the dropping chamber on which the cart/drag-free chamber travels up and down, and is driven by a DC servo motor. The cart is attached to a belt that is driven up and down by a shaft attached to the motor. The motor is located outside of the chamber and connected to the shaft via a ferrofluidic feedthrough (this device allows the vacuum to be maintained inside the chamber while a shaft rotates through the wall). The motor also turns an optical shaft encoder that provides accurate information to the dropper controller on the position and velocity of the pulley.

At the beginning of a drop, the cart accelerates downwards with an acceleration greater than g allowing the test mass to begin freefall. Once a certain separation (typically about 3 mm) between the cart and the test mass is reached, the cart slows down and then tracks the test mass, maintaining a constant separation of a few millimeters. At the bottom of the drop, the cart gently catches the test mass and decelerates to a stop.

Servo System

The tracking during the drop is accomplished by a sophisticated servo system that works as follows:

- Keeps track of the cart position using a shaft encoder on the belt drive pulley.
- Using the interferometer (fringes) to establish the object position, the distance between the cart and the mass can be derived.
 - During freefall, this separation is maintained at a constant distance by using a servo-motor drive system to control the cart inside the Dropping Chamber.
 - Because there is essentially no relative motion between the test mass and the drag-free chamber, the effects of residual air drag are eliminated.

Service Ring

The Service Ring (Figure 2-5) is at the base of the Dropping Chamber. It provides connections 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 ion pump, mounted on a 2³/₄" Conflat flange, which maintains the vacuum once the chamber has been evacuated by the roughing pump.

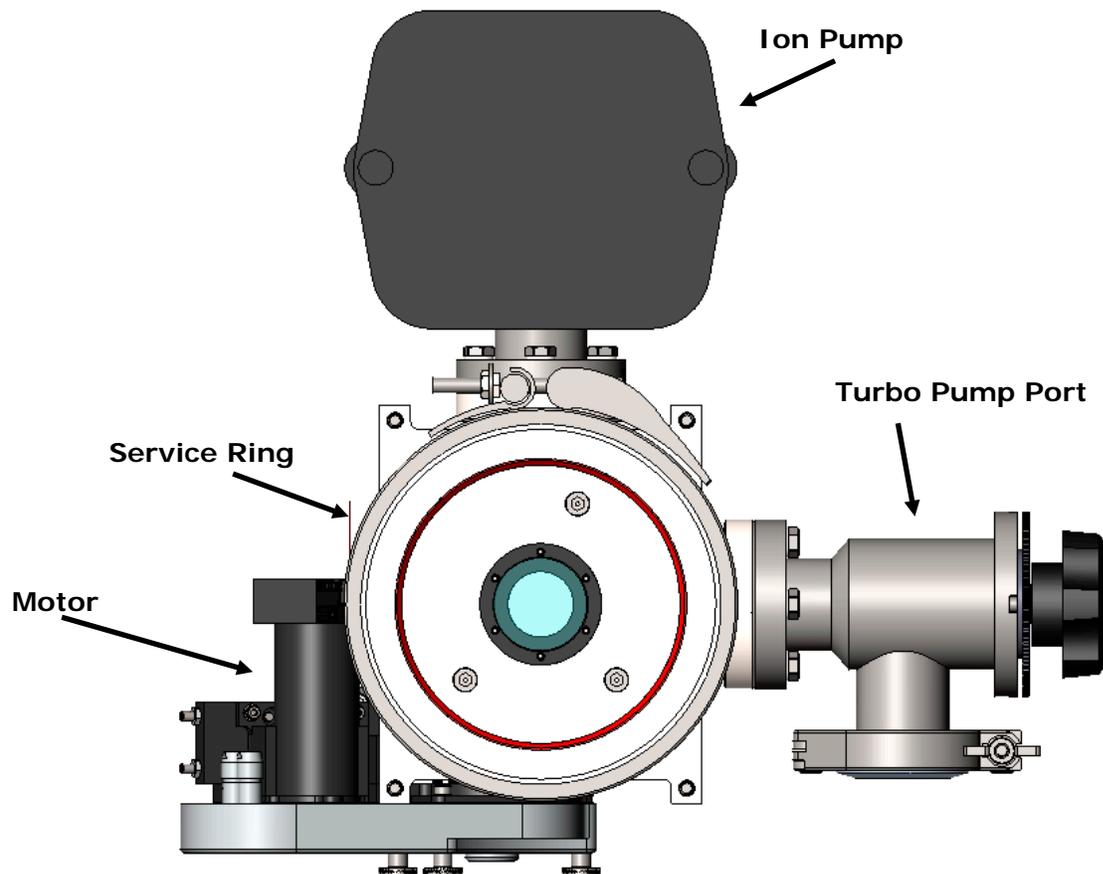


Figure 2-5 Service Ring Top View

Dropper Controller

The dropper controller is the servo circuit that controls the motor that drives the cart. Located in the SIMx (Refer to the [System Interface Module \(SIMx\) User's Manual](#) for more information), it is also the interface between the user and the dropping chamber.

The controller can be operated in two modes: **OSC** mode and **DROP** mode. The operator controls the status of these modes and the dropper triggering with the **RESET** button and the **TRIGGER** button.

Drop Mode

In **DROP** mode, a single trigger causes the controller to drive the motor to lift the cart (and test mass) to a specified height. An additional trigger then initiates the drop sequence: the cart pulls away with an acceleration greater than g , and then tracks the test mass (maintaining a specified separation distance) during free-fall, and finally softly catches the test mass at the bottom. If a TTL pulse is entered into **TRIGGER** at the back of the SIMx, cause motor to initiate a lift, and a separate **TRIGGER** pulse initiates a drop. These are normally supplied by the computer during data acquisition. To exit **DROP** mode, press **RESET**. The controller is now insensitive to triggers.

OSC Mode

OSC (oscillation) mode is used to slowly raise and lower the cart (the object is never in freefall) to create slow and constant interference fringes. The magnitude of this fringe signal is used for system alignment purposes. Refer to Setup information in [Section 03 "Fringe Optimization"](#).

To initiate **OSC** mode press **OSC** then press **Trigger**. The position LEDs on the front of the SIMx indicates a slow movement of the cart.

To stop OSC mode, press the **TRIGGER** button at any time. The cart automatically stops at the bottom of the next oscillation cycle (Alternatively, you can press **DROP**, and this will place the controller in DROP mode at the bottom of the next oscillation cycle).

Interferometer Theory

In the following description of the beam path refer to both Figure 2-6 and Figure 2-7.

The optical fiber directs the laser light from the laser head to the interferometer base. At the input of the interferometer, a lens collimates the light from the optical fiber. It is then directed to Beam splitter #1 where it is split into the Test Beam and the Reference Beam.

The Reference Beam is split again at Beam splitter #2 and travels to the Avalanche Photo Diode (APD) and the fringe viewer. Note that the path length of the reference beam remains constant.

The Test Beam is reflected vertically at Beam splitter #1, and passes through a compensator plate and a window in the bottom of the Dropping Chamber. It is then reflected back down by the corner cube in the test mass. The Test Beam returns through the window, the compensator plate, and passes down through the interferometer base to the Superspring. The Test Beam passes through the top window of the Superspring chamber to the corner cube in the Superspring mass. From here, the Test Beam is reflected back up out of the Superspring and into the interferometer base, where it reflects off Mirror #1 (or the "pick off mirror"), passes through the translator plate ("twiddler"), reflects off Mirror #2, and is recombined with the Reference Beam at Beam splitter #2.

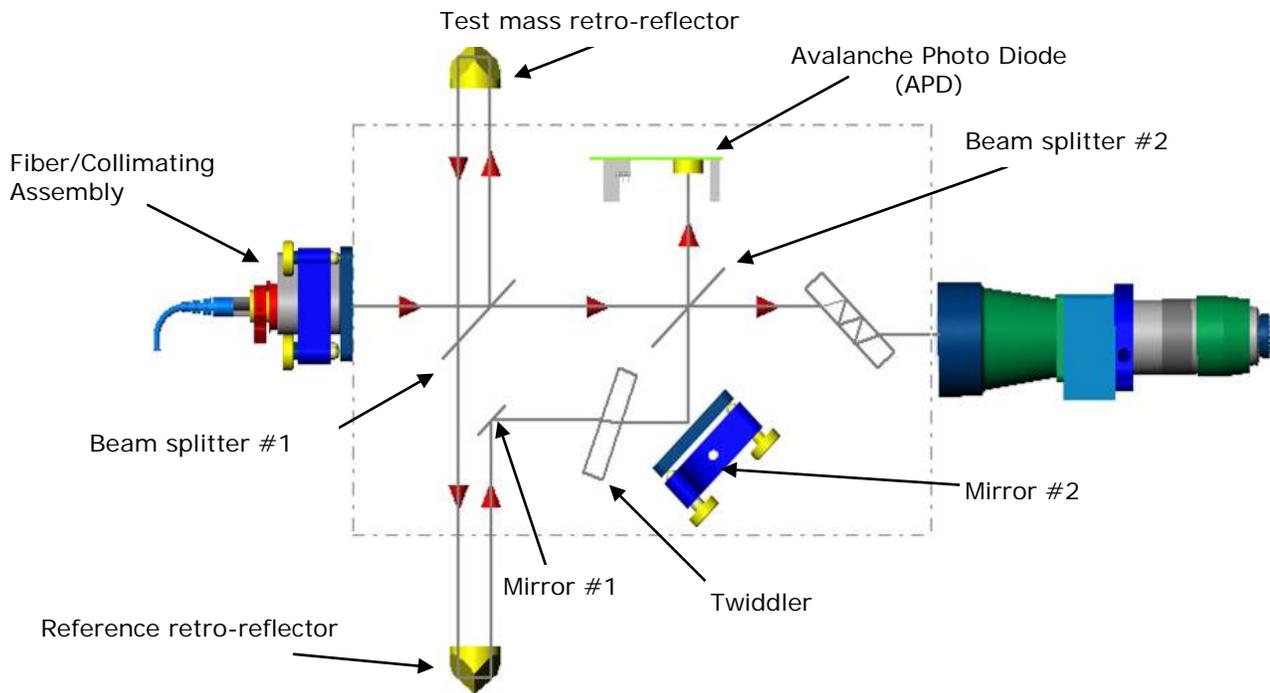


Figure 2-6 Beam Path In FG5-X Interferometer

In Figure 2-6 the Reference Beam passes straight through the first splitter and is then split again to enter the detector and the optical devices for alignment. The Test Beam leaves vertically from the first splitter, travels through the dropper and Superspring, and is recombined with the Reference Beam at Beam splitter #2. Note that only the telescope and not the fringe window (viewport) is shown in Figure 2-6.

This interferometer is the Mach-Zehnder type, with a fixed (reference) arm and a variable (test) arm. During a drop, the motion of the test mass 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.

The two beams are recombined at Beam splitter #2 and then split again. One set is focused by a lens to strike the detector

the Avalanche Photodiode (APD). The interference fringes are converted to an Analog signal and a Transistor-Transistor Logic (TTL) signal which is transmitted to the time interval analyzer card in the system controller.

The other recombined beam set travels horizontally until it reaches the attenuator. This beam is split yet again and reflects between the beam splitter coating and the uncoated side of the attenuator plate. Three beams of decreasing intensity emerge from the coated side. The first and brightest of these beams travels horizontally into the fringe viewer. The second and third beams are deflected vertically by a mirror. A flag in front of the mirror blocks the second beam, allowing the third (dimmiest) beam to exit the interferometer where it is reflected off Mirror #3 and enters the telescope.

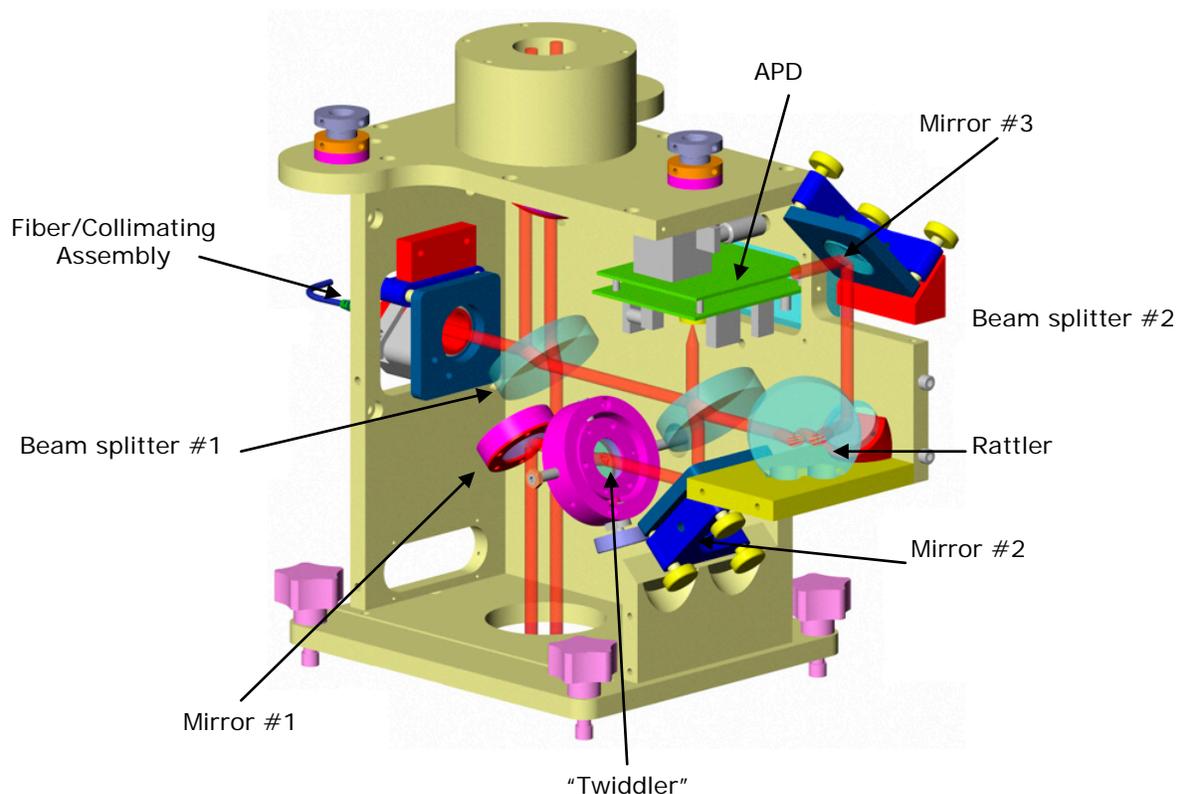


Figure 2-7 Schematic of FG5-X Interferometer

Beam Verticality

Because a non-vertical laser beam in the dropping chamber always results in a gravity estimate that is too low (an error of 9 arcsec in verticality corresponds to a gravity value error of approximately $-1 \mu\text{Gal}$). The error increases as $-\theta^2$, it is critical to align the beam with the local vertical as accurately as possible. To provide a local reference standard, a pool of alcohol is inserted in the interferometer.

