Kim Frankcombe

INSTRUCTION MANUAL

MODEL G & D GRAVITY METER

LACOSTE & ROMBERG

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This new manual is divided into seven main sections:

PRIMARY INFORMATION

OPTIONS

FIELD PROCEDURES

METER DETAILS

COMPUTER PROGRAMS

SHIPPING PROCEDURES

CALIBRATION TABLE

More will be added to the manual. Your suggestions for corrections, improvements and additions will be helpful and appreciated.

Thank You, John Fett

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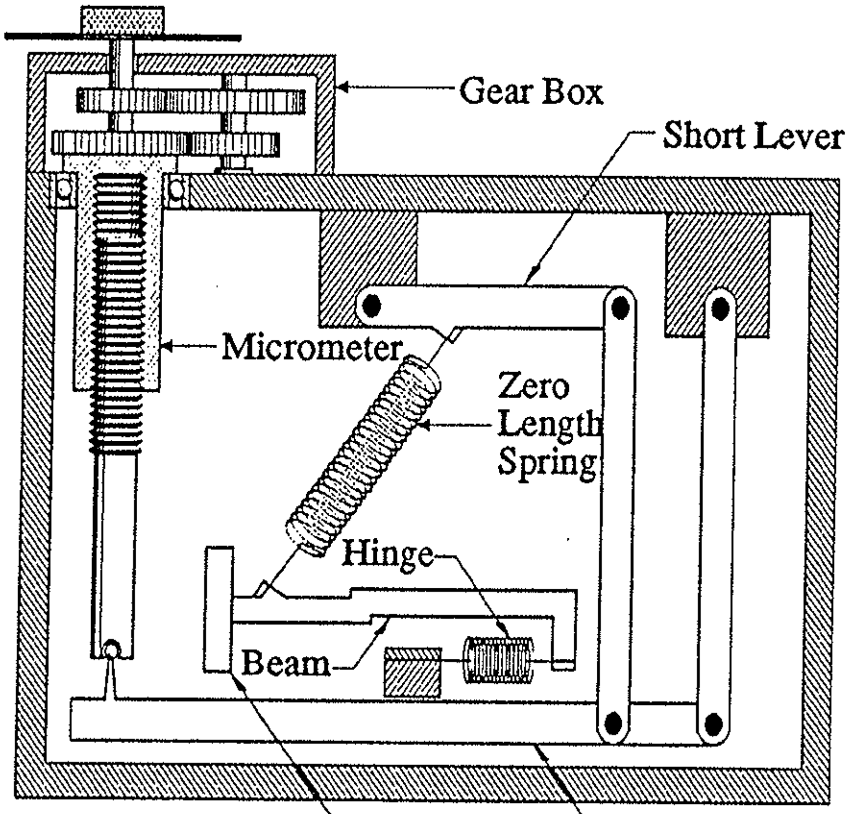
PRIMARY INFORMATION

INTRODUCTION

DESIGN

The *LaCoste and Romberg* gravity meter is made of metal parts. It is far more rugged than meters made of fused quartz glass. Because the thermal expansion and contraction of metals are generally greater than quartz, the *L and R* meters must be accurately thermostated. Since metals creep when thermally expanded or contracted, it is best to maintain the *L and R* meters at their constant thermostated temperature whenever practical.

The Model G meters have a worldwide range without resetting. The Model D meters normally have a range of 200 milligals and a reset that allows them to operate any place on earth.



The design of the meter allows it to be very sensitive to small changes in gravity. The simplified diagram of the meter shows a mass at one end of a horizontal beam. At the other end of the beam are a pair of fine wires and springs that act as a frictionless hinge for the beam. One purpose of the hinge springs is to help eliminate damage to the meter from all but the most severe impact.

The beam is supported from a point just behind the mass by a "zero length" spring. The spring is at an angle of approximately 45 degrees from horizontal. The meter is read by nulling the mass position, that is, adding or subtracting a small amount of force to the mass to restore it to the same "reading" position. This is accomplished by lifting up on the top end of the zero length spring. This must be done with great accuracy and is accomplished with a series of levers. In turn, the levers are moved by a high-precision screw which in turn is rotated by a gear box with considerable reduction.

The lever system and screw are accurately calibrated over their entire range. Calibration factors depend only on the quality of the lever system and measuring screw, not upon a weak auxiliary nulling spring as are used in other meters. For this reason the calibration factors of the *L and R* meters do not change perceptibly with time. This eliminates any need for frequent checks of the calibration.

The moving elements of the meter are restricted from movement of more than a few thousands of an inch (less than a tenth of a millimeter). Thus, if the meter sustains a severe impact it would be difficult for the moveable parts to attain enough momentum to damage themselves. For further security and to minimize irregular instrumental drift, the beam can be clamped when not in use.

When the beam is clamped, It is pushed down against the bottom movement limiters or "stops". This would elongate the main spring and induce creep in the springs metal. To eliminate this creep, the beam also is pushed backwards upon clamping. Thus the length of the main spring in the clamped position is exactly the same length as it is when unclamped and at the reading line.

Few ferrous metal parts are used in the meter. The meter is demagnetized or compensated, then installed in a double μ-metal shielding to isolate it from magnetic fields.

Changes in air pressure could cause a small apparent change in gravity because of the buoyancy of the mass and beam. This is prevented by sealing the interior of the meter from the outside air. As an additional precaution, should the seals fail, there is a buoyancy compensator on the beam.

When the meters are new, their average drift is less than one milligal per month. With a few years of aging, their average drift is usually less than half a milligal per month. This small drift is true drift, not a large drift compensated to a small value by a clock and microprocessor.

BASIC OPERATING INSTRUCTIONS

STARTING

Before unpacking the meter and its accessories, inspect the shipping carton for signs of damage during transit. Promptly report any damage to the transporting company.

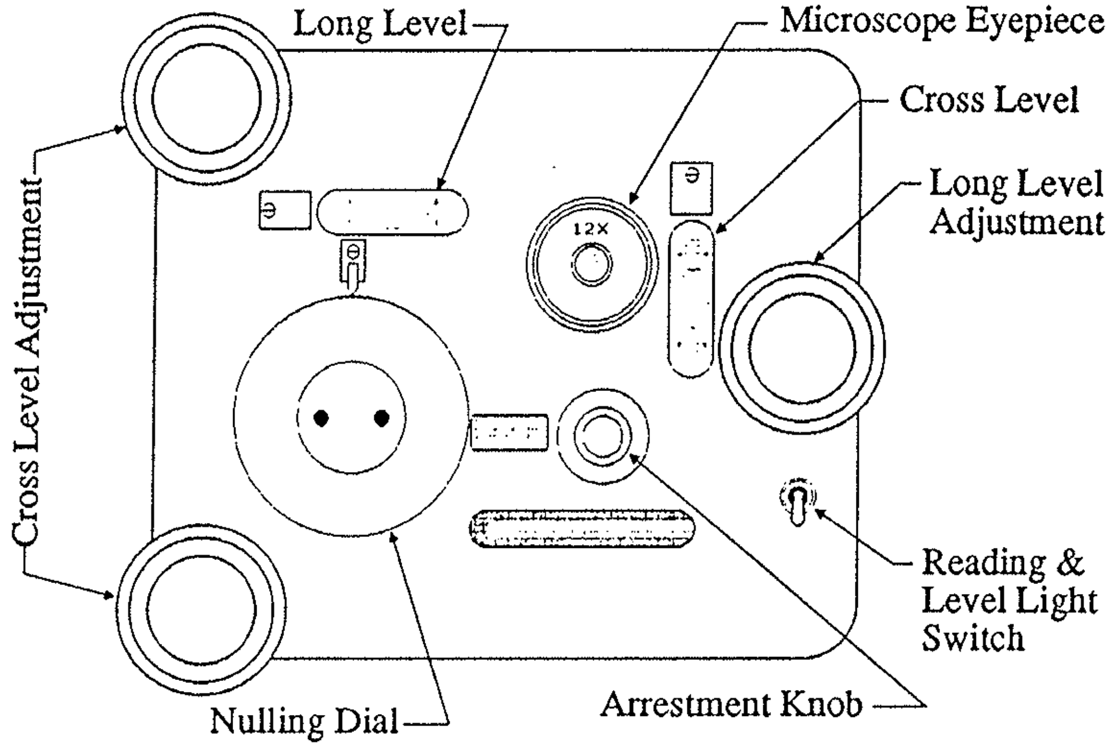
The meter is shipped cold. At all other times the meter should be maintained at its thermostated temperature. The charger/eliminator is a charger for the meter batteries and a regulated 12-volt power supply for the meter when it is not on battery power. It can operate from 50 or 60 Hertz power without any adjustment. Also, it can operate from 115 or 230 volts AC power. There is a small slide switch in the charger for selecting the voltage. AFTER setting the voltage switch, the charger should be connected to the AC power source. A power indicator lamp on the charger face should now be on. There are more details about the charger in the sections on accessories and meter details.

Now connect the meter to the charger at the fitting on the charger's face. The small red light by this fitting should now come on indicating 12-volt DC power is flowing to the meter. This light will remain on until the meter reaches its thermostated temperature. From about two to five hours will be required to reach operating temperature, depending upon how cold the meter is. Then, the power will cycle on and off as needed to maintain the constant temperature.

When the meter is at operating temperature, a series of tests may be performed to be certain the meter is in good condition. Each meter has its own operating temperature. It is recorded in the manual or on the meters' calibration table.

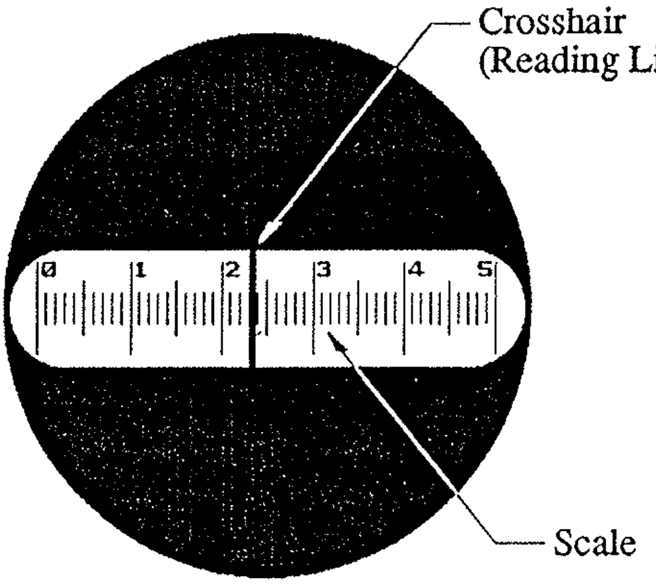
TAKING THE FIRST READING

- Place the meter on the aluminum baseplate.
- Turn on the reading light and the spirit level lights. The switch is located on the near right side of the black lid. Do not leave the light turned on for a prolonged time, especially in hot weather, if accurate readings are desired.



- Gently slide the meter in the concave baseplate until the meter levels indicate the meter is approximately level. Finish the leveling with the three leveling screws of the meter. For effiency, you may wish to level the cross level first then the long level. On the meter in the standard white box, there are three knobs atop the meter that turn the leveling screws. On some early meters in the miniature white box, these screws and their knurled turning flanges are under the white box.
- Release the internal beam of the gravity meter by turning the knurled arrestment knob counterclockwise to its limit. The knob is located on the near side of the microscope eyepiece.

- The position of the beam is determined by the image of the crosshair in the microscope. The crosshair is a very fine wire attached to the beam. A reticle or scale is placed in the optical path for a reading reference. The total motion of the beam is 15 small scale divisions. The downscale or left side of the crosshair is used as the reading edge.



- Each meter has its characteristic reading line. There is a small placard on the meter lid indicating the reading line for the meter. In the example above, the reading line is 2.3.

- Bring the left side of the crosshair to the reading line by turning the nulling dial. If the crosshair needs to move to the right, turn clockwise. If it needs to move to the left, turn counterclockwise.

- Always approach the reading line from the same direction. For uniformity, we suggest approaching from left to right, (turning clockwise). If coming from the right side (counterclockwise), turn the dial about a quarter turn past the null and approach clockwise. The play or slack in the gears and universal joint would cause an error if the null is not approached always from the same direction.