In this configuration, the Test Beam reflects directly off the surface of the liquid and back up to the first beam splitter. When the beam is truly vertical, it reflects back directly through itself, reflects off the bottom of Beam splitter #1, and is parallel to the Reference Beam. The telescope is focused precisely to infinity, and thus parallel rays are focused to the same point in the viewfinder. By adjusting the input angle of the laser fiber (left side of Figure 2-8), the reference and test beams can be made to coincide in the telescope, and this can only happen when the beam is perfectly vertical.

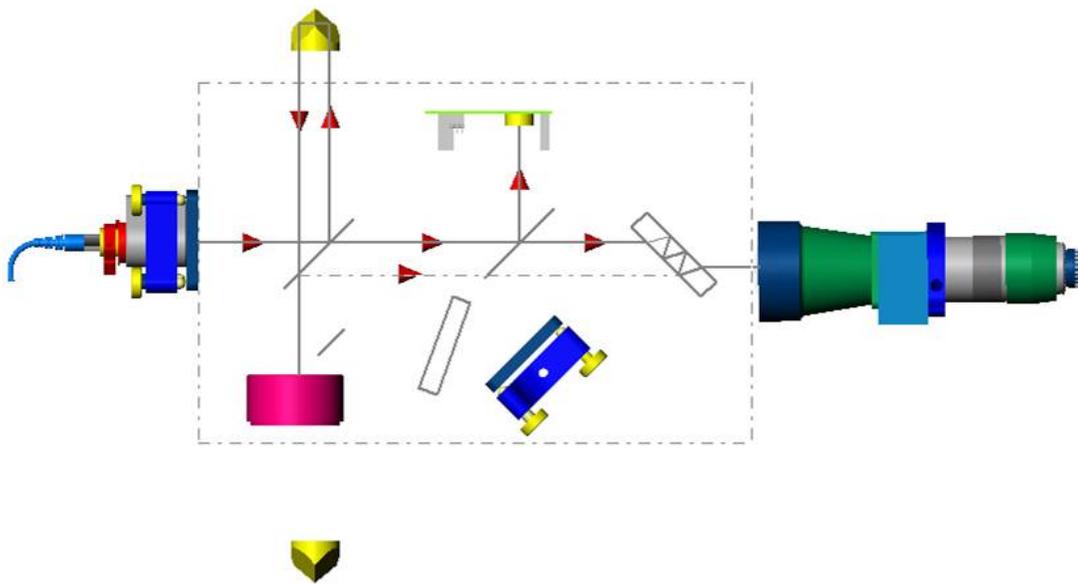


Figure 2-8 Beam Verticality Configuration

In Figure 2-8 the angle of the laser light out of the fiber is adjusted until the Reference and Test Beams (reflected off the surface of the alcohol pool) appear at the exact same location in the telescope.

Beam Alignment

In addition to making the Test Beam perfectly vertical, the user must also optimize the beam alignment. Because this procedure maximizes the interference fringe amplitude, this is often referred to as "fringe optimization". The configuration of the Mach-Zender interferometer is such that it gives the user complete freedom to make the Test and Reference Beams perfectly coincident and collinear at the detector. Refer to [Section 03 "Fringe Optimization"](#) for detail on the setup steps.

The tipping plate is adjusted to translate the Test Beam to be coincident with the Reference Beam. This is best viewed in the viewport at the end of the interferometer (not the telescope). By tilting the tipping plate about its horizontal and/or vertical axis, the Test Beam is simply translated relative to the (fixed) Reference Beam. Note that the angle of the Test Beam is not changed. This should be adjusted so that the Reference Beam is perfectly coincident with the Reference Beam in the viewport.

In addition, the angle of the Test Beam can be changed using mirror #2, below the telescope. This should be adjusted so that the Test Beam is perfectly overlapped with the Reference Beam in the telescope. When two points meet at the same point in the telescope, they are parallel.

When the Test and Reference Beams are truly collinear after beam splitter #2, concentric "bull's eye" fringe patterns will be visible in the viewport window. Good overlap should also be quantitatively verified using an oscilloscope to view the interferometer's Analog output and measuring the peak-to-peak voltage of the fringe signal. Refer to [Section 03 "Fringe Optimization"](#) for detailed set up procedures.

Superspring Theory

The Superspring (Figure 2-9) is a long-period, active vertical isolator used to compensate for small vertical motions of the first beam splitter. The Superspring has a short (20 cm) mainspring with a natural period of about one second. The mainspring is contained in a support housing (also supported by springs) that is actively servo-controlled to track the Superspring mass at the end of the mainspring. The result is a long-period (30-60 second, or 16-30 mHz), spring-mass system that isolates against ground motions occurring at a higher frequency than its own enhanced natural frequency. This insures that any change in the length of the test beam is due only to the acceleration of the dropped object.

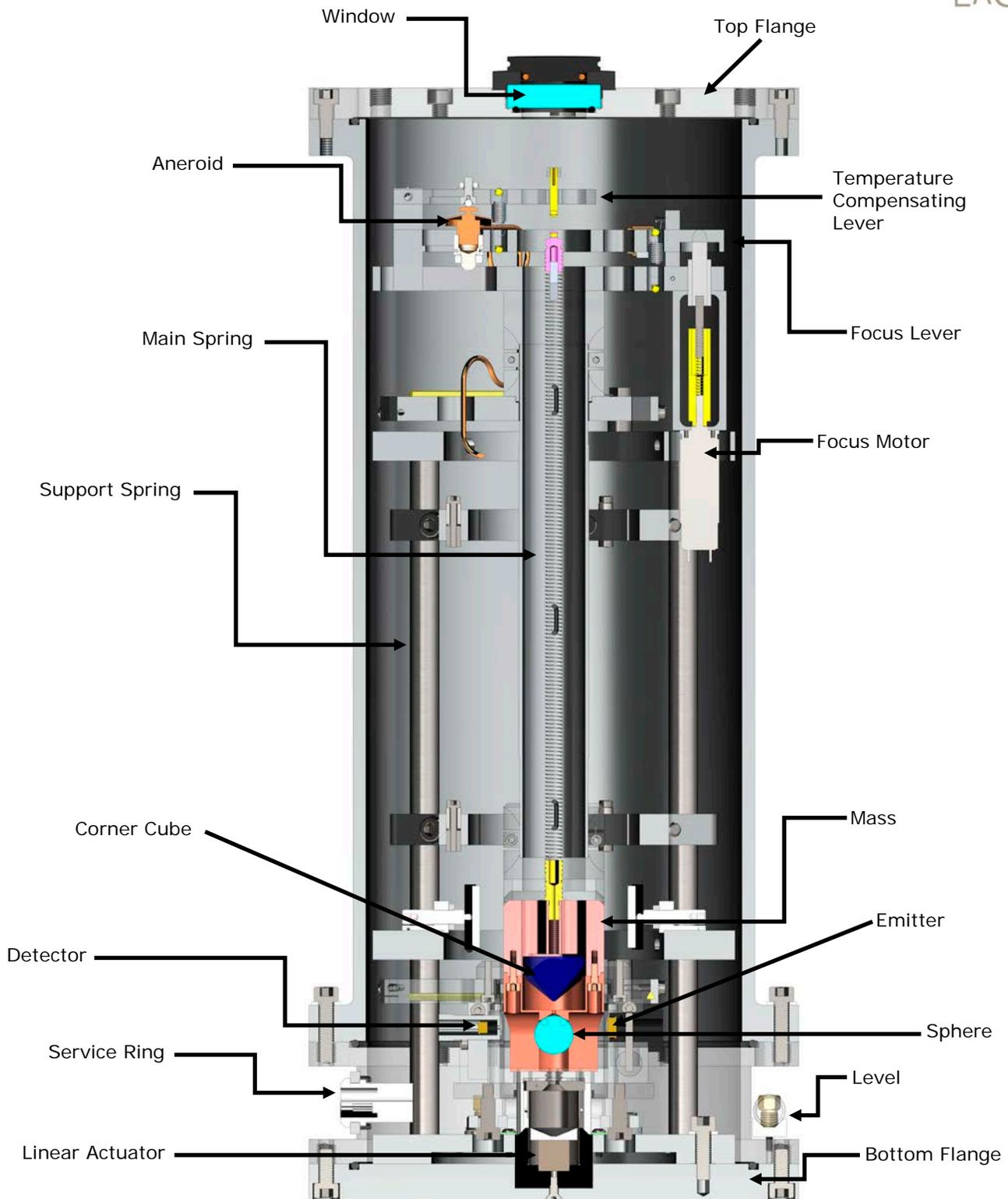


Figure 2-9 Superspring Main Housing

The servo mechanism works as follows:

- The Superspring sphere detector system senses motions of the Superspring mass relative to the inner support housing.
- An infrared LED located on the support housing directs light through an optical glass sphere attached to the Superspring mass.
- The sphere focuses this light onto a split photodiode detector mounted on the opposite side of the support housing.
- This signal from the split detector is fed back to a servo circuit which drives the support housing vertically, canceling any relative motion between the test mass and the inner housing.
- The drive mechanism is a linear coil actuator mounted between the support housing and the Superspring base.
- As vertical ground motion occurs, the linear actuator moves the support housing up or down in such a way as to keep the main spring length constant.
- This active servo effectively weakens the main spring, synthesizing a long period isolation device.
- The apparatus is constrained to move only vertically by a linear system constructed of five flexures (delta rods) arranged in an upper V-shaped array, and a lower triangular array.

The servo circuit is activated by turning SS SERVO on with the FG5-X System Interface Module (Refer to the [System Interface Module \(SIMx\) User's Manual](#) for more information).

NOTE

If SS SERVO is off and the spring is un-travel-locked, the spring is just hanging freely and bouncing with the system's natural frequency (about 1 Hz).

The Superspring system also contains a DC motor that is used to center the test mass vertically in its range---"zeroing the spring" (as described in the FG5-X Setup instructions, [Section 03 "Superspring"](#)). This motor is activated by turning SS ZERO ON with the controller. By monitoring the SS POS connector with a voltmeter, one can see the position approach 0 V indicating that the mainspring is in the center of its range.

IMPORTANT

If the gravimeter has moved to a location with a drastically different local gravity value than the previous measurement location, it might take a few minutes for the spring to get to this zero position. This is normal.

While it will not cause permanent damage to the system, it is best not to zero the Superspring with the servo activated.

Laser Theory

The FG5-X employs a stabilized helium-neon laser to provide an accurate and stable wavelength used in the interferometric measurement system. There are three lasers which are currently available for the FG5-X. Please refer to the user's manual appropriate to the laser type that shipped with your FG5-X system.

All models of lasers need to be warmed up and reach thermal equilibrium before gravity data are acquired. As a rule of thumb, it is best to power ON the laser the night before measurements, if possible. At a minimum the lasers should be on at least one to four hours for good results.

Regardless of the laser model, the light is always linearly polarized and reaches the interferometer via a single mode, polarization-maintaining fiber optic cable. The fiber polarization is set to match that of the laser light at the factory – under normal operations, it is never necessary to adjust the rotation at the input of the fiber.

The light enters the fiber optic cable via a 5-axis mount that focuses the light down to a diameter of a few microns. This adjustment is also done at the factory and is extremely sensitive. The laser light exits the fiber and diffracts at a well-defined angle to avoid back-reflections. A collimating assembly is attached to the output of the fiber and is adjusted such that the final beam is well collimated at approximately 8 mm.

NOTE

The collimation adjustment is performed at the factory. It is extremely sensitive, critical for the gravity measurement, and should not need to be adjusted.

Because the laser light is polarized, it is necessary to rotate the output of the fiber about its axis so as to evenly split the laser power between the test and reference beams (horizontally polarized light is transmitted more efficiently into the reference beam, while more vertically polarized light is transmitted in the test beam – the nominal position is thus at about 45°). This adjustment is performed at the factory and should not need to be changed by the user.

Winters Electro-Optics (WEO) Model 100

The Winters Electro-Optics Model 100 iodine stabilized laser is a primary standard for the definition of the meter at the Bureau International des Poids et Mesures (BIPM) in Sevres, France. It is a highly stabilized frequency standard (trivially converted to a distance standard in a vacuum) having an absolute frequency accuracy of 1 part in 10^{10} (50 kHz).

Winters Electro-Optics Model (WEO) 200

The Winters Electro-Optics Model 200 iodine stabilized laser is based on the 100 model, but iodine-stabilized laser is used to lock a second, more powerful laser to the same frequency. The result is a more robust output.

Micro-g LaCoste Model ML-1

The Micro-g LaCoste Model ML-1 frequency/intensity stabilized HeNe laser is characterized by a slow, linear drift. Unlike the WEO lasers, it must be periodically calibrated to achieve the best accuracy, but it is more rugged and powerful.



3. FG5-X SETUP

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These instructions are based on the assumption that all subsystems of the FG5-X are aligned correctly and operating properly. If adjustment or alignment is necessary, consult [Section 04](#) for instructions, before proceeding with set up. When setting up the FG5-X, it is helpful to use the FG5-X Setup Checklist in [Section 09](#).

Instrument Assembly

Locate and mark a reference point on the floor where gravity will be measured. The floor should be as clean, smooth, and level as possible. It is best to set up the FG5-X on a concrete pier or hard tile floor at ground level.

NOTE

These instructions assume that the dropping chamber is already at a high vacuum level. See [Section 05](#) for instructions on pumping out the dropping chamber.

Electronics Case

For a full discussion of the FG5-X electronics, refer to either the [Tele-g/Remote Gravimeter Operation User's Manual](#) and/or the [System Interface Module \(SIMx\) User's Manual](#).

- Place the electronics case in a convenient location about one meter from the reference mark.
 - Check the input voltage settings and make sure they are set to the proper AC line voltage.
 - All components in the FG5-X system, with the exception of the WEO laser, automatically switch to accommodate any line voltage from 100 – 240 VAC, 50 – 60 Hz. Refer to the WEO laser manual for instructions on setting the proper line voltage.
- If the ion pump has been maintaining the dropper vacuum on battery power, apply AC power to the ion pump power supply. See [Section 05](#) for more details on the ion pump controller.
- Make sure the following switches are off:
 - Power Supply: Main AC power (rear)
 - Power Supply: Main DC power (front)
 - Laser power (both main AC power and high-voltage key switch)
- Open the Interferometer case, and place the laser on the floor about one meter from the reference mark. Take care not to stress the fiber optic cable.

- Connect the main AC power cable from the FG5-X power supply (rear of electronics case) to the AC power receptacle.
 - If an uninterruptible power supply is to be used with the FG5-X, it should be connected to the main AC power source and the FG5-X AC power supply should be connected to the UPS output.
- Turn on the main AC power switch on the FG5-X Power Supply (rear of electronics case).
- Connect the applicable cables to the laser and turn on the laser power: first AC power, then the HV.
 - Consult the manual appropriate to the laser you are using.
 - It is important to turn on the laser as early as possible in the setup procedures to let the laser reach thermal equilibrium before the measurements begin.

Setting Up The Superspring Tripod

Figure 3-1 illustrates the location of the Superspring and Interferometer base for setup.

NOTE

The bubble-level on the Superspring tripod is on the operator's left when the FG5-X is setup. Also, the line from the center of the tripod to the bull's eye level should be oriented long the North-South axis.

- Remove the Superspring tripod from the interferometer case and place on the floor over the reference mark.
 - Orient the tripod so the bull's eye level (mounted near one of the leveling feet) is facing the electronics case, if possible.
 - A line from the bull's eye level to the center of the tripod should be aligned either north or south to minimize Coriolis accelerations on the dropped object.
 - The tripod can be centered over the mark by viewing the mark through the hole in the center of the tripod.
- Rough-level the Superspring tripod using the bull's eye level. If using an FG5-X with the Remote Operation option, consult the [Tele-g/Remote Gravimeter Operation User's Manual](#) for information on leveling the Superspring tripod.
- Measure the lower reference height using the depth gauge provided.
 - The lower reference height is the distance between the Superspring tray ring and the reference mark (approximately 5-15 cm).
 - Place the depth gauge parallel surface on the machined inside ring of the Superspring tripod.

-
- Pass the gauge rod through the hole in the center of the Superspring tripod and extend it until it hits the reference mark on the floor.
 - Tighten the locking screw and measure gauge length using the ruler.
 - Record this value in the system check log. This is referred to as the “lower set up height”.
 - Place the Superspring in the tripod.
 - Orient the Superspring so that the travel-lock (brass knurled knob on the service ring) is pointing toward the bull’s eye level.
 - Clamp the Superspring to the tripod by turning the three 5-lobe knobs fully clockwise. This rotates the clamps in place over the base of the Superspring.
 - Level the tripod noting the two precision level vials on the base of the Superspring.
 - Be sure to adjust the cross level first, then the long level. The cross level is opposite the Superspring travel-lock (brass knurled knob). If the long level is adjusted first, it will change when the cross level is adjusted. When the cross level is adjusted first, it does not change when the long level is adjusted.
 - Only turn two of the feet while leveling; this insures that the lower reference height does not change. If using an FG5-X with the Remote Operation option, please consult the [Tele-g/Remote Gravimeter Operation User's Manual](#) for information on leveling the Superspring tripod.

NOTE

While leveling the Superspring and dropping chamber tripods, note that turning the tripod feet clockwise lowers the dropping chamber tripod and raises the Superspring tripod.

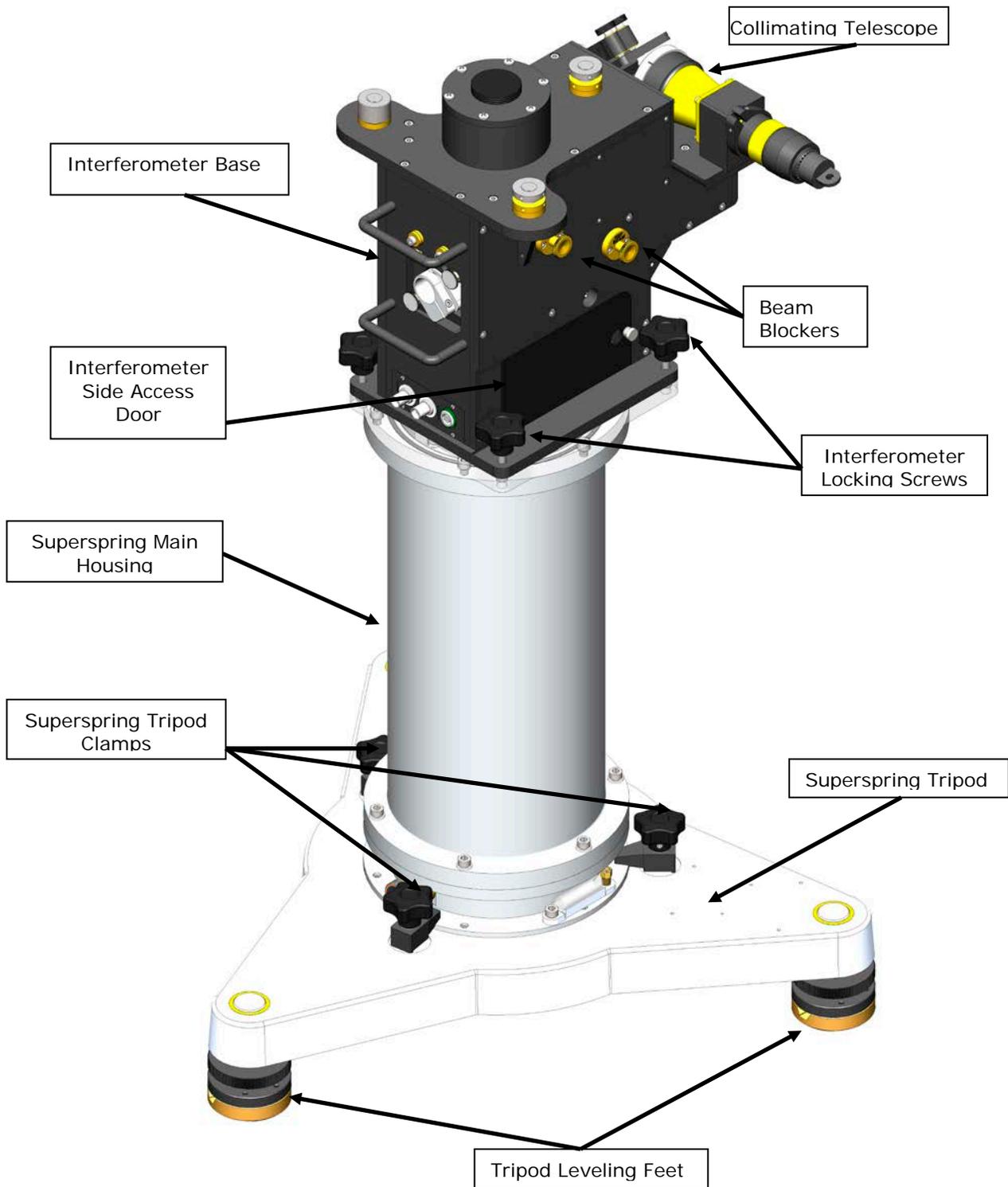


Figure 3-1 Superspring interferometer Setup

Interferometer

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

Dropping Chamber Tripod

- Remove the tripod tray from the Superspring case and place it carefully upside-down in the lid of the transit case.
- Remove the three tripod legs from the dropping chamber case and attach them to the tray. If necessary, tighten the legs by using the ~30 cm “cheater” bar.
- At this point the interferometer is used to support the dropping chamber tripod.
 - First, remove the dust cap from the top of the interferometer base.
- Carefully place the dropping chamber tripod on the interferometer.
 - Orient the tripod so that the small hole is above the Superspring travel-lock and laser fiber.
 - Be careful not to damage the mirror on the right side (near the telescope) of the interferometer base.
- Carefully remove the dropping chamber from its case by the handles and gently place it into the pocket in the top of the tripod tray, allowing the two vertical alignment pins in the tray to engage the sockets in the dropping chamber base.
 - Orient the dropping chamber so the ion pump is directly above the beam blocker controls on the interferometer.
- Lock the dropping chamber in place with the three clamps by turning the 5-lobe knob fully clockwise. This rotates the dropping chamber clamps in place over the base of the chamber.

Leveling The Dropping Chamber

NOTE

While leveling the Superspring and dropping chamber tripods, note that turning the tripod feet clockwise lowers the dropping chamber tripod and raises the Superspring tripod.

- Check the Superspring levels and adjust, if necessary, by leveling the Superspring tripod.
- When the Superspring levels are centered, the dropping chamber tripod levels should be within two divisions or so of the center position. If the levels do not agree, this may indicate a problem. Consult [Section 04](#) for instructions.
- Remove the blue pads and brass tripod feet from the Superspring case. Make sure the pads and tripod feet are clean.
- Place a tripod foot under each leg of the tripod. Raise each foot and slide a blue pad under the foot.
- 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 barely contact the balls.
 - It is important that the foot and the nylon foot of the tripod leg are perfectly centered with each other. Otherwise, the dropping chamber will shift sideways when it is lifted.
 - It is helpful to rotate, or wiggle, the foot slightly (while it is in contact with the nylon ball) to release any horizontal tension.
- After each foot is in contact with the tripod leg, rotate each tripod foot leveling screw one revolution (counterclockwise), using the mark on the top of the adjustment screw as a reference.
 - Then, rotate each tripod foot leveling foot one additional revolution as described previously. It is important to do one turn at a time – this keeps the dropping chamber centered over the interferometer.
 - The two total turns raise the tripod off of the interferometer so there is no contact between the two components.
 - Each counterclockwise revolution of the leveling screw raises the tripod about 0.75 mm
- Fine-tune the level of the tripod tray by adjusting the dropping chamber tripod feet (not the Superspring tripod legs).
 - Be sure to adjust the cross level first, then the long level. The cross level is parallel to the telescope and the long level is perpendicular to the telescope.

- It is best to adjust the levels by raising the appropriate adjustment foot. (If the foot is used to lower that side of the tripod, there is a risk that the tripod will contact the interferometer).

Note

There must be no contact between the tripod-dropping chamber assembly (and their cables) and the interferometer/Superspring assembly (and their cables) during the measurement.

- Check the Superspring levels and adjust, if necessary, using the leveling feet on the Superspring tripod. At this point all Superspring and Dropping Chamber bubbles should be centered.
- Measure the “upper set up height” using the ruler and fixture provided. The upper reference height is the distance between the top of the interferometer base and the bottom of the dropping chamber.
 - Loosen the clamp on the ruler and pass the ruler up through the access hole in the dropping chamber tripod while pulling it slightly towards yourself (the hole is located directly above fiber optic input on the interferometer base) until it contacts the top of the interferometer base.
 - The upper set up height should be approximately 6 cm.
 - Record this value in the system check log.
 - The sum of the upper and lower set up heights (approximately 13 cm) are entered as the **Setup Height** in the **Information** tab page of the **Setup** dialog of g-software. Refer to the [g-software Absolute Gravity Data Acquisition And Processing Software User’s Manual](#) for details.

Cable Connections

For details on the electronics setup, please refer to the [System Interface Module \(SIMx\) User's Manual](#) or [Tele-g/Remote Gravimeter Operation User's Manual](#).

- Connect the computer power cable to the power supply panel or AC outlet.
- Connect the PCMCIA cable from the eX-Box (older systems Magma PCI) unit to the PCMCIA slot on the computer.
- Check that the USB cable from the rear of the SIMx is connected to the computer.

- Connect the BNC cable from the interferometer base **TTL** connector to the **TTL** connector on the computer time interval card in the eX-Box (older systems Magma PCI) unit.
- Connect the BNC cable from the **10 MHz** connector on the back of the SIMx to the **CLK** connector on the computer time interval card in the eX-Box (older systems Magma PCI) unit.
- Connect the BNC cable from the **DROPPER TRIGGER OUT** connector on the SIMx to the **TRIGGER** connector on the computer time interval card in the eX-Box (older systems Magma PCI) unit.
- Connect the BNC cable from the interferometer base **ANALOG** connector to **ANALOG FRINGES IN** on the rear of the SIMx.
- For the WEO Model 100 laser:
 - Connect the BNC cable from the **OUTPUT** connector on the front panel of the laser controller to **LASER 1F** on the front of the SIMx.
 - Make sure the meter select switch on the laser controller is set to the **1F** position.
- For the Model ML-1 Laser:
 - Connect the Laser LOCK and Laser MODE BNC cables from the ML-1 controller to the respective locations on the rear of the SIMx.
- Connect the BNC cable from the **METER MONITOR** connector on the ion pump power supply to **ION PUMP** on the SIMx. Set the meter select switch to the 10^{-4} A scale on the ion pump power supply.
- Make sure DC power on the SIMx is OFF, and attach the rest of the system cables as described below. Both ends of all cables are labeled with the proper location for each connector.
 - Connect the rotary shaft encoder cable (blue Lemo connector) from the SIMx panel to the blue Lemo connector on the motor drive assembly.
 - Connect the DC motor power cable (orange Lemo connector) from the SIMx panel to the orange Lemo connector on the motor drive assembly.
 - Connect the APD power cable (green Lemo connector) from the SIMx panel **APD** to the interferometer base **IB POWER** connector.

Superspring

- Connect the Superspring control cable (yellow Lemo connector) from the SIMx panel to the connector at the base of the Superspring.
 - Confirm that the DC Power is off at this point.
 - Do not attach the Superspring control cable while Servo is on.
- 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 (approximately 180°).
 - Slowly release the travel-lock knob. The arrow on the travel-lock knob points down when the spring is locked, and up when it is unlocked.
- Use a voltmeter to monitor the spring position **SPRING POSITION** on SIMx panel, and wait for the spring to settle down so that the “scatter” is about 50mV or less.