- There may be a long way to turn on the Model G and on a Model D there may not be enough range of the nulling counter to null the meter.

Model G: If the meter was last read at a much different latitude, a rough estimate of the counter reading necessary to null a Model G may be obtained from this table:

Latitude	Approx. Gravity	Approx. Reading
0	978.046	1430
10	978.203	1600
20	978.652	2050
30	979.337	2750
40	980.178	3600
50	981.078	4530
60	981.930	5400
70	982.623	6100
80	983.073	6560
90	983.223	6700

Model D: To rerange a Model D meter, set the counter to mid-range, 1000.0, and range the meter until it is roughly balanced. This is done by turning the coarse or re-ranging screw located beneath a small cover plate near the center of the black lid. Each turn of the ranging screw is about 74 milligals. If the crosshair is on the left side of the scale, turn clockwise. If it is on the right side, turn counterclockwise. If the meter is tapped with the finger, the crosshair will bounce at the end of its range of travel. The closer the meter is to balance, the slower the crosshair will return to the end of travel. When the meter is in approximate balance, close the cover plate and finish balancing with the nulling dial. For more details on re-ranging the Model D, see the Field Procedures section .

- Obtain the reading from the counter and nulling dial. The last digit on the counter should correspond with the number on the nulling dial. This number is considered tenths of units. The dial is further divided so that hundredths of units can be read.
- It is good practice to double check the levels, the reading and the field notes after each reading.

- Clamp the meter by turning the arrestment knob clockwise to the end of travel (about 3 full turns).

After the meter has been shipped or received a hard impact, it is good practice to check the setting of the levels and sensitivity. See the paragraphs in this section for more details.

CONVERTING THE COUNTER READING TO MILLIGALS

Let us illustrate conversion of meter readings to milliGals with some examples.

MODEL G

If the counter reading is *2654.32*, look at the calibration table for your meter. Remember that each meter has its own unique table.

Portion of calibration table

Counter Reading	Interval Factor	Cumulative Value
2500	1.00794	2519.42
2600	1.00799	2620.21
2700	1.00805	2721.01
2800	1.00811	2821.82

Divide the reading into two parts.

2600.00	2620.21
+ *54.32*	+ 54.75
2654.32	2674.96

Interval factor x reading within interval

1.00799 x 54.32 = 54.75

MODEL G SURVEY OVER SMALL CHANGE IN GRAVITY

If all the readings are within an interval, you may use a single calibration factor, the interval factor.

Reading x Interval Factor = milligals

2654.32 x 1.00799 = 2675.53

MODEL D WITH SINGLE CALIBRATION FACTOR

Many model D meters have a calibration curve that is adequately straight so that a single calibration factor can be used for the meter. The calculation is almost like the example above except for an important difference: one turn of the D meter's nulling dial is equal to about 0.1 milligal (100 microgals) instead of 1 milligal (1000 microgals) on the G meter's nulling dial. Thus, the decimal must be moved one place to the left in the reading or one place to the left in the calibration factor. If the meter reading is 0943.21 and the calibration factor is 0.10123, then the converted reading is 0943.21 x 0.101234 = 95.485 . The same setting could be read 094.321 and the calibration factor 1.01234. The converted reading would then be 094.321 x 1.01234 = 95.485.

MODEL D WITH CALIBRATED WORLDWIDE RANGE

The standard Model D meter has two micrometer screws and lever systems for balancing the force of gravity. The "coarse" side has a worldwide range of at least 7,000 milligals. Normally this is not calibrated and is only used to place the meter into the operating range of the "fine side".

If the coarse side is calibrated, there are 100 turns of the coarse nulling dial for each turn of the micrometer screw. Each turn of the screw is about 70 milligals. Thus, each turn of the of the nulling dial is about 0.7 milligals.

During surveys over a gravity span of less than the range of the fine screw, the coarse side would be locked and unused. The meter would be used in the same manner as the regular Model D meter. Be sure to use the fine side calibration table.

Where the range of the gravity observations is greater than the range of the of the fine side screw, the fine side can be locked and the meter used in the same way as a Model G geodetic meter. Be sure to use the coarse side calibration table.

A better method of reading the meter over a large range of gravity is to turn the coarse screw integral numbers of turns and complete the balancing of gravity with the fine side. If there is periodic or circular error on the coarse side, full turns of the screw should minimize this possible source of error. Because of the design of the Model D meter, periodic error of the fine side should be insignificant.

Here is an example of calculating the gravity difference between two sets of readings.

	Coarse Side	Fine Side
First Reading	4565.00	1234.56
Second Reading	4865.00	1567.89

From the coarse side calibration table:

From the fine side calibration table:

First Reading

Coarse Side 3351.446 + 65.00 x 0.74682 = 3399.989
Fine Side 84.633 + 34.56 x 0.07021 = 87.059
3487.048

Counter Reading		Factor	Counter Reading		Factor
4500	3351.446	0.74682	1200	84.633	0.070210
4600	3426.128	0.74691	1300	91.654	0.070175
4700	3500.819	0.74699	1400	98.672	0.070134
4800	3575.518	0.74906	1500	105.685	0.070120

Second Reading

Coarse Side 3575.518 + 65.00 x 0.74706 = 3624.077
Fine Side 105.685 + 67.89 x 0.07012 = 110.445
3734.522

Gravity is 247.474 milligals greater at the second reading than at the first. 3734.522 - 3487.048 = 247.474 milliGals

RELATIVE INSTRUMENT

Remember that the meter is a relative gravity meter. A single reading does not determine gravity. The meter only measures the difference in gravity between two observation locations or over a time interval at one site. If the converted reading is 2789.12 milligals at Station A and 2889.12 milligals at Station B, then gravity at Station B is 100.00 milligals greater than Station A. If gravity at Station A is 980,234.56 milligals, then you have determined gravity at Station B to be 980,234.56 plus 100.00 milligals or 980,334.56 milligals.

CHECKING LEVELS AND SENSITIVITY

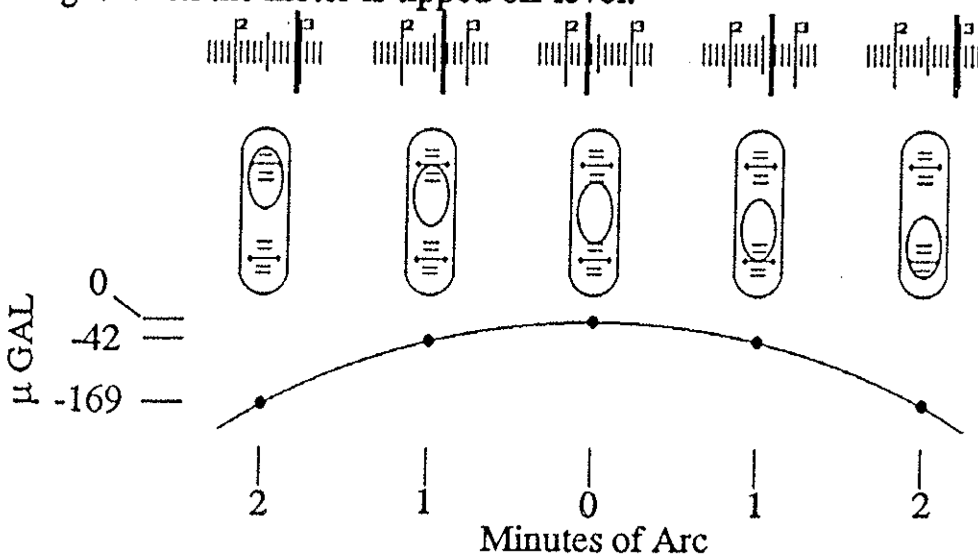
Whenever the meter has been shipped or has received a sharp blow or has been in the hands of a person not experienced with the meter (such as a customs inspector), it is good practice to be certain the levels and sensitivity setting are in proper adjustment. All good operators should know how to perform these checks and adjustments. They should not be deligated to a technician. The technician is not in the field when you bump or drop the meter. They are easy to learn and fundamental to a good understanding of the meter.

CHECKING THE TRANSVERSE LEVEL

The transverse level is also called the cross level. It is at 90 degrees from the direction of the meter's beam. With most meters, the spirit level is on the right side of the meter's lid. The galvanometer for most electronic cross levels is on the left side of the meter's lid.

The purpose of this level is to position the gravity meter, in the transverse plane, so the meter measures maximum gravity. If the meter is tipped to one side or the other (away from or toward the operator) it will not measure the full force of gravity.

If the cross level setting is correct, the gravity should decrease if the meter is tipped away from or toward the observer. That is indicated by the crosshair (and galvo on CPI meters) moving to the right when the meter is tipped off level.



If the meter is nulled to the reading line when the meter is out of level, the gravity reading will be less and less the more the meter is out of level. Be sure the other level, the long or longitudinal level, is in the level position each time the meter is read.

If the meter does not indicate a maximum gravity reading when the cross level is centered, the cross level is out of adjustment. Tilt the meter until the maximum reading is obtained. Remember to always keep the long level centered.

Now while being careful not to move the meter, use the level adjusting tool to center the level bubble. There is a small coverplate on the black lid. It is located on the far side of the cross level window. With a very small screw driver or the blade of a knife, loosen the screw that secures the coverplate. Rotate the coverplate and expose the access hole. The hexagonal level adjusting tool will fit through this hole and into the head of the level's small adjusting screw.

Repeat the testing of the cross level to be certain your adjustment was done accurately. If it was, you should obtain a maximum gravity reading when the cross bubble is in the center.

If the cross level is far out of adjustment, the meter's beam or spring may drag along the side or the other. Tilt meter considerably to one side and the other to determine at what angle the beam becomes free. If the beam moves but is unstable and can not be nulled to the reading line, check the meter's sensitivity (next section).

Some older meters do not have levels that can be adjusted through a small port in the black lid. These older meters must have their black lids removed to reach the level adjustments. See the METER DETAILS section for more information. A special aluminum tube is required to hold the eyepiece while adjusting these older levels with the black lid removed.

CHECKING THE SENSITIVITY

The longitudinal or long level is parallel to the meter's beam. It is used to set the mechanical sensitivity of the meter.

Raising the right side of the meter makes the beam less sensitive to a given change in gravity or spring tension. As the sensitivity becomes greater, the period of the beam becomes longer. If the period becomes too long, it is no longer practical to read the meter by the nulling method. Still more lowering of the meter's right side causes the beam to have an infinite period, and still more lowering of the right side and the beam becomes unstable with the beam accelerating as it moves toward the upper or lower limit of its movement.

The beam is limited in movement by "stops". They are factory adjusted to limit the beam movement to 15 small optical lines. The reading line is usually close to the center of the range of movement. *L and R* places a small label on the black lid indicating the reading line when the meter was last tested at *L and R*. When the beam is clamped, it is pushed down onto the bottom stop. Because of the optical system, the bottom appears toward the left side of the optical scale and the top toward the right.

To check the sensitivity:

- Level the meter.
- Turn on the reading lamp.
- Observe the position of the beam. It will be close to the bottom stop.
- Unclamp the beam.
- Turn the nulling dial to locate the lower and upper stops.
- Position the crosshair about one small optical division above the bottom stop. Be sure to approach from the left (clockwise turn of the nulling dial).

- Turn the nulling dial approximately one milligal clockwise. This would be one full revolution for the Model G and ten full revolutions for the standard Model D.
- Observe the number of small optical divisions the crosshair moves in the eyepiece.
- If the beam moves approximately 9 to 11 small optical divisions, then a long level adjustment is not necessary. (9 to 10 optical divisions if the electrostatic nulling system is used)

If the sensitivity is out of the above range, the long level and sensitivity should be adjusted in small increments, usually about a fourth or a half of a bubble division.

If the sensitivity is too low (less than 9 small optical divisions), lower the right side of the meter a small amount so the level bubble moves away from the eyepiece stalk. Recheck the sensitivity of the meter. If the sensitivity is now within the acceptable range, reset the long level as follows:

- Be careful not to move the meter.
- Open the small level adjusting access hole at the left end of the long level.
- Insert the hexagonal adjusting tool through the access hole into the level adjusting screw.
- Gently turn until the level bubble is centered.