DC Power On

- Turn on DC Power.
 - On the front of the SIMx under **STATUS** note that the Rubidium clock light will flash briefly and then stay dark until the clock locks at 10 MHz (typically within 5 or so minutes).
 - On the SIMx, verify that the dropper is in reset mode, and the spring has both **ZERO** and **SERVO** off. Depending on conditions, it is possible that one or more of these switches will be ON when the power is enabled. Make sure to turn them off as quickly as possible.
 - For more information on the SIMx, please refer to the [System Interface Module \(SIMx\) User's Manual](#).
- Next determine the spring position.
 - After un-travel locking, the spring will take a few minutes to settle. After it has settled, determine its approximate mean position. If it is farther than about 20 mV from zero, enable the **ZERO** switch on the SIMx. This brings the spring to the center of its range within a few minutes. When the position is within about 20 mV of zero (or stops moving) disable **SS ZERO**.
 - It is normal for the SS POS value to fluctuate as the reference mass bounces on its spring, but eventually it should damp out, and the fluctuations should be ≤ 20 mV. At this point, enable **SERVO**.
- After five minutes or so, the “scatter” of the spring position should be 1-2 mV on a voltmeter. If the spring is not totally at

thermal equilibrium, the position slowly drifts in one direction. This is normal and should not affect the measured gravity value. The spring is moving at approximately a constant velocity and will not affect the gravity determination.

Beam Verticality

- Before optimizing the alignment of the interferometer, make sure the test beam is perfectly vertical.
 - Place the alcohol pool in the interferometer taking care to roughly center the laser beam in the pool. In the telescope you should see a solid light (the reference beam) and a vibrating light (test beam) that is reflecting from the alcohol pool.
 - Adjust the angle of fiber optic using the mirror mount (left side of IB) until the test beam is exactly centered over the reference beam in the telescope. Use the beam blockers as necessary to help determine the positions of both the reference and test beams.
 - Then remove the alcohol pool.

NOTE

It is possible to move the test and reference beams to the center of the telescope viewfinder by adjusting mirror # 3, located in front of the telescope objective. This does not affect the interferometer alignment; it is only for the user's convenience.

Fringe Optimization

- To optimize the fringe signal, the test and reference beams must be made perfectly coincident and parallel. The two interfering beams should be perfectly overlapped and also have no angular deviation for the greatest signal.
 - If at this point the reference beam is vertical, no further adjustments can or should be made to the reference beam.
 - The test beam is adjusted to match the position of the reference beam. The translation of the test beam is done by adjusting the translator plate (usually called the "twiddler"). The angular deviation is adjusted by adjusting mirror mount # 2, located below the telescope (Refer to [Section 02, Figure 2-7](#)).

NOTE

It is possible to move the test and reference beams to the center of the telescope viewfinder by adjusting mirror # 3, located in front of the telescope objective. This does not affect the interferometer alignment; it is only for the user's convenience.

- Look in the viewport (on the right side of the IB – not the telescope) and adjust the twiddler until the test beam overlaps the reference beam.
- Look in the telescope and adjust mirror # 2 so that the test beam overlaps the reference beam. Use the two knobs that are diagonally opposite of each other. The two beams are now at least roughly coincident and parallel.
- Connect the **ANALOG FRINGE** output on the SIMx to an oscilloscope, with the following settings:
 - Vertical scale = 50 mV/div
 - Horizontal scale = 2 μ sec/div
 - AC coupled input
 - Automatic trigger at 0 V
- Make sure the laser is locked. Set the dropper to OSC mode by pressing **OSC** on the SIMx. Press **TRIGGER** to make the cart move slowly up and down at a constant velocity which produces a constant frequency fringe signal which is useful for adjusting the twiddler and mirror #2.
- Maximize the fringe signal on the oscilloscope by adjusting mirror #2. Use the two adjustment knobs that are located diagonally from each other. Optimize the mirror in both directions (horizontal and vertical).
- Further maximize the fringe signal on the oscilloscope by adjusting the twiddler.
- Return to mirror #2 and fine tune in both directions to perfectly maximize the fringe amplitude. Nominal fringe signal is 300 - 400 mV, peak-to-peak.
 - Record this value in the system check log.

IMPORTANT

Do not operate the FG5-X if the fringes are below 300 mV or above 400 mV. This can adversely affect the measured gravity value. Refer to [Section 04 "Adjustment and Maintenance"](#) for troubleshooting details.

- Terminate OSC mode by pressing **DROP** on the SIMx
 - This places the dropper controller in DROP mode, ready for data acquisition
 - The cart is brought safely down the bottom at the end of next OSC cycle.
 - The **DROP** button can be pressed at any point in the cart's motion. Alternatively, pressing **TRIGGER** places the dropper in *REST mode at the end of the next OSC cycle*.
 - If the fringe amplitude is too small (less than 250 mV, or has dropped noticeably from earlier measurements), it is most

likely an alignment problem. Make sure that there is enough range in the twiddler to overlap the beams well. Make sure that the beams are both circular, and not "clipped".

- Laser power is also directly related to fringe amplitude, and it is possible that the laser may have lost power to a bump that has changed either the internal or fiber optic cable alignment. Check the DC voltage (laser power) on the WEO controller to make sure it is what you expect (typically 5-10 V is adequate). A complete discussion of laser power is beyond the scope of this manual (refer to the WEO-100 User's Manual for additional information).
- Double-check verticality one last time, in case any bumps or misalignments occurred. Then do not touch the instrument until the end of the measurement cycle.

Software Setup

FG5-X specific setup procedures are listed below. Refer to the [g-softwareAbsolute Gravity Data Acquisition And Processing Software User's Manual](#) for complete software and setup procedures.

Computer System Power On Sequence

- Power on the AC to the eX-Box (older systems Magma PCI) unit. Turn on the power switch on the front of the eX-Box (older systems Magma PCI).
- Verify that the PCMCIA cable is attached from the eX-Box (older systems Magma PCI) unit to the PCMCIA slot on the laptop computer.
- Power on the laptop computer

IMPORTANT

Do not let the laptop "sleep" or "hibernate". This causes problems with the laptop/Magma connection, and a total power-down reboot in the above order is required.

Information Setup

Enter the total reference height information.

Reference Height = The sum of the lower and upper reference height measure in [Section 03 "Setting Up The SuperspringTriopod"](#).

System Setup

With "L Series" (Micro-g ML-1 lasers).

- The laser frequencies are calibrated at Micro-g (see [Section 02 "Laser Theory"](#) for details on the ML-1 laser).
- It should not be necessary to change these values.
- Set the Pre-run lock time to be approximately 30-60s. This is the time the laser is allowed to lock prior to the beginning of each set. During data acquisition it is necessary to make sure that there is enough time to take all the data and allow for laser lock between sets.

With WEO (100 or 200) lasers.

- These wavelengths are determined at BIPM, and should never be changed.
- Refer to the WEO manual for the exact value of the laser modulation frequency.
- Use a voltmeter to measure the 1Fvoltages for peak names D-G, and enter these values here. (Note that if a peak name D-G is chosen for data acquisition, it is not necessary to enter values for H-J).

Guide Card Parameters

The correct Guide Card Parameters must be set in the same manner using the **Setup** button beneath the Fringe Card box. Refer to Table 3-1 for the standard FG5-X recommended settings.

Table 3-1 Standard FG5-X Dropper Recommended Settings

Input Multiplexor	4
Prescale	250
Fringes Acquired	700

A2D Card Settings

A2D card settings must also be entered. For the National Instruments card, the recommended settings are as shown in Table 3-2.

Table 3-2 DAQ Card Settings (Older systems with SIM)

	Offset	Multiplier
Channel 0	0	100
Channel 1	0	1
Channel 2	0	1
Channel 3	0	1
Channel 4	537.5	125

The settings for the new SIMx (serial) are automatically loaded when the serial card is selected. Table 3-3 lists the defaults. Channels 5 - 10 can be changed by the user for custom inputs.

Table 3-3 DAQ Card Settings (Newer systems with SIMx)

	Offset	Multiplier
Channel 0	0	0.122076
Channel 1	0	0.000153
Channel 2	0	0.000153
Channel 3	0	0.000153
Channel 4	537.5	0.0095552
Channel 5	0	1
Channel 6	0	1
Channel 7	0	1
Channel 8	0	2.44141
Channel 9	0	2.44141
Channel 10	0	2.44141

Serial Baro

The pressure sensor is internal to the SIMX and communicates through the same USB cable. Ensure that the **Serial Baro** box on the **System** tab page of the g-software **Settings** dialog is checked and the appropriate COM port is selected (Same as SIMX).

Acquisition Setup

- Select the appropriate start time option
- Then enter the drop interval (a minimum of 5 seconds should be used with an FG5-X). The set interval should be set to your choosing.
- Check the Pulse Delay
 - The Pulse Delay is the time between the lift and drop of the test mass.
 - It should be about 1/3 of the drop interval, or set to a minimum of 3 seconds.
 - If the intervals are inconsistent the software issues a warning.
 - Typical intervals for an FG5-X are 10 seconds per drop.

There is a whole possible philosophical discussion of “how much data is enough?” The short answer is to take enough data so that statistically you have the precision you desire. This might require a short test run to determine the drop-to-drop scatter in the measurements.

Control Setup

General Terms Section

The General Terms section in **Control Setup** shows the gravity correction terms that can be applied. For the initial setup, select all of these terms.

Tidal Terms Section

In the Tidal Terms section, select **ETGTAB** for the first test run.

For each new location, it is necessary to enter **Setup** and **Run Ocean Load**.

- Make sure that the ocean load files created have unique filenames.
- Make sure the correct files for your current location are used.

Laser Section

In the Laser Section, select the **Auto Peak Detect**. The software automatically selects the mode and locks the laser prior to each set.

Data Section

In the **Data** Section enter the start and stop fringe time, typically 25 ms to 245 ms.

Refer to the g-software Absolute Gravity Data Acquisition And Processing Software User's Manual for a complete discussion of all of these options.

Running The Gravimeter

Before starting the gravimeter, check the following:

- Superspring has been unlocked.
 - The Superspring servo is ON.
 - The Dropper has been separated from the Interferometer.
- The SIMx automatically puts the dropper controller into the correct t mode.
- For ML-1 lasers:
 - The laser is in **REMOTE** mode
 - The left LED illuminated, (and should therefore be UNLOCKED at this point. Whether the mode is RED or BLUE at this point is irrelevant.) The software will automatically select the mode and lock the laser prior to measurement.
- For WEO lasers:
 - The laser is locked on a peak (d – g). Typically runs on “e”.
 - The Monitor output is connected to **LASER 1F** on the SIMx.
 - The Rubidium LOCK is ON.

Starting The Measurement

To start processing in g-software, select **Go** from the **Process** menu or press the **GO** button on the toolbar (or use **F5** as a quick key).

The **State** dialog in g-software shows the value of gravity, a graph of each drop relative to the current mean value, and the residuals of the parabola fit.

Refer to the g-software Absolute Gravity Data Acquisition And Processing Software User's Manual for a complete discussion of all the g-software windows.

When the first measurement set is completed, it is automatically saved to disk.

NOTE

If at this point, the application is stopped, the Project is no longer in real time mode. In g-software, if you select **Stop** under the **Process** menu and then select **Go**, the program replays the data, rather than operate the FG5-X.

When all the sets have finished, it is safe to quit the application (the data are already automatically saved at the end of each set).

If you notice a problem, and stop the acquisition during the first set, you can restart the project without creating a new project. If you stop during any other set (after Set 1) however, g-software will automatically save all the completed sets and you will lose whatever data was in the incomplete set.

WARNING

It is important not to stop g-software until the data from the previous set(s) has been written to disk. This process can take several seconds. This can be seen on the bottom right of the screen.

Stopping the program during this time can cause g-software to crash and data to be lost.

Data Quality

A complete discussion of data analysis and interpretation is beyond the scope of this manual; however, a basic understanding will help ensure that your data is of high quality.

Drop Residuals

- The residuals are the difference between the actual, measured fringe location and the final, best-fit parabola.
- Make sure that the residuals are relatively flat (<1 nm).

The State Window

- Note the Drop Gravity Value.
- Verify it is reasonable.
- Note the values of the analog signals.
 - Check for reasonable and stable barometric pressure and spring position values
 - Check for reasonable gravity correction values (in μGal).

Drop Gravity

- Verify the Drop Gravity value is reasonable for your location.
 - In a quiet, stable, laboratory, this should be approximately 5 – 30 μ Gal.
 - In the field this might be higher.
- Verify that the mean value is stable. There should be no noticeable drift in the mean value throughout the set.

Laser (ML-1)

- Between sets, verify that the system is unlocking the laser, and then relocking to the alternate laser peak before the next set starts.
- From set-to-set, are the RED and BLUE gravity values self consistent?
 - If for some reason the RED and BLUE locks have become switched in the software, a 1.4 milli-Gal difference will be observed.
 - This can be easily fixed by stopping data collection and clicking the 'Switch' button found in the 'Setup' tab of the 'System' parameters. (This can be done in replay as well.)

Laser (WEO)

- Is the software automatically detecting the right peak? The difference, in μ Gal, between laser peak wavelengths is about 25 μ Gal.

Reprocessing Data

Once the measurement is finished (or if it is stopped after the completion of at least the first set), in g-software, selecting **Go** under the **Process** menu causes the system to "replay" the data. g-software asks if you would like to overwrite the previous output file (project.txt).

Clicking **YES** (or choosing a different output filename), causes the program to read the data files from the disk, and re-process each drop.

If desired, it is possible to change the input parameters (common examples include a new nominal pressure, more detailed location values, etc.) and then replay the data.

The parameter settings in place at the actual time of measurement can always be recovered by selecting **All** from the **Reset** selection list under the **Edit** menu in g-software.

Shutting Down The FG5-X

If the FG5-X is not used for a long period, shut everything down with the exception of the ion pump power supply. Even if the instrument is to be stored for a few months, it is better to leave it under vacuum with the ion pump on. Turn the ion pump off only if shipping regulations require it.

Shut Down Process

- Back up any data if applicable.
- Then close all the windows on the computer and power the computer down.
- Turn DC POWER OFF.
- Turn off the laser high voltage and then turn off laser power.
- Back up data if applicable and shut down the laptop computer
- Turn AC POWER OFF.

Dropping Chamber

- Travel lock the Superspring:
 - Pull out the travel-lock brass knob until it engages the locking mechanism, and rotate the lock 180° clockwise to lock it in place. The arrow on the travel- lock knob points down when it is locked and up when it is unlocked
- Open the three dropping chamber clamps by turning the 5-lobe knobs fully counterclockwise so the clamps are outside the bottom flange of the dropping chamber.
- Gently lift the chamber off the tripod and set it in its case. If the HV and safety ground cables are still connected, take care not to stress them.
- Disconnect the following cables:
 - APD power cable (green)
 - Superspring control cable (yellow)
 - Dropper motor (orange) and encoder (blue)
 - Interferometer TTL BNC cable
 - Interferometer Analog BNC cable
 - Ion pump monitor BNC cable
 - Any cable connected to the system computer.

Dropping Chamber Tripod

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

Interferometer

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

Superspring

- The Superspring should already be travel locked.
- Insert the dust plug in the top of the Superspring.
- Loosen the three 5-lobe knobs which attach the Superspring to the Superspring tripod.
- Remove the Superspring from the tripod and place in its shipping case.
- Close the Superspring shipping case and secure all latches.



4. ADJUSTMENT AND MAINTENANCE

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With proper and careful setup and operation, the FG5-X provides accurate and reliable results. A full list of all adjustments is beyond the scope of this manual. Listed below are some common issues, their explanation, and their resolutions. If you suspect that there is a problem, contact Micro-g LaCoste (<http://www.microglacoste.com/contact.htm>) first before attempting these repairs or adjustments yourself.

Superspring

Superspring problems usually manifest themselves as either an inability to zero properly or through high drop scatter and strange residuals. In some cases it will be necessary to open the Superspring to ascertain the source of the problem.

Removing The Superspring Cover

If it is necessary to open the Superspring:

- Place the superspring in its tripod
- Level it.
- Make sure it is travel locked.
- Loosen the six screws at the bottom of the main can.
- Remove the whole can and lid straight up together. Note that there are punch marks to indicate the orientation of the can relative to the Superspring base.

WARNING

Do not open the cover by removing the bottom flange. This will damage the internal electrical connections through the service ring.

Spring Position Is Off The Detector

Problem

The mass is extremely far from the center of its range (e.g. due to an extreme change in either temperature or local gravity), the spring controller may appear to be behaving incorrectly: it may appear to go the “wrong way” (e.g. more negative, even though the motor is set to lift the mass)

Cause

The light from the LED is not actually on the detector. As more light misses the detector (either going off the top or bottom), the absolute value of the voltage becomes less and less, making it appear that the spring is nearer zero than it actually is. This

problem is handled automatically in the newer Superspring controllers.

Solution

Refer to Figure 4-1. If the LED light is off of the detector, the SPHERE position will read about zero volts. As the light is brought on the detector, the voltage appears to go the “wrong” way at first. Keep moving the spring position until it is about the “true” zero value.

IMPORTANT

To be sure the Superspring is centered about the middle of its range (and not off the detector), verify that the spring is bouncing through both positive and negative SPHERE voltages. If it is always displaying a slightly negative (positive) value, then spring is below (above) the detector.

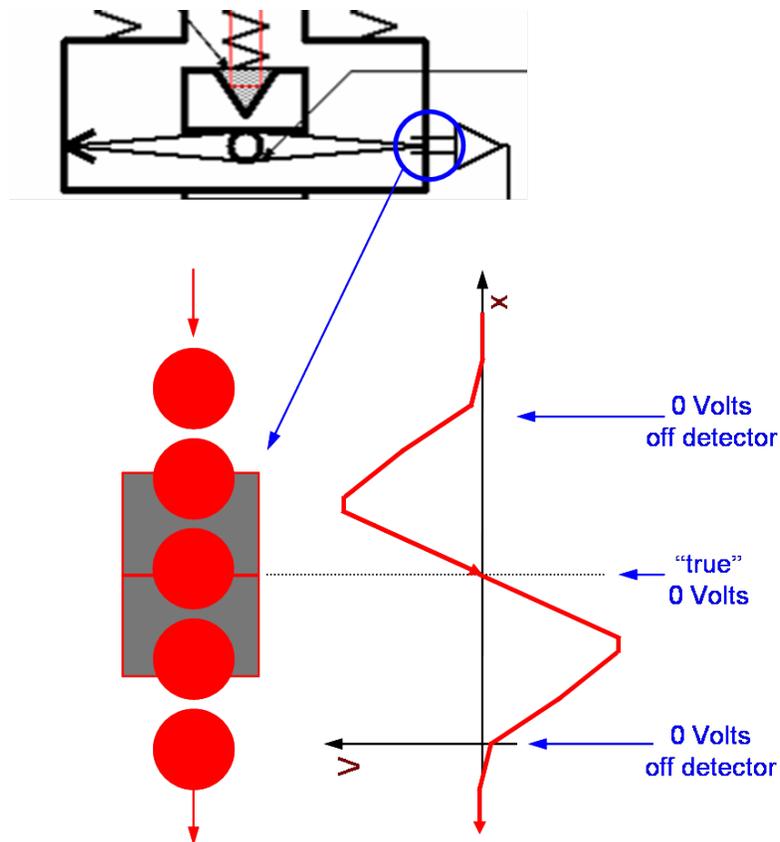


Figure 4-1 LED Light Intensity As A Function Of Detector Position

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

The Zero function of the SIMx (refer to the System Interface Module (SIMx) User's Manual) automatically accounts for this when zeroing the spring position. As a check to make sure everything is functioning normally, the spring should oscillate between positive and negative voltage when it is around the true zero (center) of its range.

Superspring Will Not Go To Zero

Problem

In some cases, the automatic zero function will not bring the system to the center of its range. Normally this happens when the spring is so far out of range that the circuit “thinks” the spring really is at zero (or it is so close to zero that the motor moves extremely slowly).

Solution

The “trick” is to enable **ZERO** on the SIMx, and then travel lock and un-travel lock the Superspring (perhaps repeatedly). This causes the mainspring to bounce, and the end will, at some point, cross the detector. This allows the circuit to “see” the true position, and adjust the position accordingly.

If that does not work, open the Superspring (as described above) and check to make sure that the limit switches have not been engaged.

Gravity Data Shows Very Large Scatter or Large Residuals

Problem

The gravity meter shows larger-than-normal scatter, or the residual size is larger than about 10 nm. This can indicate bent or broken Superspring flexures.

Cause

This is typically caused by rough handling during transport.

Solution

Remove the Superspring cover as described above, and check each flexure for straightness. Figure 4-2 shows a photograph of a bent Superspring Flexure. The small wire and the brass portion of the flexure should be parallel.

If the flexure(s) is slightly bent, the repair can be as simple as taking a standard pencil and using the eraser end to “push” the flexure back straight. Otherwise, contact Micro-g LaCoste for instructions.

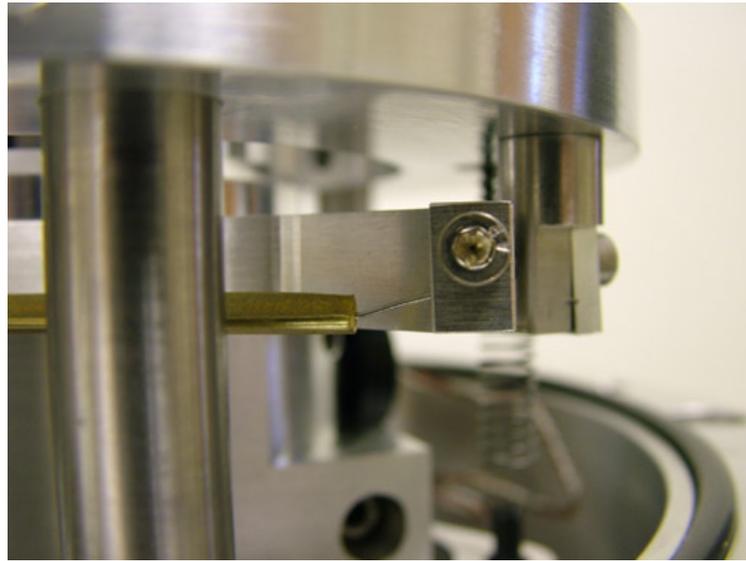


Figure 4-2 Bent Superspring Flexure

If the small wire portion of the flexure has completely broken off, it needs to be replaced..

- Loosen the Allan screws and remove the broken flexure.
- Take a replacement flexure (standard pieces in an FG5-X toolkit), and attach the end on the “outside” of the Superspring first.
 - The “outside” is the portion that connects to the main rings and vertical posts that are attached to the Superspring base.
- Attach the “inner” side of the flexure.
- Un-travel lock the Superspring and let it settle.
- Locate the six guide pins along the Mainspring tube, as shown in Figure 4-3.
- Use a feeler gauge on the Superspring guide pins to verify that that all six gap spacing are equal.

- If one or more is too small, loosen and reset the inner portion of the corresponding flexure.
- Iterate this procedure for all flexures until all six gaps at the guide pins are equal.

WARNING

Never loosen the guide pins. These are set at the factory and are your only reference for aligning the flexures that allows the servo mechanism to have the necessary clearance to function.



Figure 4-3 Superspring Guide Pins And Feeler Gauge

Alignment

Completely aligning the Superspring is beyond the scope of this manual, but in the rare case that the Superspring bubble levels become misaligned:

- Place the Superspring on a perfectly level table.
- Set the bubbles to the center using a 2.5 mm Allan wrench and an 8 mm open end wrench.

Dropping Chamber

Dropping chamber problems are broken into the following categories:

- Ion Pump
- Feedthrough
- Dropper Tuning Adjustments

- Drive Belt Replacement
- Dropper Alignment

Ion Pump

Once the vacuum is established and the ion pump is functioning, typically there is very little that can go wrong with an ion pump.

Problem

If the vacuum is somehow lost, and the vacuum level is compromised while gravity data are being acquired, a characteristic "sine wave" starts to appear in the residual plot (Refer to Figure 4-4. Note the vertical scale is about 10X larger than normal.) At this point, the data are un-recoverable, and the system needs to have the vacuum restored.

Solution

Refer to [Section 05](#) for more details on restoring the vacuum.

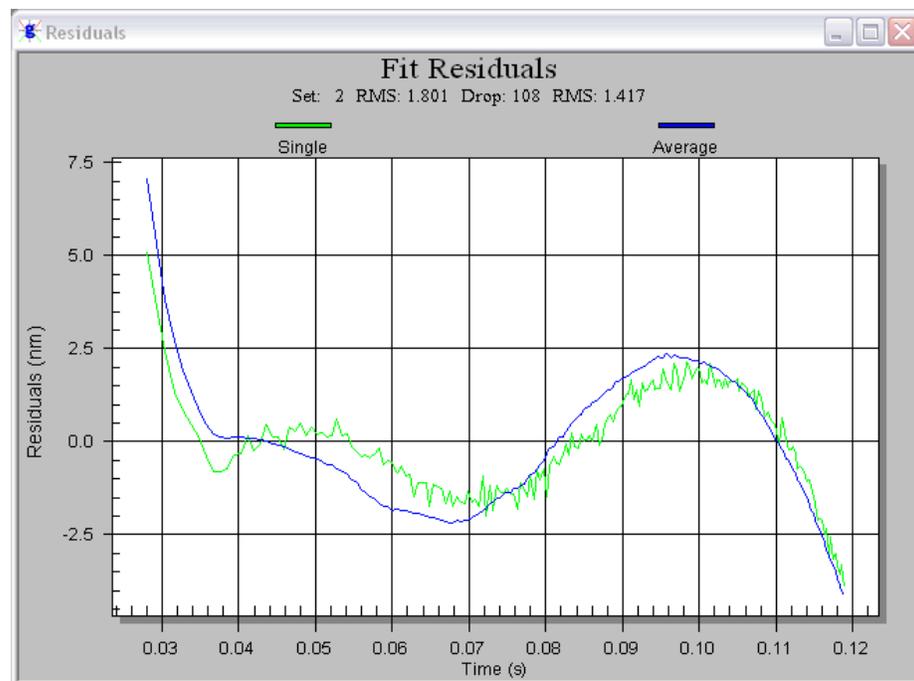


Figure 4-4 Characteristic Residual "Sine Wave" Signal

Feedthrough

The ferrofluidic feedthrough allows the external motor to drive the dropper cart through the vacuum wall. When the FG5-X has been sitting idle for a while (10s of minutes), it is normal to see a momentary increase in ion pump current for the first few drops. This is due to the release of molecules in the feedthrough mechanism. The ion pump then “catches up”, and the vacuum returns to normal.

Problem

The feedthroughs typically have a lifetime of about two to three years. When they begin to fail, the ion pump increases are larger, and take many, many drops to return to normal. When the feedthrough fails completely, the increase is “permanent” through all the drops, and the vacuum does not recover until the dropper is idle.

Solution

At this point, it is necessary to replace the feedthrough. The replacement procedure is beyond the scope of this manual. Please contact Micro-g LaCoste for instructions on the replacement.

Dropper Tuning Adjustments

A full discussion of the dropper tuning circuit is too large for this manual. The SIMx dropper controller is very robust and problems with dropper tuning are rare. If needed contact Micro-g LaCoste for instructions on how to change tuning.

Drive Belt Replacement

Problem

The drive belt breaks.

Solution

Drive Belt is a non-serviceable item. Contact Micro-g LaCoste for factory service.

Dropper Alignment

The bubble levels are set at the factory to insure that the dropper is oriented correctly at each setup. They are used to ensure that the cart precisely catches the test mass at the bottom of the drop (even if they are not precisely vertical with

respect to the outside of the chamber, or even if they are not exactly straight).

Problem

If the bubble level setting somehow changes or the chamber is opened for any reason, they need to be reset.

Solution

NOTE

Unlike the Superspring, the bubble levels are not simply set to make the dropper level. The dropper needs to be tilted (generally, not level) to an optimal position, and then the bubble levels are set so that this position can be repeated.