If the sensitivity is too high (greater than 11 small optical divisions), raise the right side of the meter a small amount so the long level bubble moves toward the eyepiece stalk (to the right). Recheck the sensitivity. If the sensitivity is now within the acceptable range, reset the long level with the level adjusting tool as described above.

During all of the above adjustments, be sure the cross level remains with its bubble in the center.

CHECKING THE READING LINE

- Level the meter.
- Turn on the reading lamp.
- Unclamp the meter.
- Use the nulling dial to adjust the crosshair to the reading line as specified on the meter. If the reading line is not known, choose the optical line midway between the beam stops.
- Keeping the cross level in the level position, tilt the long level one division in one direction and record the eyepiece reading.
- Tilt the long level one division to the other side of the level positions and record the eyepiece reading.
- If the crosshair moves upscale approximately the same amount for each tilt, then the chosen reading line is correct.
- If the crosshair moves upscale appreciably more when the meter is lowered on the right (the long level bubble is one division farther away from the eyepiece stalk) than when the meter is raised on its right side, The assumed reading line is too ~~low~~. High.
- If the crosshair moves downscale when the meter is lowered on its right, the assumed reading line is too low.
- If the correct reading line was not chosen in the above test, relevel the meter, reposition the crosshair with the nulling dial to a new trial reading line and repeat the above procedures.

The reading line should be checked whenever the long level has been adjusted.

STANDARD ACCESSORIES

BATTERIES

Two 12-volt gel-type rechargeable lead-acid batteries are provided with each new meter. They have a capacity of 6.5 amp-hours. An electrical connector is securely mounted on the battery. Since 1984, a 2-pin Cannon KPT02A-8-2S connector has been used. Prior to 1984, a 3-pin Bendix JT06A-8-3S fitting was used. To prolong the life of the batteries, it is important not to deep discharge the batteries and always to recharge them as soon as possible after use.

The batteries are fully charged when shipped but should be recharged before using. Recharge only with the *LaCoste and Romberg* charger. Other chargers may reduce battery life.

Though the acid electrolyte is stabilized in gelatin, the batteries can discharge damaging acid if they become hot and are not upright. Left on their side in a hot vehicle is a likely way to damage the battery and surrounding property!

Do not ship batteries inside the meter carrying case. There is considerable energy and value in close proximity if an accident should occur.

Batteries should be stored in the fully charged state. Preferred storage temperature is 20° C (70° F) or below. The batteries should be recharged every two or three months while in storage. If the temperature is above 20° C more frequent recharging is required to prolong the life of the batteries. Storage at temperatures above 40° C (100° F) should be avoided.

A charging period of 12 to 20 hours is usually sufficient to bring a fully discharged battery to a full charge. A fully charged battery should provide enough energy to maintain the meter for a long field day in all but the coldest weather.

Eventually batteries gradually lose their capacity to fully recharge. When operating time after a full charge is no longer satisfactory, it is time to replace the battery.

CHARGER/BATTERY ELIMINATOR

The charger/eliminator serves two purposes: to charge the batteries and to provide a regulated 12-volt DC power for the meter when it is not in the field.

The charger/eliminator is powered by 115 or 230 volts ± 10% at 47 to 420 hertz: AC power only!

FIRST set the input voltage switch to 115 or 230 volts. Chargers shipped before 1989 have the switch on the face of the charger. From 1989 onward, the switch is located inside the charger. AFTER setting the switch, connect the power source. The charger may be damaged if the switch is set to 115 volts and the charger connected to 230 volts power.

A charger that operates from 12-volt DC power is available as an option. It can also operate from 115 or 230 volts AC power.

ALUMINUM CARRYING CASE

The carrying case is made of anodized aluminum and is divided into two padded compartments. On the left is the meter compartment and on the right the battery compartment. The case should be dried as soon as possible if it becomes damp. This will minimize corrosion to the gravity meter's leveling legs. Good field practice dictates periodic cleaning of the pads and removal of debris accumulated beneath the bottom pads.

Spare fuses and reading lamps are stored in a small box taped to the inside of the carrying case lid. Remove the cushion to expose the fuse and lamp box.

The most common malfunction of the case is a failure of the latches. If prolonged field work in a remote location is anticipated, a spare pair of latches is advisable.

The case is modified for use with meters that are equipped with the analog electrostatic nulling option. The meter side of the case is about 15mm (⅝-inch) wider.

ALUMINUM BASEPLATE

A standard aluminum baseplate is supplied with each meter. It has three legs about 50mm (2 inches) long and a bullseye bubble at its center. The low temperature functional limit of the bubble is -54°C (-65°F) and the bubbles can tolerate -62°C (-80°F).

There are several optional baseplates available for special purposes (see options).

CABLES

Each new meter is provided with a power extension cable for use with a 12-volt power source other than the standard batteries or eliminator. The cable attaches to the end of the standard meter power cable and has two color coded battery lugs at the other end. Red is positive and black is negative.

Meters with the CPI option are equipped with a recording cable. It is a short two-conductor cable with a miniature phone plug at the meter end and lugs at the recorder end.

ALLEN ADJUSTING TOOL

For adjusting the levels, an Allen driver is provided with each new instrument. It has a screw driver handle and a hexagonal shaft and tip. The tool is stored in the carrying case. The tool comes in two lengths: a short one for meters that only have spirit bubble levels and a long one for meters with electronic levels.

SPARE FUSES AND LAMPS

Spare ATO-3 fuses and reading lamps are stored in a small box taped to the inside of the carrying case lid. Remove the pad from the inside of the lid and the box is apparent.

MANUAL

Each meter is provided with a manual. *L and R* is endeavoring to improve the manual and have it translated into several different languages. Suggestions for improvement or adding additional information would be appreciated.

CALIBRATION TABLE

Each meter has its own unique calibration table. Some Model D meters have a single calibration factor. If the table is lost, *L and R* maintains the original, together with the raw data from which the table was generated.

SPECIAL METER SHIPPING CONTAINER

The shipping container in which the instrument is shipped from *L and R* is a reusable container. It is important to retain it in good condition for use when the meter is next shipped.

Warranty

All *LaCoste and Romberg* gravity meters are guaranteed for a period of 1 year after delivery. At the Purchaser's request, *LaCoste and Romberg* will make all necessary adjustments, repairs and parts replacements. All parts will become the property of *LaCoste and Romberg* on an exchange basis. This guarantee will not apply if such adjustments, repair or parts replacement are required because of accident, neglect, misuse, operation on improper power, transportation or causes other than ordinary use. All necessary adjustments, repair or parts replacement will be made at no charge to the Purchaser provided that the Purchaser pays all transportation cost to and from the *LaCoste & Romberg Gravity Meters, Inc.* laboratory in Austin, Texas. The period of the guarantee is extended by the length of time that the gravity meter is in transit and in the laboratory for repairs. The guarantee is void if the internal sensing element is opened by an unauthorized person.

The foregoing guarantee is in lieu of all other guarantees expressed or implied, and all obligations or liabilities on the part of *LaCoste & Romberg Gravity Meters, Inc.* for damages, including but not limited to consequential damages arising out of or in connection with the use or performance of the meter.

SERVICE

There are three basic types of service:

- Repair a specific part
- General testing, cleaning and adjusting
- Long term servicing

Repairing a specific part is usually charged on a time and material basis. There is a fixed rate for some of the more common repairs.

General testing, cleaning and adjusting is a fixed price. It includes:

- Testing the meter
- Opening
- Cleaning the beam stops
- Adjusting the hysteresis compensator
- Making other internal adjustments
- A 16 hour check of the meter seals
- Flushing meter with dry inert gas
- Sealing meter
- Retesting to verify adjustments were made properly
- Field testing
- Cursory check of calibration (17 milligal range)

The time required for the above is usually one to two weeks.

Long term servicing includes all of the above plus:

- Replacing all seals
- Removing the micrometer screw (two for Model D), cleaning, inspecting and relubricating

- Removing the gear box, cleaning, replacing any questionable micro-bearings or gears and relubricating.

The time required for long term servicing is usually two to three weeks. There is a fixed price for the work. Any significant updates are an additional charge. Long term servicing should be performed every EIGHT TO TEN YEARS. Seals will start failing after that many years due to hardening. The lubrication on the micrometer screw ages and should be cleaned and replaced, regardless of the amount of use.

L and R is proud to service and maintain its instruments, regardless of their age. Almost every Model G and Model D meter is in service with G-1 looking and working like a new meter.

Our service policy is to charge a reasonable price for service and to perform it promptly.

WARNING!

DO NOT OPEN THE SENSOR. It is sealed with dry inert gas. There is nothing in the sensor that can be repaired outside the *L and R* laboratory. Only SEVERE AND COSTLY damage can result from opening the sensor.

OPTIONS

CAPACITANCE BEAM POSITION INDICATOR (CPI)

This option is sometime referred to as "electronic readout". It is the most popular and useful of the meter options. It consists of a capacitance bridge sensing the position of the meter's beam and reporting this to a galvanometer or liquid crystal display (LCD) on the meter lid.

ADVANTAGES

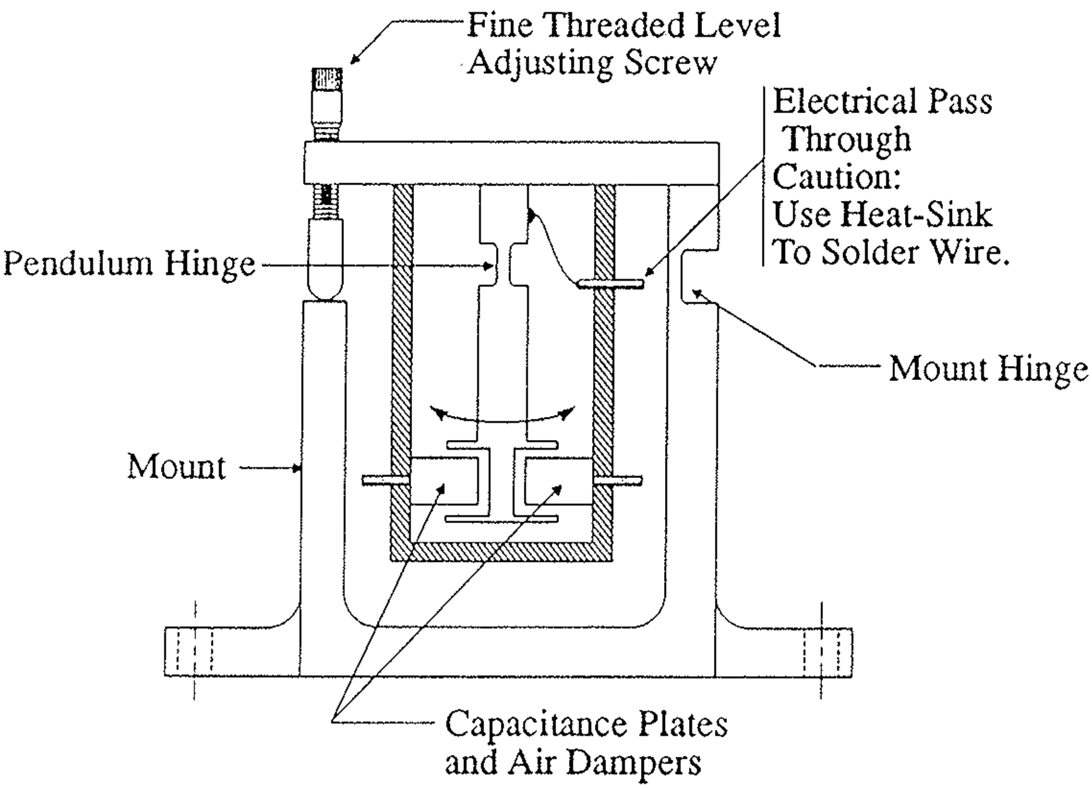
- Operator fatigue is reduced since the microscope need only be used when checking or adjusting the CPI.
- The galvanometer can be set to have greater sensitivity than the optical system, allowing more accurate reading.
- An electric outlet is provided for the signal that drives the galvanometer. A recorder can be driven by this signal to demonstrate earth tides and long period seismic waves.
- An external R-C filter and voltage indicator (galvo or digital multimeter) can be used to read the meter when ground vibration is troublesome.

This option is required for various options such as analog and digital electrostatic nulling and variable damping.

The only noticeable difference between meters with CPI and those without CPI is the addition of the galvo or LCD on the top of the meter and the miniature phone jack outlet. For more information see the Meter Details section of this manual.

ELECTRONIC LEVEL (PENDULUM TYPE)

Electronic levels are an option for the gravity meter. They are hard mounted directly to the sensing element inside the white box. The existing bubble levels are not removed, but revert to a back-up role. Each electronic level is a simple pendulum that is air damped. The position of the pendulum is sensed by a capacitance bridge with the two air dampers being the fixed capacitance plates and the pendulum the moving plate. These levels first became an option in 1979.



CHARACTERISTICS

Principle: simple pendulum
Damping: air
Linearity: plus / minus 2% full scale
Natural Period: .26 second / cycle
Range: plus / minus 10 arc minutes
Resolution: 1/2 arc second
Readout: capacitive (displacement sensing) with a galvanometer for visual display
Stability: 1 arc second / month
Temperature Effect: 1 arc second / 1 degree C.

ADVANTAGES

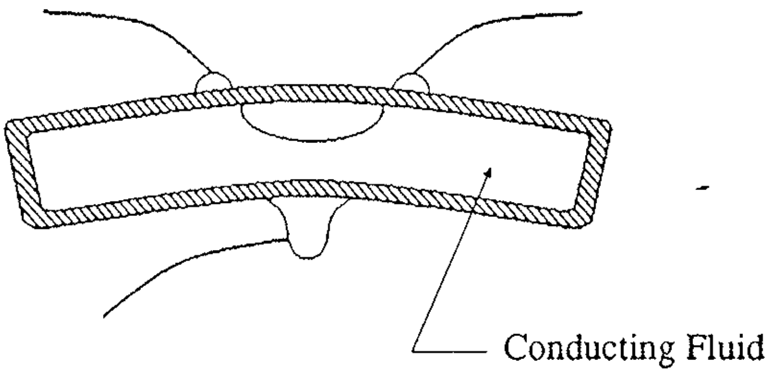
- Bubble levels must be carefully shaded on a warm or sunny day to prevent variations in level reference of up to 1 arc minute (approximately .04 milligal error).
- The fast, perfectly damped motion of the levels speeds work and reduces operator fatigue.
- Smaller level increments are more easily detected on a galvanometer than with bubble level markings.
- Electronic beam and level readouts make it possible to determine the reading line more accurately than can be done with optics and spirit levels. When using the optics, the reading line is usually determined only to the nearest microscope division, thereby making it accurate only to about a half microscope division. Furthermore the level bubble divisions are not as uniform or as readable as the microammeter divisions of the electronic levels. It is particularly important to use an accurately determined reading line when microgal accuracy is desired.

ELECTRONIC LEVEL (LIQUID TYPE)

These levels are a compromise. They are much less expensive than the pendulum type electronic levels. However, they do not have the very fast response and perfect damping of the pendulum levels.

They consist of a bubble inside a curved glass tube. The fluid is a conductor and there are electrodes to sense the change in resistivity as the bubble moves along the glass tube.

They are located below the insulation and just atop the meters sensor. The standard spirit levels can be retained as a back-up. This option was introduced in 1989.



VARIABLE DAMPING

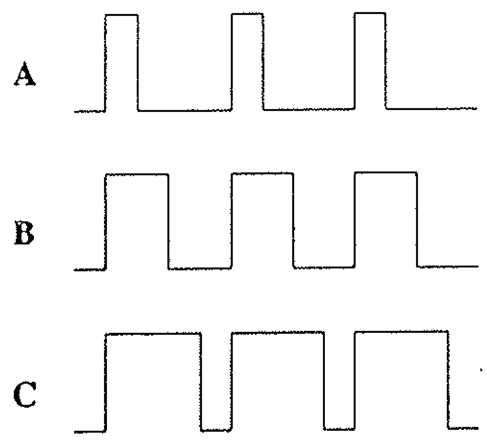
The variable damper is an option for the gravity meter that allows the operator to adjust damping to suit different needs.The gravity meter is identical to the standard meter except for the variable damping feature. Damping can be set at standard damping or at 25 times standard damping. With care, damping can be set at intermediate values.

This option was developed for reading gravity atop frozen lakes. It is useful for observing gravity in areas of severe ground motion. For areas of severe ground motion, the CPI option with an R-C filter should be adequate.

Meters with this option can be recognized by a large nylon plug on the bottom of the meter and two white button switches on the operator side of the black lid. The plug on the bottom side allows access to the engaging device.

When full damping is engaged, the method of reading the meter is slightly different. The two white buttons called "cheater switches", are used to electrostatically push the beam to the reading line. According to the direction and velocity the beam moves away from the reading line, the nulling dial is turned to the next estimate of the null reading. The beam is once more pushed back to the reading line and the procedure is repeated. With a little practice, the reading can be made almost as fast as normal readings with standard damping.

Below are three examples of pulse width modulation.



B causes two times as much force on the beam as does A and C causes three times as much force on the beam as does A. Since the voltage can be maintained at an exact amount, only the time the voltage is applied must be measured.

After the analog electrostatic nulling option is calibrated, the balancing force (gravity reading) can be read on a digital multimeter in microgals.

Besides field use, the option has another advantage. It can assist in recording earth tides and teleseismic surface waves. There are three analog outputs from the device. One is the same signal as sent to the LCD. The second is filtered with three stages of 10 sec. RC filtering. These can be recorded on a strip chart or digital data logger. The filtered signal is useful for measuring gravity under conditions of severe ground motion and is an alternative to variable damping. Connecting a voltmeter or data logger with more than 3½ digit resolution allows precisions greater than 1 µGal to be obtained. The third output is the unfiltered beam motion and contains higher frequency information useful for recording teleseismic surface waves.

The meter can always be used as a regular meter. There is a disabling switch on the top of the analog nuller housing. Or, the device can be removed from the meter. It is held to the side of the meter by four screws. It is electrically connected to the meter by a ribbon cable. If the unit is removed from the meter, disconnect the unit from the ribbon cable and place the small jumper plug on the end of the cable. The meter will now function as a normal CPI meter. For convenience, the black lid can be raised temporarily and the ribbon cable tucked out of sight under the meter lid.

The manual for this option has more detailed information.

DIGITAL ELECTROSTATIC NULLER

This option is similar in principle to the Analog Electrostatic Nuller. However, it is not as portable and uses digital electronics. With digital electronics there is greater long term stability, flexibility in selecting filters and the capability of sending its data to a digital data logger or computer via its RS232C serial port.

The unit is in a box separate from the gravity meter and is connected to the meter by a small ribbon cable. When not in use, the unit can be disconnected from the meter, the ribbon cable tucked under the lid of the meter and the meter used in its standard mode.

If the meter is properly insulated from air temperature changes, the digital system makes a fine earth tide recording system. *L and R* is pleased to provide advice on the application and has computer programs available for processing and analysis of the data.

A power supply and clock are required for the digital nuller. They may be provided by the user. Many observatories have an accurate source of one-second time pulses. *L and R* has two power supplies/clocks available. One is supplied by 115 or 230 VAC power, provides the regulated DC voltages need by the nuller and has a dividing circuit for obtaining one-second pulses from the 50 Hertz or 60 Hertz AC power. The other *L and R* power supply/clock is supplied by unregulated 12 VDC power, has a DC-to-DC power supply and a high precision quartz clock. If the AC power source has frequent interruptions or does not have good long term timing accuracy, the 12 VDC unit is the preferable unit.

The manual for this option has more detailed information.

EXTENDED RANGE MODEL D

If ordered in advance of construction, the range of the Model D meter may be 300 Milligals instead of the standard 200 milligals. This does not cause a reduction in meter sensitivity. All components are the same. The micrometer screw is allowed to travel over a 50% greater length. Laboratory calibration must be done over this extended range and a detailed calibration table is provided over this extended range

COARSE AND FINE SCREW CALIBRATION OF MODEL D

The coarse or ranging micrometer screw of the Model D meter may be equipped with a gearbox, counter and nulling dial. There are several advantages to doing this. The resulting meter has all the advantages of both the Model D and Model G and more.

The meter makes an excellent high precision geodetic meter. If there is a small amount of circular or periodic error in the coarse world-wide range screw, this can be minimized by only turning exact integral revolutions of the coarse screw. Final balancing can then be finished using the fine nulling screw, which by its design has minimal circular error. The reading technique is illustrated in the Primary Information section of this manual.

The coarse screw gearbox has a ratio of 100 to 1. Thus it is easy to make integral numbers of turns of the screw.

An existing Model D meter can be retrofitted with a gearbox, counter and nulling dial on the coarse screw. The existing gearbox on the fine screw is retained. It has a ratio of 32.5 to 1.

If the option is ordered before construction of the meter, a special gearbox can be utilized that has a ratio of 100 to 1 on the coarse screw and 50 to 1 on the fine screw. (The use of these special meters is described in more detail in a technical paper by Fett and LaCoste.)

BASE PLATES (LEVELING DISKS)

There are several types of base plates available. All are 10.5 inches (28 cm) in diameter and have a concave upper surface. They are made of cast aluminum. All have three legs. Most have legs that are 2.5 inches (6 cm) tall. The standard base plate has a bullseye level bubble in the center.

After using the meter for some time, few operators continue to observe the base plate's level bubble. For that reason, *L and R* offers the base plate without the level or the level's machined hole, resulting in a cost savings.

Another variation of the base plate is available without the level, but with a central hole threaded ⅝-inch national coarse. This allows the base plate to be mounted atop a standard surveyors tripod. This is of great advantage for underground observation work in the deep snow or vertical gradient observations.

Finally, there is a base plate with oak wood legs approximately 20 inches (50 cm)long. When using this baseplate, care should be exercised to make proper corrections for the height of the meter above the survey elevation marker.

BACKPACK

A backpack is available for carrying the meter and its battery in the standard aluminum case.

HIGH SPEED CRANK

The purpose of this device is to expedite gravity readings between stations where large gravity changes are encountered.This crank makes it possible to turn the dial about 10 times faster. It is a small cylindrical gear box with a small crank handle at one end and two pins at the other end. The pins are inserted into two holes on the top of the nulling dial.

The high speed crank can save time during geodetic surveys with the Model G meter when there are large differences in gravity between readings. It can also be useful with the Model D meter when there are moderate differences in gravity between observations. This is particularly true for periodic repeat surveys.

DC TO DC CHARGER

This charger has all the features of the standard charger/battery eliminator. Instead of the power being supplied by AC power, unregulated 12-volt DC power is used. That power may come from a vehicle battery. The unit is slightly larger than the standard DC unit. It is particularly useful when working in remote locations where AC power does not exist or requires a motor generator. The *L and R* rechargeable batteries can be recharged promptly after discharge, thus extending their useful life. This charger will also work from 115 or 230 volts AC power.

COMPUTER PROGRAMS

Several software packages are offered by *L and R* for reduction of land, sea, earth tides and borehole gravity data. When purchasing a software package, it is copywritten and remains proprietary. The owner is registered and *L and R* will provide improvements to the program at no additional charge except shipping.

GRAVPAC

GRAVPAC is an MS-DOS program for the entry, reduction, and tabulation of gravity survey data. The data are in the form of meter readings, times, and station coordinates and may be entered in segments as they become available during a field survey. Data reduction includes meter calibration factors, solar plus lunar tides, and drift corrections. Report-ready tables are made of the raw data, observed gravity, free-air gravity, and Bouguer gravity. Provision has been made for multiple base stations, tares in the drift control, multiple Bouguer-slab densities, and terrain corrections. GRAVPAC also determines absolute gravity at any temporary or secondary base stations inferred by their ties to bases of known absolute gravity. Both primary and secondary bases are then used to determine meter drift. The processed data can be stored on disk files and/or output to a line printer. GRAVPAC runs on MS-DOS compatible computers with Epson compatible line printers although the printer is not needed if no printout is required. GRAVPAC can also produce earth-tide tables.