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

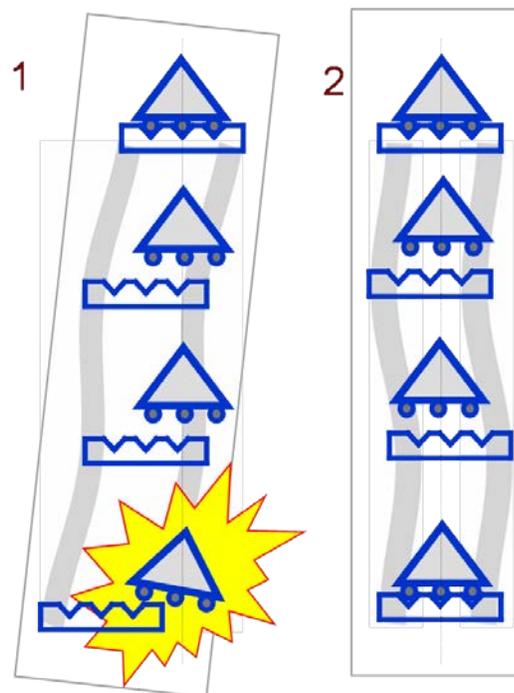


Figure 4-5 Chamber Alignment

Refer to Figure 4-5. Plot 1 shows poor alignment. Plot 2 shows the dropping chamber tilted such that the cart position at the bottom of the drop is directly below the top of the drop.

In general, the tilt of the chamber is not necessarily vertical. And the tilt and rod-bend have been greatly exaggerated.

To align the chamber:

- Place the XY detector (part of the standard FG5-X toolkit) in the path of the vertical beam.
- Attach the power cable to the Auxiliary output connector on the FG5-X Power Supply.
- Attach the X and Y outputs to Ch1 and Ch2 of an oscilloscope and place the oscilloscope in "XY" mode (500 mV/div on both channels and ~250 ms in time).
- Use the oscilloscope's position knobs to center the two grounded channels in the middle of the oscilloscope.
- Attach the Σ (or sum) channel to a digital voltmeter.
- With the oscilloscope set to DC coupling on both channels, use the adjustment knobs on the XY detector to center the signal in the oscilloscope.
- Set dropper into OSC mode.
 - Watch the value on the voltmeter, and make sure that it doesn't change by more than 10% throughout the travel of the cart (thus indicating that laser light is staying on the detector the whole time).
 - If the spot moves visibly as the cart is raised and lowered, use the tripod feet to tilt the chamber so that the spot appears stationary.
- Then repeat the above: center the signal and make sure the spot stays on the detector throughout the cart's travel.

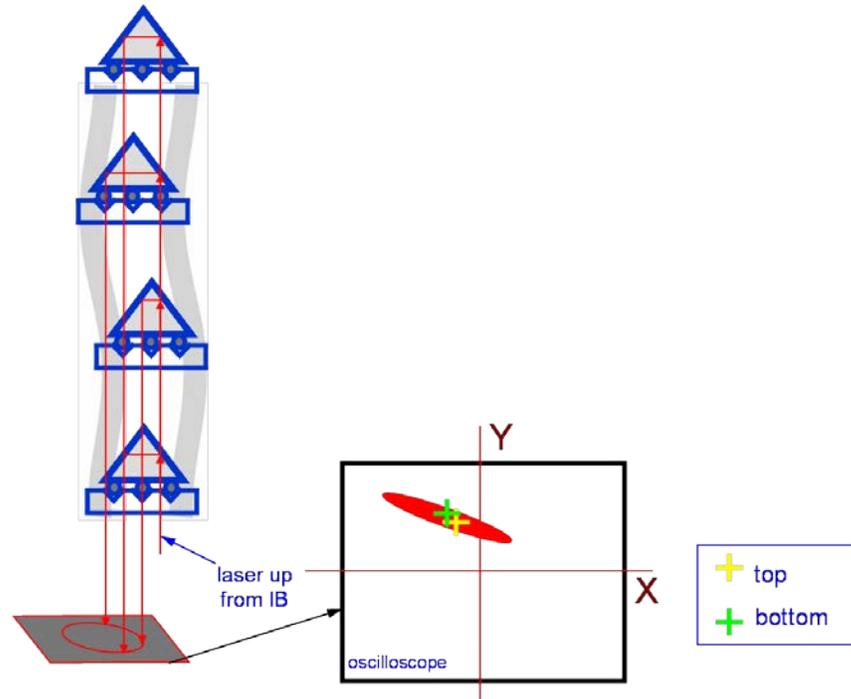


Figure 4-6 Using X-Y Detector

Figure 4-6 demonstrates using the X-Y detector to set dropping chamber bubble levels. In general, as the cart is lifted up and down, it also moves slightly sideways. Thus, the reflected laser beam appears to translate. Tilt the chamber until the position of the reflected beam at the top of the drop is the same as at the bottom of the drop. Then set the bubble levels to read zero. The rod bend and translation are exaggerated in this example.

To set dropping chamber level bubbles:

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

feet” refers to the large feet on the ground used to decouple the dropping chamber tripod from the interferometer.

- Repeat the procedure:
 - Raise the cart
 - Note the position
 - Watch the motion as it is lowered, and adjust the appropriate tripod feet.

As the chamber angle is improved, it becomes necessary to go to finer and finer voltage scales to see changes in the motion. When the top and bottom position agree on the oscilloscope to ~10 mV, the chamber is aligned.

NOTE

If the rods have a slight curve, the signal might do a little “loop” or “wobble” as the cart is raised and lowered. This is normal. It is only important that the top and the bottom of the travel are overlapped.

- Once the chamber is aligned, center and lock the bubble levels.
- Re-couple the dropping chamber tripod to the interferometer.
- Use the spanner wrenches provided in the FG5-X toolkit to tilt the dropper tripod so that the dropping chamber bubble levels are centered to agree with those of the Superspring. Refer to Figure 4-7 for the location of the feet used to tilt the dropping chamber tripod relative to the interferometer base. By adjusting the height of these three feet, the tilt of the dropping chamber can be made to match that of the Superspring.

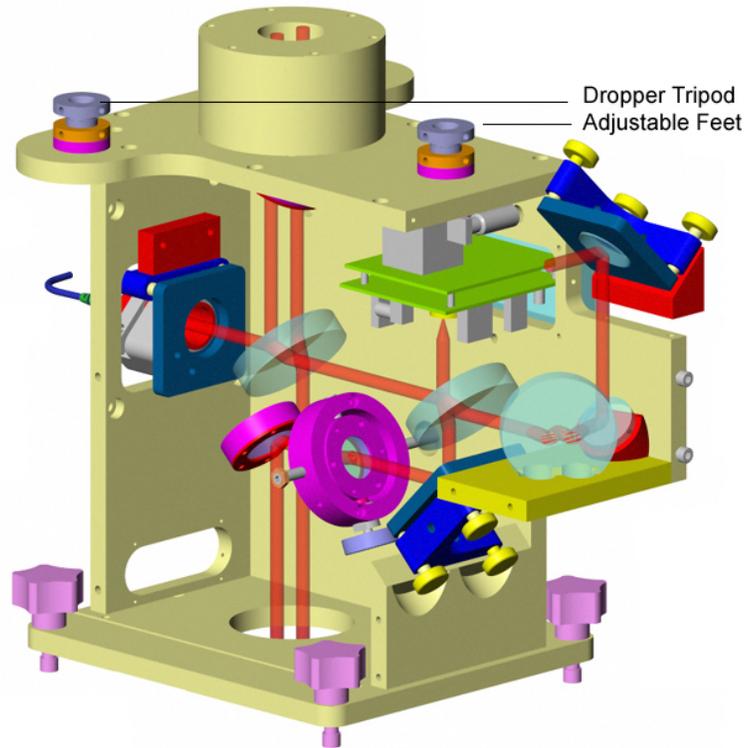


Figure 4-7 Location Of The Dropper Tripod Adjustable Feet

The Laser

Laser problems can usually be grouped into two categories: stability problems and alignment problems.

Stability in the laser wavelength is crucial. This provides the length standard with which the gravity value is calculated. It must be stable to at least a few parts in 10^9 .

Alignment problems in the laser usually result in a loss of power which ultimately causes a decrease in the interference fringe amplitude. If the amplitude is too small, the data acquisition system will fail.

With careful analysis, it can actually be quite easy to at least diagnose most laser problems.

Laser Stability

ML-1 Lasers

For a complete description of the ML-1 operation, refer to the [ML-1 Polarization Stabilized Laser Operator's Manual](#).

Temperature changes are the biggest cause of laser wavelength instability in the ML-1. The laser housing is designed to be temperature stabilized, but even minute changes in environment temperature (fractions of a °C) can cause the laser wavelength to change, which in turn causes a noticeable change in the measured gravity value (even 10s of μGals). The RED or BLUE gravity values change as the temperature changes. However, the mean value is usually quite stable to a few μGals (i.e. if the RED "drifts" up, the BLUE will "drift" down a roughly equal and opposite amount). Always let the laser come to thermal equilibrium before acquiring gravity data. This typically takes 1-4 hours.

WEO Lasers

Refer to the [WEO User's Manual](#) for a complete discussion of the laser operation. Unlike the ML-1, if the controller indicates the laser is locked, the wavelength of the laser output is correct and stable. However, if the laser has not yet reached thermal equilibrium, it will frequently lose lock status and then take a few seconds to re-lock.

The wavelength is labeled by a peak name (e.g. "D, E, F, or G"). (See [Section 03 "System Setup"](#) for additional description) Each peak has a unique 1f voltage. This is entered into the g-software so the correct wavelength can be used in the gravity value calculation. When the laser is not in thermal equilibrium (i.e. when it is first powered on), these 1f voltages will change. Therefore it is important to wait until equilibrium (a minimum of about 1-4 hours) before measuring the 1f voltage.

- If the software is using the wrong wavelength for the gravity calculation, the reported gravity value will be incorrect.
- If it is using the adjacent peak name value ("off by one peak name", e.g. "D" instead of "E"), the gravity value will be wrong by approximately 25 μGal .
- If gravity data appears to have 20 – 30 μGal jumps between sets, double check that the 1f voltages and autopeak detection setup in the g-software are configured correctly.
- If the laser "hops" between peaks during a set acquisition, the average value of the set can be off by any fraction of 20 – 30

μGal (i.e. if the laser hops halfway through a set, the gravity value would be off by about 12 μGal).

Laser Alignment

Aligning the fiber to the laser head correctly for both the ML-1 and WEO lasers, is extremely important. Proper alignment ensures the maximum interference fringe amplitude and it also governs the power stability of the laser light. Both the fiber optic cable and the laser light itself are polarized, and it is crucial that the fiber be aligned with the direction of the laser beam and also rotated about its axis so that its polarization matches that of the laser beam.

Optical Isolator

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

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

The only necessary adjustment on the optical isolator is rotating the whole unit so its polarization matches the laser. To rotate the unit, place a power meter at the output of the optical isolator and rotate the optical isolator until the power is maximized. Then clamp the optical isolator in place.

5-Axis Mount

The fiber is coupled to the laser head via a "5-axis" mount. The name refers to the fact that the mount allows lateral translation of the fiber relative to the beam in both the X and Y directions (2 axes), the mount allows tilt of the fiber in both pitch and yaw (2 axes), and the mount allows longitudinal translation of the fiber to focus the laser beam into the fiber (1 axis). The mount also allows rotation of the fiber relative to the beam (one more axis for an actual total of six axes) and discussed in the following [Fiber Polarization](#) section.

Getting the laser light through a fiber requires patience and practice. The location of the fiber entrance, the fiber's angle, and the polarization of the fiber must be made to coincide with that of the laser beam. These all require extremely precise positioning.

Alignment Procedure

- Attach the 5-axis mount to the laser head and translate it such that the laser light is traveling through the center.
 - Verify by holding a piece of paper up and making sure the beam is not clipped.
- Attach the fiber to the 5-axis mount and tighten firmly.
- Use the X and Y screws on the side of the 5-axis mount to get some light through the fiber.
 - Never look directly into the fiber.
 - It should be possible to see the output end of the fiber “glow” with a small amount of light.
 - If no light is visible, slowly translate the X and Y screws in a search pattern while looking for a “glow” at the output end of the fiber.
 - When a small glow is visible, attach the fiber to a laser power meter.
- Using the power meter, carefully adjust the X and Y screws until the power is maximized.
- Use the three screws on the front to adjust the angle of the fiber.
 - Iterate through all three screws.
 - This changes both the angle and the focus (distance from the fiber entrance to the focusing lens)
 - Turning each screw in the direction of maximum power.
- Now return to the X and Y screws and adjust them slightly to maximize the power. Then return to the three front screws and repeat the procedure.
- After ten or more iterations the laser power should be maximized.

Fiber Polarization

When the power is maximized (or is at least about 100 μ W for an ML-1 laser) it is then necessary to rotate the fiber to match its polarization to that of the laser. This procedure requires not only a sensitive laser power meter, but a high quality, rotatable, polarizer as well.

Polarization Procedure

- Shine the light from the output of the fiber through the polarizer and onto the laser power meter.
- Rotate the polarizer until the laser power is maximized.
 - Note the value. This is the “transmitted” power.
- Rotate the polarizer until the power is minimized.
 - This might require a rescaling of the power meter.
- Form a coil of excess fiber in your hand and let the heat slightly change the length of the fiber.
 - This will most likely cause the power to increase.
 - Note the maximum value attained. This is the “rejected” power.
- Calculate the ratio of “rejected” to “transmitted” power. This ratio should be less than 1:100.
- If the rejection ratio is $\leq 1:100$. Make sure the “large” black screws on the front of the 5-axis mount are tight.
 - Fine-tune the laser power and proceed to the Last Step.
- If the rejection is $\geq 1:100$.
 - Note the orientation of the fiber relative to the 5-axis mount.
 - Slightly loosen (Do not to drastically change the angle of the fiber) the three “large” black screws on the front of the mount.
 - Slowly rotate the whole fiber. There are two optimal orientations of the fiber, 180° apart.
- If the rejection was close to 1:100.
 - Rotate a few degrees.
- If the rejection was basically 1:1
 - Rotate approximately 90° .
- If the rejection was in between
 - Use the above information to estimate a reasonable amount of rotation.
- Once the orientation has been chosen, use the five adjustment screws to get at least $100 \mu\text{W}$ of light through the fiber.
- Repeat the rejection measurement and calculation.
- Repeat the whole procedure (rotate, regain the light, measure the rejection) until the rejection is at least 1:100.
- Once 1:100 is achieved, use the three large black screws to clamp the fiber rotation into place.
- Now that there is laser light through the fiber and the rejection is better than 1:100, optimize the laser power. Use all five screws to maximize the power. See ["Using the Power Meter"](#)

[step in the Alignment Procedure section](#) above to maximize the power.