GMODEL

GMODEL finds the gravity anomaly of models assembled from: infinitely-long horizontal polygons, finite-length horizontal polygons, vertical polygons, and spheres. The calculations may be either along a profile or a grid on a surface. For profile calculations, observed gravity may be entered and displayed with the modeled gravity. The user may then modify the model or print the results. Surface calculations on a regular grid are written to a disk file for subsequent contouring by an appropriate program, such as SURFER. GMODEL will also invert a profile of gravity observations into a single irregular interface such as might represent the contact between surficial alluvium and bedrock. For this option, the user controls the average depth and dip of the interface and the program finds its configuration. GMODEL runs on MS-DOS compatible computers with Epson-compatible line printers. If no printout is required, the program may run without the printer.

TIDECV

TIDECV accepts the time and value of a gravity meter reading and returns the tide-corrected metered gravity. It can be used to reduce raw survey data or for quality control during a field survey. By running TIDECV at each base station tie, the surveyor can readily detect offsets (tares) in the data and determine at the end of each loop the amount of meter drift that occurred during that loop. TIDECV runs on HP-41 programmable calculators. (TIDE71 is available for HP-71 computers. It also prints tide tables if a printer is available.) The program is available on either magnetic program cards or mini cassettes and comes with complete instructions on a laminated plastic card. Included is another program for the HP-41, GMOD, which does modeling for spheres, horizontal cylinders, thin plates, and thick plates.

More details are presented in the Computer Programs section.

L and R will be introducing more programs for data reduction and analysis as well as more complex modeling.

TRAINING

Training is provided at the *L and R* facilities or in the field or at your facility. Training at our facilities may be on a one-to-one basis or may be an organized course. The average course is two to three days in duration.

- The first day consists of microgravity field observations over three culverts and learning to check the meter and do cursory servicing and troubleshooting.
- On the second day, the field data are entered into the computer, familiarization with the software is acquired and there is elementary modeling and interpretation.
- If a third day is available, additional theory, interpretation, case histories and special techniques are discussed.

FIELD PROCEDURES

INTRODUCTION

The following is a guide to help the operator avoid some of the more common problems encountered in conducting a gravity survey. However, the observant and thoughtful operator is always able to further improve his technique, regardless of the months or years of experience he or she has accumulated. For shipping precautions, please refer to that section of the manual.

PROMPT DATA REDUCTION

Prompt reduction of the gravity data allows the operator to know how good or poor his technique is while he still can recall the details of the field work. Thus he can associate a bump to the carrying case or a rough road with irregular and high drift rates. He soon can learn what care in handling the meter must be provided to attain results of a given quality.

One of the fastest methods of learning the quality of the field work and the performance of the meter is to obtain the gravity tide at the time of each base station reading and calculate the tide-corrected drift the meter has just undergone during the time since the previous base reading. The tide correction may be obtained in the field from pre-calculated tables from GRAVPAC or computed on a hand-held computer such as the HP-41 using program TIDECV.

Meter Vibration

One of the larger sources of error in a field survey comes from large and irregular meter drift. The main cause of the problem is rough treatment of the meter. The more vibration and bumps, the more irregular the drift. Certain vibration frequencies are worse than others. Snowmobiles and helicopters may cause severe short-term drift. The smoother the ride, the better the meter performance. For very accurate work, it may be necessary to carefully hand carry the meter. If transported in a vehicle, it may be necessary to hand-hold the meter off the seat and minimize the vibration that is transmitted from the vehicle to the instrument. The selection of a field vehicle with softer suspension is usually worthwhile. A vibration isolation carrying case rack is used by some observers.

Temperature Extremes

If the meter goes above or below its thermostated temperature, there will be intolerable instrumental drift. Each instrument is thermostated at a different temperature. Unless especially designed, the thermostated temperature will be between 47°C and 55°C. It is best to use a meter thermostated at the lower temperatures when working in a cold climate, as it will conserve battery power. It is best to use one thermostated at the higher temperatures when working in a hot climate, as it will be less likely to go over temperature.

Cold

When the meter is placed in much colder air, often it will make several loud cracking sounds. This is due to contraction of the fiberglass housing or other superficial parts. Be sure to check the liquid levels after these noises occur.

Spirit levels may change somewhat when the meter is in cold air. They may require re-adjustment after the meter has been in the cold. Electronic levels are within the insulation and are not affected by changes in ambient air temperature, a distinct advantage when working in cold weather. In severe cold weather, electronic levels are required for accurate and efficient work.

Keep the baseplate cold when operating on ice or frozen ground. A warm baseplate will thaw the ground and it will be impossible to keep the meter level long enough for a reading. If the plate is warm, you may use a board or chips of wood between the baseplate feet and the frozen ground. In snow you may wish to use a special plate with long wooden legs (see options).

In severe cold, the standard battery will not last for a full day of field work. This is due in part to the extra power consumed by the meter to keep it at its thermostated temperature. The main limitation is the battery not releasing as much energy when it is cold. Try to keep the battery and spare battery warm so they will yield more energy. With severe cold, some operators use the power extension cable and a larger battery such as a sealed motorcycle battery.

Ni-Cad batteries are generally more expensive, have a shorter life and are more troublesome to work with than are gelatin stabilized lead-acid batteries. However, they are not affected as severely by cold.

For high precision work in cold climates, a double oven meter will be available in spring of 1990.

HOT

There are several methods for keeping the meter cool in hot weather. Avoid allowing the sun to shine directly on the carrying case. A towel or cloth with a short slit cut in its middle can be placed over the carrying case and allow the carrying handle to come through the towel. In dry hot climates the towel can be moistened. Evaporation will provide some cooling. Try to minimize or eliminate use of the reading lamp. It adds considerable heat to the system. In severe heat, a block of frozen gelatin in a well sealed plastic pouch can be carried on the battery side of the carrying case. These are commercially available. If condensation accumulates in the carrying case, it should be dried periodically.

It may be necessary to conduct field work at night and in the early morning hours when air temperature is cooler and when radiation from the sun can be avoided.

Leaving a meter in a parked vehicle with closed windows in a hot climate is a likely way to drive the meter over temperature.

The semiproportional heater control option allows the minimal amount of energy flow to the meter when the ambient temperature is approaching the thermostated temperature. It is a distinct advantage if the meter is tending to go above its thermostated temperature.

The CPI electronics generate about 1½ watts of heat and are located against the side of the sensor. Half of that heat is generated by a single component on the PC board. This component can be mounted on long wires and placed just below the black lid, keeping the heat away from the sensor.

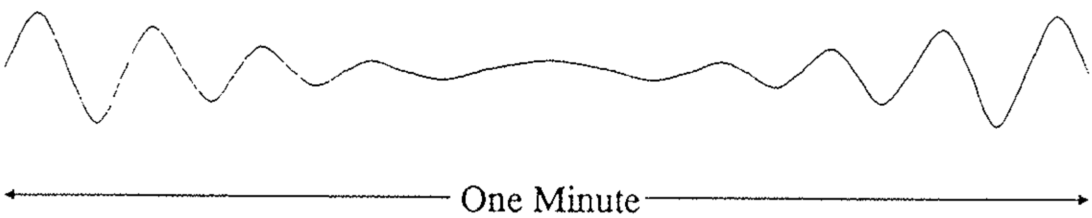
Each meter is normally thermostated at the temperature which gives the smallest change in reading for a given small change in internal temperature. Under prolonged severe heat, if the above field methods do not work, the thermostated temperature can be set to a higher temperature. This will decrease the accuracy of the meter as small changes in internal temperature from heater cycling or use of the reading lamp will have greater effects on the meter. However, for regional gravity surveys these errors may be well within the tolerance of the survey.

The procedure for changing the thermostat setting is given in the Meter Details section of this manual.

MICROSEISM

The continental crust of the earth is an efficient wave guide for seismic surface waves of certain wave lengths. When ocean waves of longer period strike the coast and reflect seaward, the resulting standing waves can massage the continental shelf and initiate these crustal seismic waves. In North America they can travel half way across the continent. Winter storms in the north pacific are the major causes in western and central North America. After severe storms in the distant North Pacific, gravity observations may be difficult in western states and provinces.

Microseisms usually have a period of about 4 to 5 seconds and, because of constructive and destructive interference, usually build up then die away with about five to twelve cycles per packet of waves.



To observe gravity during times of large amplitude microseisms, the variable damping option can be used. If the meter has the CPI option, another equally satisfactory solution is a simple R-C filter and external galvanometer or digital multimeter. A third option is to use electrostatic feedback nulling with or without additional filtering. Since the time-constant of the feedback loop is set near 90 seconds, the system effectively averages high to medium frequency seismic noise. This can average the oscillations of the microseism.

EARTHQUAKES

Local earthquakes seldom are a problem during gravity observations. They occur and are gone before they are any inconvenience.This may not be the case with volcanic tremors. In the vicinity of a very active volcano, there may be frequent small tremors. The observer may wait for quiescent periods to observe. If available, the variable damped meter or meter with electrostatic nulling may be of assistance.

Distant earthquakes can delay observations for several hours. This is particularly true for large earthquakes on the opposite side of the earth. Their dispersive waves form a very long wave train when at a great distance from the source. A great earthquake with several major aftershocks can hamper careful gravity observation for days; three days following the 1975 China earthquake, for example.

Often observers have not identified the oscillation of a distant earthquake as such. They often believe the oscillation of the meter to be a malfunctioning of the meter. There is nothing in the design of the meter that could internally provide continuous oscillation. The electrostatic nulling options are an exception. If in doubt about the occurrence of an earthquake, you are welcome to telephone our lab. Usually we have at least one meter recording.

VEHICULAR AND MACHINERY VIBRATION

Though the frequencies may be different than those of microseisms, the solutions to observing may be the same; the variable damping , the R-C filter on the CPI option, electrostatic nulling option. At higher frequencies and larger amplitudes, the R-C filter may be a better solution and the electrostatic nulling option is the best solution. When the heavy damping is engaged on meters with variable damping, there is about 25 times normal damping.

If there is some nonlinearity in the air damper and the vibration is not sinusoidal, there may be some error due to "pumping".

Lateral vibration has little or no effect on the meter. The reason for this insensitivity is explained in the section Physics of the Sensor.

WIND

Wind movement of the meter is particularly troublesome. It causes two effects that are difficult to separate. It tips the meter out of plumb, this reducing the observed gravity. It also rocks the meter back and forth causing the beam to oscillate. If practical, place the meter in a location sheltered from the wind. If this is not feasible, place the meter so the wind direction is normal (90°) to the direction of the beam. Averaging the oscillations of the beam or galvanometer will not give accurate results, as the meter is out of level a portion of the time and at those times, is not observing the full force of gravity. Strong wind dictates shelter or curtailing gravity observation. The gravity observer can take advantage of these times to reduce data or help the survey crew establish station positions and elevations.

BASE SELECTION

In selecting the location of a local basestation, a site near the center of the survey is best. Less time is wasted returning to the base and the meter undergoes less vibration traveling to and from the base. It is possible to return to the base more frequently and overall accuracy is improved. If the survey area is large, several local bases can be established. The local bases are tied to the main base or regional base several times.

Try to select quiet locations for bases. Also, select locations that will be easy to relocate years later in case the survey may be extended or tied to other surveys in the region. Good field notes describing bases are an indication of a professional observer.

A sheltered base is a great advantage for closing a loop of observations, if weather becomes severe during the survey.

RERANGING THE MODEL D

The standard Model D has a range of 205 to 250 milligals, depending on the meter's calibration factor. This is enough to work over elevation differences of about 1,200 meters (4,000 feet).

If a survey area is mostly at a higher elevation than a base, it might be wise to re-range with the counter set about 1500.00. If the survey area is mostly at a lower elevation than the base, the meter could be reranged with the counter set at about 0500.00.

Once a survey is under way, The meter should not be re-ranged except at a station or base where gravity has already been measured.

TRIPOD ON ASPHALTIC PAVEMENT

When observing on asphaltic pavement, the standard baseplate will gradually sink into the pavement. In all but the coldest weather, this will prevent the meter from remaining level enough for a reading. If you cannot find a convenient location away from the asphalt, distribute the load of the three legs by placing a board or other flat rigid material between the tripod and the asphalt.

TRIPOD IN FROZEN COUNTRY

If the tripod is above freezing temperature, it will gradually sink into the ice or frozen soil. Instrument leveling will be difficult or impossible. If convenient, keep the tripod cold; outside the vehicle and out of the sun. If this is not convenient, the tripod can be placed atop a board or other rigid item with a low coefficient of thermal conductivity. Even if the non-metal item is warm it will not melt an appreciable amount of ice or soil.

RADIO TRANSMITTERS

When operation near powerful radio transmitters or when two-way field radios are very close to the gravity meter, they can cause the CPI electronics and/or the galvanometer to be affected. Under these field conditions, revert to the use of the microscope to determine beam position. The optical system is not disturbed by a strong EM field.

OBSERVING GRAVITY BELOW GROUND

There are many reasons for measuring gravity below the earth's surface. If gravity is measured in a mine drift and on the surface, areas of greater density rock can be located and the optimum location for stoping selected.

If the ceiling is not too high, the meter can be placed halfway between the floor and ceiling. The significant local anomaly from the missing mass of the mine will cancel itself at the mid elevation. A special baseplate is available for this purpose. It has a flat surface on the center of its bottom and has a standard threaded hole (5⁄8-inch N.C.) for mounting atop a surveyor's tripod. The baseplate still has the standard three feet and can be used as a normal baseplate.

For more details there are several technical papers with case histories and more details. A recent paper is:

Casten U., and Gram, Chr., Recent developments in underground gravity surveys, *Geophysical Prospecting*, Vol. 37, pp 73-90, January 1989.

VERTICAL GRADIENT MEASUREMENTS

If the ground surface is irregular, large errors are introduced into vertical gradient observations. Where the ground surface is smooth, vertical gravity gradients may be a useful technique for investigating shallow targets. A meter of high precision is required, such as a Model G with the electrostatic nulling option or a Model D. The meter must be in good repair, especially the hysterisis compensator.

A special tripod can be used that has an upper and lower baseplate with a constant separation between the two plates. This has the advantage of not having to carefully measure the difference in elevation between the upper and lower reading. If a special tripod is not available, a standard baseplate can be used on the ground. After finishing the ground reading, the plate can be left in place while a surveyors tripod is positioned above it and the height above the ground baseplate can then be carefully measured. A special tripod baseplate can then be affixed to the tripod and the upper observation made.

MORE THAN ONE METER ON A SURVEY

If more than one meter is used on a survey, it is best not to intersperse the work of two meters. The effects of any minor irregularities in calibration can be minimized by assigning to each meter its sector of survey area.

PERIODIC GRAVITY SURVEYS

There are many considerations in performing a competant periodic gravity survey.

More text to be added.

METER DETAILS

LEVELING SCREWS

The leveling screws are made of stainless steel. Their threads are ¼-inch with 48 threads per inch. The tips are ground to a sharp point to minimize the meter moving on the baseplate while the meter is being leveled.

When the meter is at *L and R* for standard cleaning and adjusting, the leg tips are resharpened if needed.

The threads of the legs turn in special metal inserts that are glued into the bottom of the white box. To reduce the chance of the stainless steel threads galling, the inserts are made of a lead rich steel. This alloy is capable of corrosion. Always dry the carrying case and meter legs when they become damp. Never store the meter in a damp case. A light lubricant on the threads will reduce the risk of corrosion.

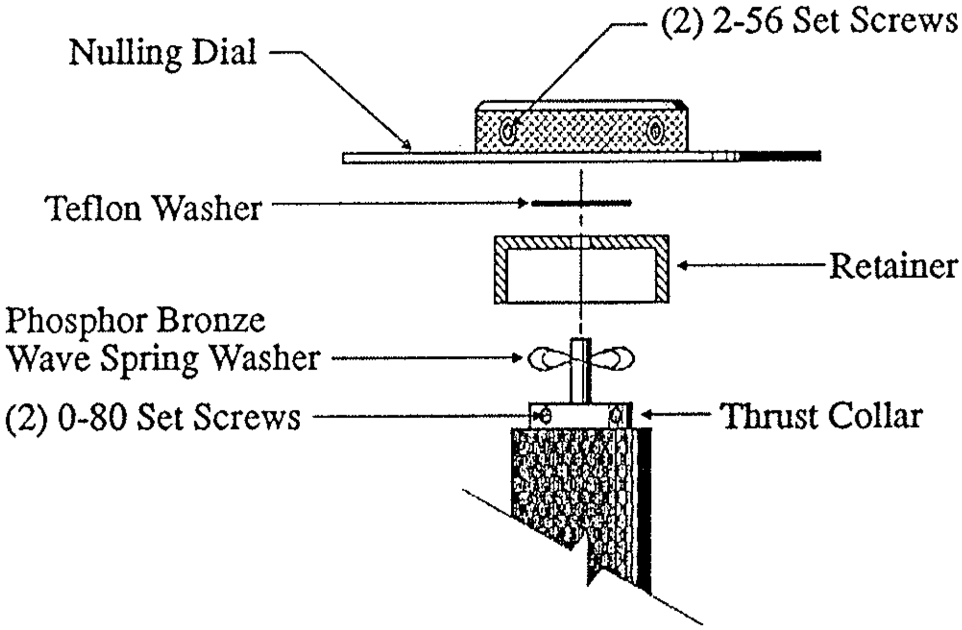
CAUTION, do not extend the legs too far below the base of the white box. They will punch through the base pad of the carrying case, bump the bottom of the carrying case and jar the meter. Also, there is a greater risk of damage to the threads.

NULLING DIAL POINTER

If the instrument has received a hard blow, the meter may shift inside the white box. This can cause the nulling dial and arrestment shaft to be off center as they pass through their holes in the black lid. This is of little consequence other than appearance. However, the dial pointer is fixed to the black lid and may now rub against the dial. To correct this problem, the single hole in the pointer can be filed oblong and the pointer replaced on the black lid a little farther away from the dial.

NULLING DIAL

The nulling dial is a flat aluminum disk with a hundred division marks etched on it and a knurled knob to assist in turning the dial. Except for early meters, the knob has two holes drilled in it to accept the prongs of the high speed crank. The high speed crank is mentioned in the Options section. It is convenient when the nulling dial must be turned through a great range of the meter.



To remove the nulling dial, loosen the two set screws within the knurled knob. Do not put excessive force on the nulling shaft. Hold the screw driver with one hand and the knob with the other hand. Below the dial are three parts that act as an adjustable friction brake for the dial. When replacing the dial, the farther down the dial is pressed against the spring washer, the greater the friction when rotating the dial. The ideal setting is to have just enough friction that there is no backlash of the dial. When the dial is reinstalled on the meter, be sure to phase the number on the dial with the last number on the counter.

ARRESTMENT KNOB

The arrestment knob is knurled and made of aluminum. It is held on the shaft by two very small set screws. It is positioned very close to the arrestment stalk to minimize the chance of dirt entering the top of the stalk.

If something is dropped on the top of the knob, the knob may be driven down and drag on the stalk. To repair, use a 3⁄32-inch Allen tool to loosen the knob set screws, raise the knob about a tenth of a millimeter (a few thousands of an inch) and retighten the set screws.

If the meter is subjected to salt spray or is stored damp, enough corrosion may develop between the knob and the stalk to cause dragging. Repair in the same way as above.

If the knob is very hard to turn and is not dragging on the stalk, the problem is more serious. The bearings or seals in the stalk may require servicing at *L and R*.

REMOVING BLACK LID

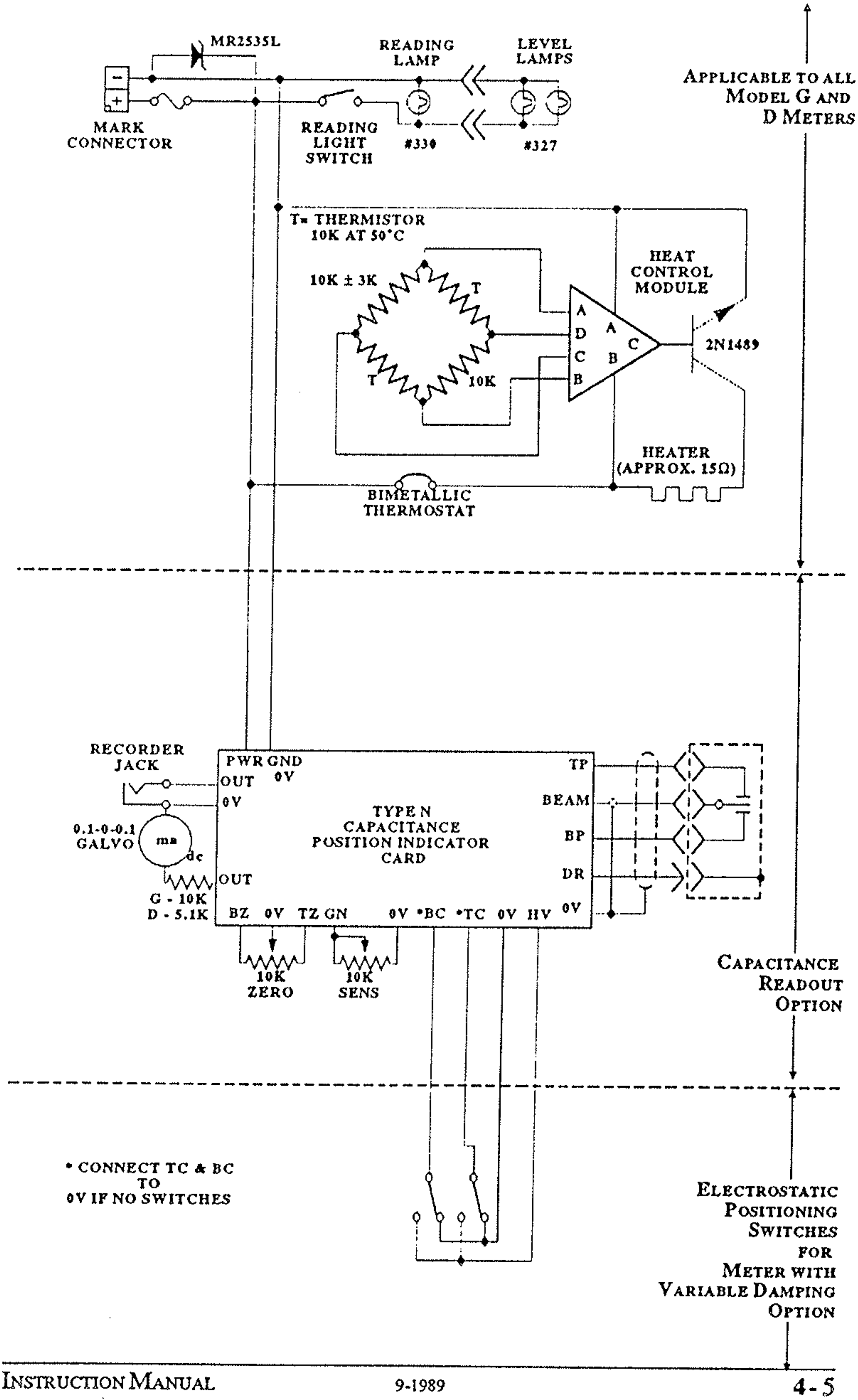
To remove the black lid, turn the three leveling knobs counter clockwise and lift the level legs up and out of the meter box. Remove the nulling dial and the three brake parts beneath it. Remove the four lid screws, one located at each corner of the lid. Now lift the lid upward. It may be stuck to the top of the white box. Loosen with care.

WINDOWS IN LID

Some of the glues used in the past to fix the window into the bottom side of the black lid were water soluble. When these meters are used in moist conditions, the windows loosen. To repair, remove the black lid, clean away the old glue and reglue. If "Super Glue" is used, only 3 or 4 drops are needed, as surface tension will distribute the glue. Allow to dry completely before replacing the black lid. If not vented, the fumes will condense and make a milky coating on the glass.

If replacements are required and it is not convenient to obtain them from *L and R*, you may have them cut from thin glass. The easiest source of this glass is a microscope slide.