- Carefully loosen the translation screws that attach the 5-axis mount to the laser head.
 - Loosen as little as possible so that the angle is not significantly changed and yet the 5-axis mount can still translate.
 - While monitoring the output power, move the whole 5-axis mount relative to the laser beam until the power is maximized.
- It is often possible to get an additional 15 μW of power using this “trick”.
 - When the power is maximized, tighten the 5-axis mount back in place and fine tune with the five adjustment screws, if necessary.

Goals:

- The optical isolator transmits roughly 60% of the laser power
- The fiber optic coupler transmits roughly 60-70% of the power
- With an ML-1 laser producing about 1.2 mW, it should be possible to achieve 400 μW of power at the output end of the fiber.



5. VACUUM CHAMBER: TURBO PUMP AND BAKING OUT

Turbo Pump Setup.....	5-1
Turning On Power.....	5-4
Baking Out The Dropping Chamber.....	5-5
Starting The Ion Pump.....	5-5
Migrating System To Ion Pump.....	5-5

Under normal operations, the vacuum in the dropping chamber is maintained by an ion pump. Any residual molecules in the chamber that enter the ion pump are ionized by the 4 kV potential and plated out, and thus the pressure in the chamber is directly proportional to the number of ionizations per second (i.e. the current drawn by the ion pump). Normal operation of the ion pump is indicated by 4 kV and a stable current of less than about 3×10^{-4} A. It is normal for the current drawn to fluctuate with temperature.

This procedure only works at relatively high vacuum levels ($\sim 10^{-6}$ mbar). If the vacuum has been degraded (i.e. the ion pump has been off for more than a few hours), the turbo pump must be used to "regain" the vacuum. If the vacuum is very poor (ion pump off for many weeks, or the chamber has been opened to atmosphere), the backing changer needs to bake while turbo pumping.

Turbo Pump Setup

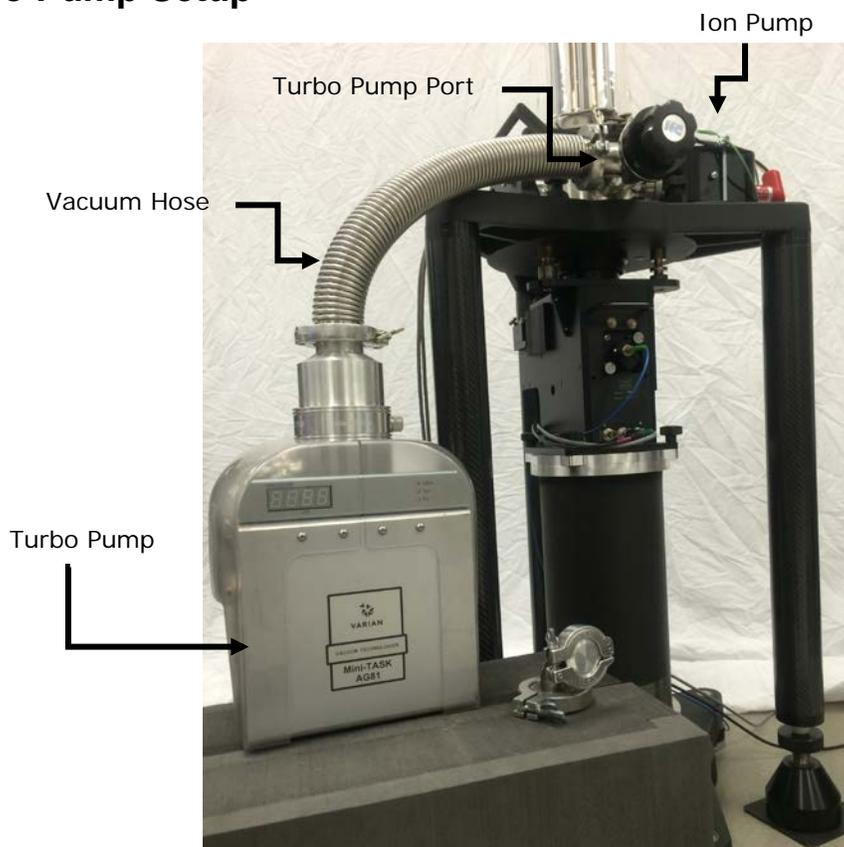


Figure 5-1 Turbo Pump Connected To Dropping Chamber

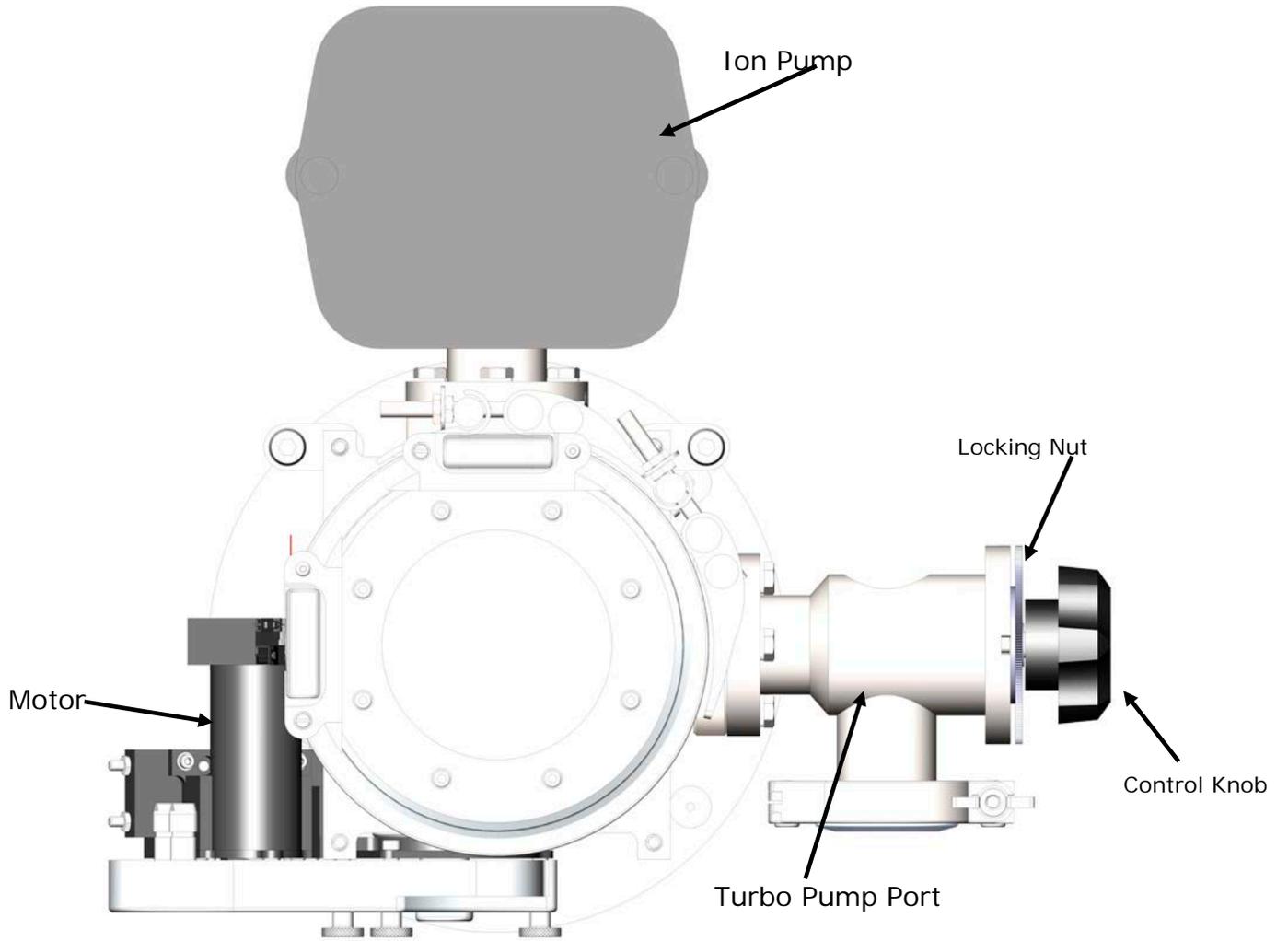


Figure 5-2 Top View Turbo Pump

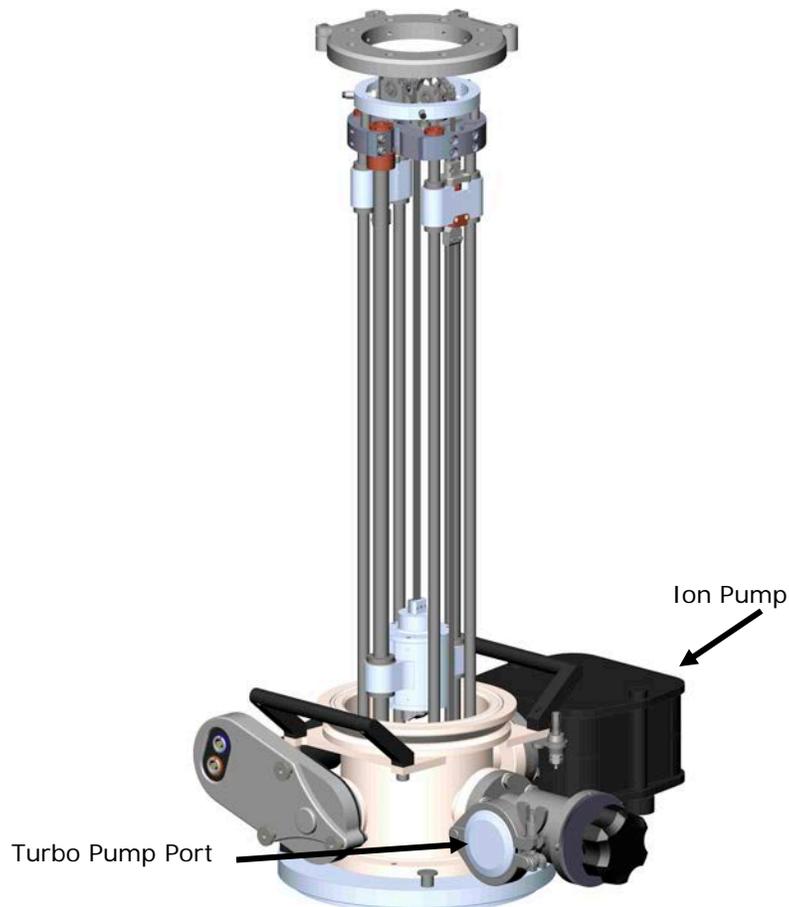


Figure 5-3 FG5X Turbo Pump Port and Ion Pump

- Make sure the ion pump power is OFF.
- Remove the turbo pump from its case and place it near the dropping chamber vacuum flange.
- Connect the turbo pump to the dropping chamber using the flexible vacuum hose which has a vacuum flange on both ends.
 - The vacuum hose is normally stored in the turbo pump case underneath the turbo pump.
 - Make sure not to stress the bellow tube.
 - Refer to Figure 5-1, Figure 5-2 and Figure 5-3 .
- Attach the vacuum hose to the turbo pump port.
- The quick flange has a clamp which mates the two vacuum flanges with an o-ring seal.

- It is important to keep the o-ring seal and vacuum flanges free of dirt or scratches to avoid leaks.
- Plug the turbo pump into the proper AC power.
- Make sure the small relief valve on the turbo pump vacuum flange is closed.

Turning On Power

Important

Before turning on the power, it is very important to determine the status of the vacuum in the chamber.

Depending on the vacuum level inside the chamber, the bellows valve, located between the vacuum hose and the vacuum chamber, should either be open or closed before turning on the turbo pump power. It is important to correctly set the valve position before turbo pumping.

- If the dropping chamber is under partial vacuum, the bellows valve should remain closed.
 - Do not open this valve until the turbo pump has evacuated the air inside the flexible hose and come to full speed. Otherwise air in the hose can be sucked into the chamber. Full speed is indicated by the blinking green LED near the power switch, turning solid green.
 - Once the turbo pump has reached a normal speed and normal operating pressure, slowly open the valve.

IMPORTANT

It is important to open this valve slowly because if there is actually air in the chamber, a large amount of air can damage the turbo pump.

- Slowly turn the valve until it is completely open, while making sure that the turbo pump is still at full speed.
- If the dropping chamber is at full atmospheric pressure (i.e. the chamber was open for maintenance), the vacuum valve must be opened before starting the turbo pump. This allows the roughing sequence of the turbo pump to remove the air from the hose and the chamber at the same time. This is important because the turbo-pump can be damaged if it is suddenly exposed to air when operating at its normal pumping speed.

In general, the dropping chamber also requires a baking-out procedure to remove water vapor from the system. Contact Micro-g LaCoste for special instructions.

After determining the correct position for the bellows valve on the dropping chamber, turn the turbo pump power switch ON. The roughing sequence of the pump starts immediately, then the turbo pump slowly increases its speed. When the turbo-pump reaches nominal operating speed (usually about 70-75 krpm), the small green LED on the side of the turbo pump begins to blink until the turbine has come to full speed, at which point remains steadily lit.

It is recommended to use an Uninterruptable Power Supply (UPS) while turbo pumping. If the power is interrupted, the system will not actually vent to atmospheric pressure. The turbo pump has a valve that closes automatically in the event of a power outage.

Baking Out The Dropping Chamber

It is no longer necessary or needed to “bake out” the dropper chamber. If the chamber needs to be exposed to air, contact Micro-g LaCoste for special instructions.

Starting The Ion Pump

Before starting the ion pump check:

- The system is room temperature.
- The dropping chamber is under a good vacuum.
- The turbo pump is operating at normal speed.
- The ion pump turned OFF.

Migrating System To Ion Pump

The next step is to migrate the system to the ion pump so that the turbo pump can be removed

- Attach the ion pump HV and safety ground cables to the chamber and the ion pump controller.
- Turn on the ion pump controller AC power, DC power (this charges the backup battery), and HV.
- Monitor the ion pump voltage on the main display by selecting “kV”.
 - Leave the turbo pump running and connected to the dropping chamber.