SCHEMATIC


MR2535L
READING LAMP
LEVEL LAMPS
MARK CONNECTOR
READING LIGHT SWITCH
#330
#327
APPLICABLE TO ALL MODEL G AND D METERS
T= THERMISTOR 10K AT 50°C
10K ± 3K
T
T
10K
HEAT CONTROL MODULE
A
D
C
B
A
C
B
2N1489
HEATER (APPROX. 15Ω)
BIMETALLIC THERMOSTAT
RECORDER JACK
0.1-0-0.1 GALVO
ma
dc
G - 10K
D - 5.1K
PWR GND
OUT 0V
0V
OUT
TYPE N CAPACITANCE POSITION INDICATOR CARD
TP
BEAM
BP
DR
0V
BZ 0V TZ GN
0V *BC *TC 0V HV
10K ZERO
10K SENS
CAPACITANCE READOUT OPTION
* CONNECT TC & BC TO 0V IF NO SWITCHES
ELECTROSTATIC POSITIONING SWITCHES FOR METER WITH VARIABLE DAMPING OPTION

THE FUSE

Starting approximately in 1980 with meters G553 and D46 the meters have been equipped with a fused safety device which is intended to help protect the electronic circuitry from reversed polarity of the power leads and/or power input over-voltages of greater than 22 volts. This is not to imply tolerance of reversed polarity, or over-voltage greater than about 16 volts.

The fuse is located near the power input connector. The black bakelite meter lid must be removed to replace the fuse. *Use only a 3 amp ATO fuse for replacement.* Spare fuses are provided with new instruments with this protection. They are located in a small box taped to the inside of the lid of the aluminum carrying case. Do not bypass or use a larger rated fuses.

A blown fuse will shut down all electronic circuitry in the instrument: heater circuit, electronic readout, and level and reading lights.

If you are out of fuses they may be obtained from *L and R* or most automotive parts stores.

Whenever older meters are returned for service, we encourage the retro-fitting of the fuse, especially if the meter has the CPI option.

READING LIGHT SWITCH

This switch is a standard single pole, single throw toggle switch. It can be replaced with any miniature SPST toggle switch.

- Disconnect the 12-volt power
- Remove the black lid
- Remove the two screws on the side of the white box that hold the switch bracket.
- Lift the switch and bracket up to expose the three wires.
- Resolder a new switch. The order of the wires is important.
- Connect the 12-volt power and determine the toggle position for the reading light being off.
- Disconnect the 12-volt power
- Install the new switch on the brass bracket so the toggle is toward the operator when the switch is off.
- Replace the black lid and reconnect the 12-volt power.

READING LIGHT

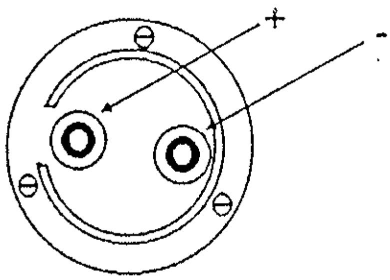
The reading light is on the operator's side of the white meter box. It is behind a round aluminum cover plate. The plate is held in place by three screws. The housing for the reading light is adjustable. It holds a No.330 12-volt aircraft bulb. Spare bulbs are stored in a small container taped to the inside of the carrying case lid. The bulb can be rotated so its filament is optimal for the optics and the bulb holder can be moved to place the bulb in the best position for brightness and sharpness of the image. Two screws secure the bulb holder in place.

MARK POWER FITTING

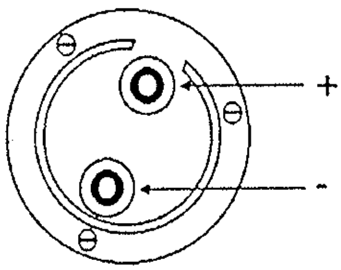
On the upper right side of the white box is the electrical fitting that passes 12-volt power into the meter. There are two types. They look almost identical. The early type was used from 1967 through 1984 on meters from about G154 through about G742 and D1 through D105. These fittings are characterized by their cable orientation key being under the cable and by two power pins being inline with the cable. These fittings and their cables are obsolete and can not be obtained. Since changing the power fitting to the new type is more difficult than at first appearance, it is imperative that these obsolete fittings and their obsolete cables be replaced when the meter is at *L and R* for other servicing. Should the obsolete cable fail in field use, the meter would have to be returned to *L and R* or some primitive splice or solder connection made in the field.

The new Mark power fitting can be recognized by the orientation key being on the top and the power pins being 90° from the direction of the cable. Also, there is a half-round groove just inside the socket that accepts a half-round protrusion on the molded cable fitting at the meter end of the power cable. The new Mark fitting solved a serious drawback of the older fitting. The half-round protrusion and groove hold the cable in place and a good electrical contact is assured. Cables with the old type Mark fitting sometimes were bumped loose when returning the meter to the carrying case. The meter would go off power and temperature, resulting in errors in the observations.

Very early Model G meters had an Amphenol 126-216 power connector. Most of these have been replaced with old or new type Mark connectors.



OLD



NEW

BATTERY & CABLE FITTINGS

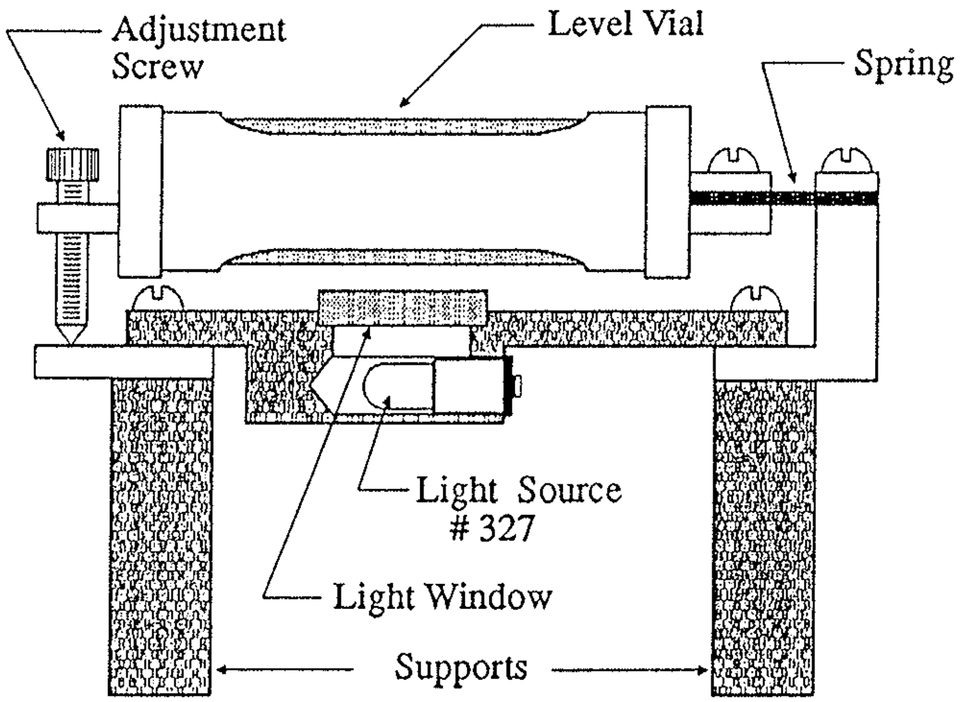
Prior to 1984 (about G720 and D99) batteries and chargers were equipped with three-pin Bendix JT02A-8-3S connectors. These became very high priced and then obsolete. Since 1984, the less expensive and more common two-pin Cannon KPT06B-8-2S connector has been used. The matching cable connectors are JT06A-8-3P-SR and KPT06B-8-2P, respectively. As meters are serviced at *L and R*, the 3-pin connectors are being updated to 2-pin connectors.

LEVELS

Three types of levels are available for the land meters. The standard and original levels are spirit bubble (liquid) levels. In 1979 electronic levels became an option. These are high precision air damped pendulums. Their position is measured with a capacitance bridge and registered on two galvanometers or an LCD (liquid crystal display). In 1989 inexpensive electronic levels were introduced. They are liquid levels with electrodes and conductive fluid.

SPIRIT BUBBLE LEVELS

These are the original levels used in almost all *L and R* land meters. In most Model G meters their sensitivity is 60 seconds per division and in most Model D meters their sensitivity is 30 seconds per division. They can be stored at temperatures down to -51°C (-60°F). The lowest temperature for correct reading is -18°C (0°F). The levels are illuminated from below by a No. 327 bulb when the reading light switch is turned on. This is a 28-volt aircraft bulb operating at 12-volts. Its lifetime should be very long.



The bubble levels have three distinct disadvantages:

- A small amount of direct sunshine on the levels causes differential heating, fluid density gradients and inaccuracy
- The levels are located just beneath the black lid. On very cold days, there is sometimes enough differential contraction of the vials, housing and supports to cause significant error, assuming the levels had been adjusted in a warm environment.
- The levels are slow to creep to a final position, especially in very cold weather.

The levels are adjusted with a hexagonal allen tool provided with each meter. The adjusting screw is at one end of each level and is reached through a small access hole in the black lid. The hole is covered with a small square black metal plate. Loosen the small screw holding the plate in place and rotate the cover plate to expose the access hole.

Some older Model G meters before G??? do not have externally adjustable levels. It is necessary to remove the black lid to make level adjustments. Two special tools were provided with these meters to facilitate level adjusting. One is an aluminum tube to hold the eyepiece while the black lid is removed and the other is a special wrench for adjusting the level nuts. Many of these meters have been retrofitted with external access level adjusting and it should be considered when the meter is at *L and R* for other servicing.

ELECTRONIC LEVELS (PENDULUM TYPE)

These levels are ideal except for their high cost. They overcome all of the above mentioned disadvantages of the spirit bubble levels. For specifications and a diagram, see the Options section.

ADJUSTMENT

Electronic level adjustment procedures are similar to those used for the spirit levels. The directions for spirit levels can be utilized, realizing that 4 galvanometer increments equal approximately 1 bubble division: 15 seconds of arc for a Model G and 7 or 8 for a Model D. If more or less sensitivity is desired, it may be adjusted at *L and R*.

The longer level adjusting tool is required to adjust the electronic levels, as they are farther below the meter lid than are the spirit levels.

The easiest method of initially adjusting the electronic levels is to first adjust the spirit levels in accordance with this manual. Then, with the Allen wrench, reset the electronic level adjustment screws until both galvanometers display 0. The locations of these adjustment screws are shown on the following illustration. Do not readjust the electronic levels on a daily basis as they are more stable than the spirit levels. The optical reading line may increase one small division when going to high latitudes or decrease when going to equatorial latitudes.

When the gravity meter is moved over very large differences in latitude, displacement sensitivity changes can occur. If the sensitivity change is large, both long levels (electronic and spirit) must be readjusted. This will cause a small difference in the reading line position, therefore it should be adjusted also.

DETERMINING A MORE PRECISE READING LINE

- Using the electronic levels, level the gravity meter carefully.
- Using the optical readout, set the microscope cross hair on the reading line specified for the gravity meter. If the reading line is not known, assume a reading line position midway between the beam stops. With the gravity meter nulled at the above optical reading line, adjust the zero of the electronic beam readout microammeter to make it read zero. Use the electronic beam readout in all further adjustments.

- Keeping the cross-level in the level position, tilt the longitudinal level 2 small scale divisions on the longitudinal level microammeter, first in one direction and then in the other. Note both the magnitudes and displacements of the corresponding beam microammeter. Repeat several times to be sure of the results.

- If the beam microammeter moves to the right (upscale in the microscope) the same amount for each tilt, then the chosen reading line is correct.

- If the reading line is not correct, proceed as follows. Make the previously described 2-division long level tilt by lowering the side of the gravity meter which has a single leveling screw. If the beam microammeter then moves upscale more than it does with the opposite tilt, the assumed reading line is too high (too far to the right on the beam microammeter). Otherwise the reading line is too low.

- Shift the reading line 2 microammeter divisions in the direction determined above and repeat the above step. Continue shifting the assumed reading line position until the correct position is found or passed. This procedure will determine the correct position for the reading line within 2 microammeter divisions or better. Continue adjusting until the reading line is determined as well as possible. After this has been done, reset the zero of the beam microammeter to make it read zero at the correct reading line.