- Check that the voltage is increasing to approximately 4 kV (reading 4.0 on the "kV" scale) within five minutes after turning on the ion pump.

Check Ion Pump Voltage

If the ion pump voltage does not reach the operating voltage 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.
- Leave the ion pump on with low voltage.

NOTE

Excessive current significantly shortens the lifespan of the pump.

IMPORTANT

If the ion pump voltage immediately goes to 4 kV without "ramping up", this could indicate a possible open in the ion pump circuit. This means the ion pump is at full voltage, but is not actually ionizing any molecules (i.e. it has not started "pumping"), and the current it draws may be very near zero. In this situation the ion pump is possibly not ready.

Leave the turbo pump on with the valve open. Next take a hard object (i.e. a screwdriver) and gently, but firmly, tap the ion pump (not the controller). This can release molecules in the ion pump and start the ionizing process.

If successful, you should see the ion pump voltage drop and then slowly ramp back up to near 4kV. The current should now also be non-zero. This indicates that the ion pump is functioning and ready to proceed to the next step.

Monitor Ion Pump Current

Once the ion pump has reached its operating voltage, monitor the ion pump current. This value should be approximately 0.1-1 mA and, if the vacuum is good enough, slowly falling as the ion pump ionizes fewer molecules (drawing less current). This means the ion pump is operating normally (though the turbo pump is still helping at this point).

If the voltage is stable, but the current continues to increase after five or so minutes, turn the ion pump off and wait approximately one hour before trying the ion pump again.

Once the ion pump has started and the current seems to be steadily decreasing, close the vacuum valve fully (but leave the turbo pump on). It is normal for the current to increase after the valve is closed, but after a few minutes it should begin decreasing again as the ion pump continues to pump. After the current has begun to decrease reliably (for five or so minutes), the turbo pump can be turned off.

Remove Turbo Pump

After the turbo pump has come to a stop, use the relief valve on the turbo pump to re-fill the vacuum hose with air (and then close the valve so as to be ready for a future pump-down). Remove the hose from the chamber and turbo pump. Replace the blank flanges on the vacuum valve and turbo pump intake and remove the bellows tube. Pack the turbo pump in the shipping case; it will no longer be needed for operation.



6. ELECTRONICS CONNECTIONS

SIMx	6-1
eX-Box	6-2

The following lists the basic connections needed to measure gravity with the FG5-X. Note that when shipped from the factory, the cables that connect the various FG5-X electronic components are labeled. Refer to the System Interface Module (SIMx) User's Manual for additional information.

SIMx

Front

ION PUMP (Ion Pump Current)	↔	Ion Pump Controller, METER MON
LASER 1F (WEO 100 Laser)	↔	WEO 100 Controller, METER Output

Rear

ANALOG FRINGE IN	↔	FG5-X Interferometer, ANALOG
DROPPER TRIGGER OUT	↔	eX-Box Time Interval Analyzer (TIA) Card ARM
USB	↔	Computer USB
10 MHz Out	↔	eX-Box TIA Card CLK
APD (Green)	↔	FG5-X Interferometer, Power (Green)
Superspring (Yellow)	↔	Superspring Chamber
ENCODER(Blue)	↔	Dropper Chamber, Encoder (Blue)
MOTOR(Orange)	↔	Dropper Chamber, Motor (Orange)
ML1 LASER LOCK (ML-1 Laser)	↔	ML1 – Controller, LASER LOCK
ML1 LASER MODE (ML-1 Laser)	↔	ML1 – Controller, LASER MODE

eX-Box

Rear

TIA Card, TRIGGER	↔	SIMx, Rear, DROPPER TRIGGER OUT
TIA Card, CLK	↔	SIMx, Rear, 10 MHz OUT
TIA Card, TTL	↔	FG5-X Interferometer, TTL
COMPUTER CONN		Computer PC-Express Card



7. GRAVITY SITE SELECTION

Geologic Stability	7-1
Site Stability	7-1
Environmental Noise.....	7-1
Temperature / Humidity Control.....	7-1
AC Power	7-1

Geologic Stability

To achieve best results, a site should be located in a geologically stable area. 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.

Site Stability

It is 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.

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.

Temperature / Humidity Control

Although the FG5-X operates properly between temperatures of 15 - 30°C, it is important to have a site with good temperature stability to minimize possible problems with temperature sensitive components (e.g. the laser and Superspring).

Whenever possible operate and store in a humidity controlled environment. It is suggested to use a dehumidifier or an Air Conditioning unit.

AC Power

Problems with AC power are not uncommon, especially in remote/field environments. Make sure that ground is available before plugging in the system. It is best to use voltage

stabilizers and/or uninterruptible power supplies to minimize problems with unreliable line voltage. Some system components (e.g. the WEO Model 100 iodine laser) are more sensitive to line voltage fluctuations than others. It is best to stabilize line voltage to satisfy the requirements of the most sensitive component.

Verify that all voltage input selectors are set to the local voltage before plugging in and powering ON.



8. WARRANTY

FG5-X Absolute Gravimeter Warranty 8-1

FG5-X Absolute Gravimeter Warranty

Micro-g LaCoste, Inc. hereby warrants to purchaser that the instrument delivered hereunder shall be free of defects in material and workmanship appearing within one year from the date of delivery. Purchaser, or any third party purchaser, must give written notice of any defect covered by this warranty to seller within 13 months of the date of delivery of the instrument to purchaser. For any defect covered by this warranty, seller shall repair or replace defective components of the instrument on a timely basis at its sole expense provided that such warranty service shall be performed by seller at its facility in Lafayette, Colorado, U.S.A., and all cost of returning the instrument to seller shall be borne by purchaser. This warranty does not cover labor costs and other contingent expenses incurred by purchaser or a third party for the diagnosis of defects. It does not extend to the instrument if it has been:

(a) Subject to misuse, neglect, accidents, acts of God or causes of a similar nature.

(b) Altered by anyone other than seller without seller's prior approval.

This warranty is in lieu of all other warranties except seller shall pass through any warranty issued by a manufacturer of any component part of the instrument and subrogate purchaser with respect to any claims thereunder.

This warranty is expressly conditioned on the following performance by the purchaser during the warranty period:

1. In repairing or replacing component parts in the instrument, purchaser shall use only the following parts:
 - Parts supplied by seller.
 - Parts obtained from third parties to the extent such parts were made by the same manufacturer as the part being replaced.
 - Similar parts, upon prior written approval of seller, which approval shall not be unreasonably withheld.
2. During the warranty period set forth above, purchaser shall give seller prompt notice of any and all problems associated with the operation or integrity of the instrument.



9. CHECKLISTS

FG5-X Setup Checklist	9-1
FG5-X Tear Down Checklist	9-3

FG5-X Setup Checklist

For details on each step, please consult [Section 03](#).

- _____ 1 Place electronics box approximately 1 m from measurement location.
- _____ 2 Check line voltage settings (especially for WEO laser).
- _____ 3 Check that the ion pump is powered ON and operating correctly. Connect to reliable AC power source.
- _____ 4 Make sure the FG5-X SIMx AC & DC power is OFF.
- _____ 5 Make sure the WEO Controller switches (AC and HV) are set to OFF.
- _____ 6 Turn FG5-X SIMx AC power ON.
- _____ 7 Place laser on stable surface, connect cables to WEO controller, turn WEO controller ON and enable HV. The laser should emit laser light within a minute or so.
- _____ 8 Place Superspring tripod at measurement location. Orient the line from the center of the tripod to the bull's eye level along a North-South axis.
- _____ 9 Use tripod feet to center the bull's eye level.
- _____ 10 Measure and record the lower reference height.
- _____ 11 Place and lock Superspring in tripod with travel lock oriented towards bull's eye level.
- _____ 12 Level the Superspring tripod to the Superspring bubble levels.
- _____ 13 Remove Superspring dust cap.
- _____ 14 Place IB on top of Superspring with fiber optic oriented towards bull's eye level.
- _____ 15 Assemble dropping chamber tripod.
- _____ 16 Remove dust cap from IB.
- _____ 17 Place dropping chamber tripod onto IB with the small hole in the tripod oriented towards the bull's eye level.
- _____ 18 Place dropping chamber into dropping chamber tripod with the ion pump oriented towards the beam-blocker side of the IB.
- _____ 19 Place the dropping chamber tripod feet under the tripod and adjust them until they are "just touching" the legs of the dropping chamber tripod.
- _____ 20 Turning each foot one turn counter-clockwise one turn at a time, lift the dropping chamber two total turns.

- _____ 21 Fine-tune the level of the dropping chamber.
- _____ 22 If necessary, fine-tune the level of the Superspring.
- _____ 23 Measure and record the upper reference height.
- _____ 24 Verify DC power is OFF. Connect the cables from the electronics to Superspring, IB, and dropping chamber.

- _____ 25 Un-travel lock the Superspring.
- _____ 26 Turn DC power ON.
- _____ 27 If necessary, Zero the Superspring.
- _____ 28 When spring motion has calmed down, enable Superspring Servo.
- _____ 29 Check and adjust (if necessary) beam verticality.
- _____ 30 Use twiddler and lower mirror to maximize fringe signal. Check with oscilloscope and OSC mode.

- _____ 31 Check and adjust (if necessary) beam verticality again.
- _____ 32 Place dropper in DROP mode.
- _____ 33 Verify that Rubidium clock has stabilized (RUB POWER light is steady ON).
- _____ 34 Turn eX-Box ON if necessary.
- _____ 35 Turn laptop PC power ON.
- _____ 36 Enter the total reference height and check all other parameters.
- _____ 37 Take data.

FG5-X Tear Down Checklist

- _____ 1 Back up data (if applicable) and turn computer power OFF.
- _____ 2 Turn DC Power OFF.
- _____ 3 Turn laser HV and AC power OFF.
- _____ 4 Turn AC Power OFF.
- _____ 5 Travel lock Superspring.
- _____ 6 Disconnect all cables. Get power ON to ion pump and leave fiber optic connected between laser and IB.

- _____ 7 Unless shipping overseas, keep ion pump powered ON.
- _____ 8 Remove dropper.
- _____ 9 Remove dropper tripod and disassemble.
- _____ 10 Remove IB from Superspring. Place Superspring and laser in shipping box.
- _____ 11 Pack Superspring tripod.



10. SYSTEM SPECIFICATIONS

System Specifications	10-1
General Specifications	10-1
Performance Specifications	10-1
Power	10-1
Weight	10-1

System Specifications

General Specifications

Total Shipping Weight	150 kg in 6 containers
Total Volume	1.5 m ³
Floor Space Requirement	3 m ²
Input Voltage	110-240 VAC, 50-60 Hz
Nominal Power Requirement	-500 W

Performance Specifications

Accuracy	2 µGal
Precision	2 µGal/√Hz at a quiet site 15 µGal/√ Hz at a quiet site [eg. ~1 µGal in 3.75 minutes, or 0.1 µGal in 6.25 hours]
Operating Dynamics Range	World-wide
Operating Temperature Range	15° to 30°C

Power

- All Components: 100 – 240V AC
 - The WEO laser is manually selectable.
- Average load: 350W

Weight

Component	Weight
IB & Laser	20 kg
Dropper	25 kg
Superspring	20 kg
Turbo Pump	15 kg
Dropper Tripod	20 kg
Superspring Tripod	12 kg
Electronics Rack	15 kg



11. SUPPORT

Contact.....	11-1
Support Request	11-1
Service Request.....	11-1

Contact

For questions, service request or support request please contact Micro-g LaCoste Customer Service at info@microglacoste.com.

Support Request

Providing complete detailed information helps us diagnose and respond with a more accurate and timely response. Instrument model and serial number information is required.

NOTE

For large file uploads contact Customer Service for ftp site instructions.

- Scenario description
 - Setup
 - Environment
- Complete Detailed Problem Description
- Screen Shots and/or Video as appropriate
- Applicable Files:
 - Data Files
 - Error Logs
- Text of any error message if applicable.
- SIMx software version if applicable.

Service Request

A Service Request Form (Figure 8-1) must be faxed to Micro-g LaCoste for hardware service requests. After receipt of this form a return authorization number is sent along with a purchase order.

Contact Customer Support for a copy of this form and any additional instructions.

SERVICE REQUEST FORM

Due to multiple points of contact for customer service requests, email messages will no longer be considered as formal requests for service. Please complete the following form and then fax it to (303) 828-962-7983 or email to info@microglacoste.com. After receipt and review of this form, a return authorization number will be issued and a purchase order requested from the customer

Estimated Ship Date for Service:	Return Authorization No
Customer Information:	
Name: _____	
Address: _____	
Contact Person: _____	
Products to Return:	

Reason for Return:	

Specific Problems:	

Specific Requests:	

Additional Comments:	

By:	Date:

Figure 11-1 Example Service Request Form



APPENDIX A RUBIDIUM CLOCK CALIBRATION

The following instructions are for calibrating the rubidium clock using a standard clock, a two channel oscilloscope and a stopwatch.

Procedure

The most straightforward way to calibrate two 10MHz clocks is to use a two channel oscilloscope to watch the phase of the two clocks to change/compared to the other.

1. Put the standard reference clock into channel A of the oscilloscope and set the triggering so that the standard clock waveform is stationary on the oscilloscope.
 - Recommend using the auto setup key on the oscilloscope if there is one.
2. Then plug the FG5 rubidium clock into channel B of the oscilloscope.
 - Check that the rubidium clock moves relative to the standard reference clock.
 - The time frequency error is given by $1/DT$ where DT is the time needed for the two clocks to slip relative to each other by one full cycle.

NOTE

Assuming that the standard reference clock is 10MHz an error of 0.005Hz will cause an error of about 1 microGal ($2df/f = dg/g$). This means that it would take about 3 1/3 minutes for the two clocks to slip by one cycle if the clock error was big enough to cause a one microGal problem.

3. Use a stop watch to time the cycle slip time.
 - If the FG5 clock being calibrated appears to be moving to the left (right) on the oscilloscope screen compared to the stationary reference clock then its frequency is higher (lower).
4. Calculate the FG5 rubidium clock frequency as:
 $f_{\text{rubidium}} = f_{\text{standard}} \pm 1/dT$.

Use + if the rubidium clock is moving to the left on the screen of the oscilloscope and - if the rubidium clock is moving to the right relative to the standard clock on the oscilloscope. dT is the time for the two clocks to slip by 1 cycle.