REPAIR

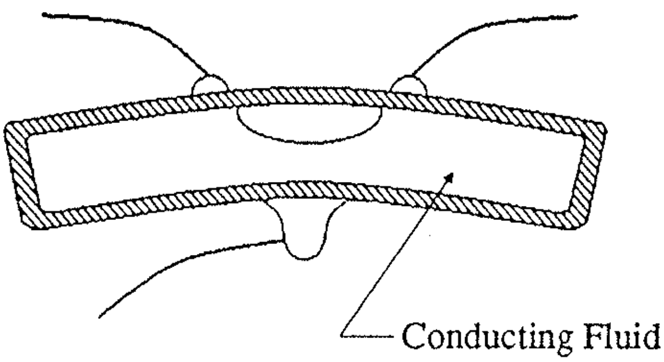
If there is a need to replace the level in the field, care must be exercised. If the wire connected to the side of the level must be resoldered, over heating can damage the interior of the level. The heat should be applied to the tip of the wire lug. A heat sink should be located on the lug between the level housing and heat. A small pair of needle-nose pliers should be adequate.

There is a small chance that a level might stick to one end of the range of travel. A very light tap of the finger on the meter lid will free the pendulum. When the meter is next at *L and R* for servicing, the sticking level will be cleaned as part of the standard servicing.

ELECTRONIC LEVELS (LIQUID TYPE)

These levels are a compromise. They are low in cost and they overcome the first two disadvantages of the spirit bubble levels. Optimum damping for a level would be about 70% of critical. The pendulum levels have optimum damping. At thermostated temperature, the liquid electronic levels are damped to approximately 40% to 50% of critical.

They consist of a bubble inside a curved glass tube. The fluid is a conductor and there are electrodes in the tube to sense the change in resistivity as the bubble moves along the curved tube. Since they are located just above the sensor in a thermostated area, they are not affected by ambient air temperature or sunlight.



CAPACITANCE BEAM POSITION INDICATOR (CPI)

The CPI was mentioned in the Options section of this manual. It is the most popular and important option. It senses the position of the beam with greater accuracy and less fatigue than the microscope. It is a capacitance bridge with a capacitance plate on the beam and a fixed plate above the beam and another fixed plate below the beam.

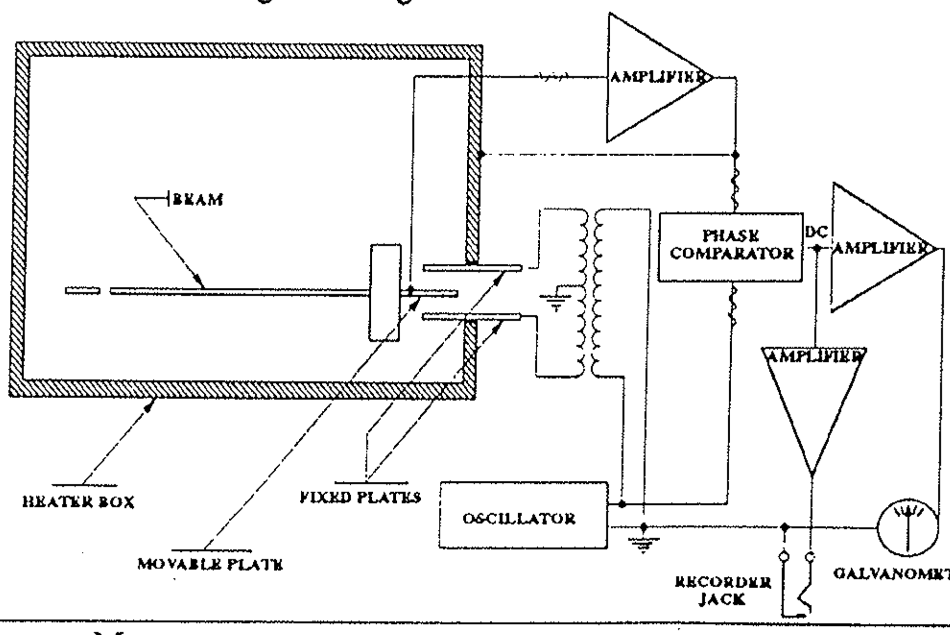
The electronic card of the CPI fits into a pocket on the outside of the meters heater box. The card has had three main types during its evolution: discrete components card, Hybrid card and N-card.

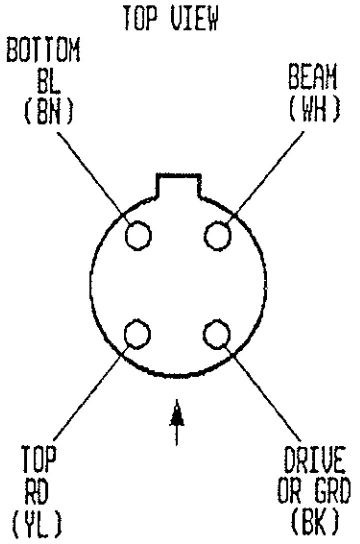
Discrete component cards were used from about G-130 (1967) and the first Model D meters until approximately G-375 and D-10. Hybrid cards were used from then until G-472 and D-25. The Type N card was then introduced.

No Model G meters before G-100 had a CPI as original equipment. Their type of card depends on when they were retro-fitted with CPI.

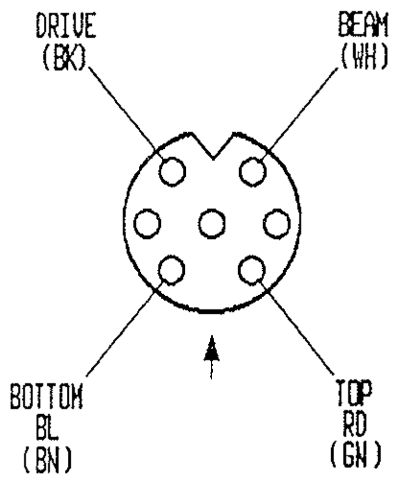
When the Hybrid card is damaged by reverse polarity of the power supply, it is not repairable. The N-card is usually easy to repair.

The following two diagrams show some of the details of the CPI.

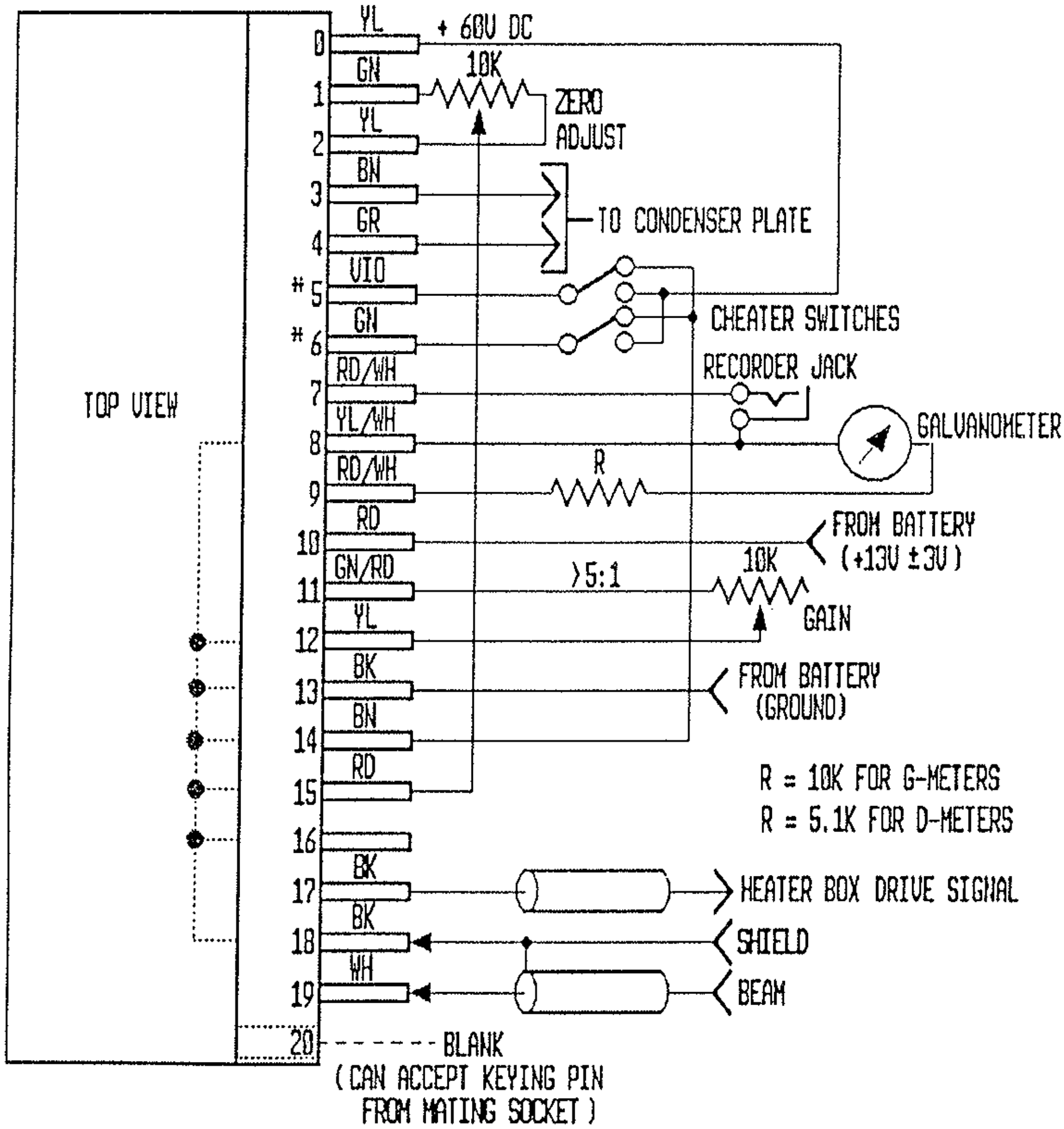




STATHAM CONNECTOR



MICROTECH CONNECTOR



PINS 5 & 6 ARE TIED TO PIN 14 IF THE CHEATER SWITCHES ARE NOT USED

ADJUSTING GALVO GAIN & ZERO

There is a small rectangular black cover plate on the far side of the black lid. Beneath it are two variable resistors. One adjusts the gain of the galvo and the other sets the zero position of the galvo. Common gain settings for the Model G are 100 microGals per large galvo division for regional surveys and 50 microGal for more detailed surveys. For Model D, typical settings are 40 microGals for average work and 20 or even 10 microGals per large division for high precision work.

Whenever the galvo gain is adjusted the galvo zero position must be reset. Null the meter with the microscope. When the cross hair is on the reading line, turn the zero variable resistor until the galvo pointer is on the exact center of the dial.

GALVO HIGH-LOW SWITCH

Some meters have an extra switch on the black lid. It allows switching from low galvo sensitivity (gain) to high sensitivity. On most meters the galvo is set so one eyepiece division is equal to one or two galvo divisions. With this switch, the meter is usually set so one eyepiece division equals two galvo divisions on low and five divisions on high. On most meters with the switch, the gain may be set as high as 10 microGals per galvo division.

To set the sensitivity, place the switch in the high position. Set the sensitivity as outlined in the manual, to the desired level. Remember to reset the zero position after any change of galvo sensitivity. Then with the gain switch in the LOW position, adjust the HI-LOW gain pot (variable resistor) to the desired level. This gain pot is just a resistance in series with the galvo.

With the electrostatic nulling option, changing the galvonometer sensitivity will alter the time constant of the feed-back loop and increase the amount of galvonometer jitter induced by the electrostatic nulling system.

REPLACING THE GALVANOMETER

Meters before about G467 and D27 have round galvanometers. These are obsolete and new replacements are not available. Occasionally a used one becomes available. There is a short pair of wires on these galvos and an electrical connector. Exchanging them is straightforward.

When the round galvanometer became obsolete, it was replaced with the rectangular galvanometer. These are less satisfactory. A single drop of rain can be drawn into the galvo by surface tension. Condensation on the working surfaces can cause the galvo to be sluggish and inaccurate. After the galvo dries it may work satisfactorily. However, there is a chance that subsequent corrosion may cause the galvo to fail at some time in the future. A very small line of clear silicone rubber between the clear plastic galvo cover and the black lid will give some protection from water but cause some bother whenever the black lid must be removed.

Replacing the rectangular galvanometer requires a soldering iron.

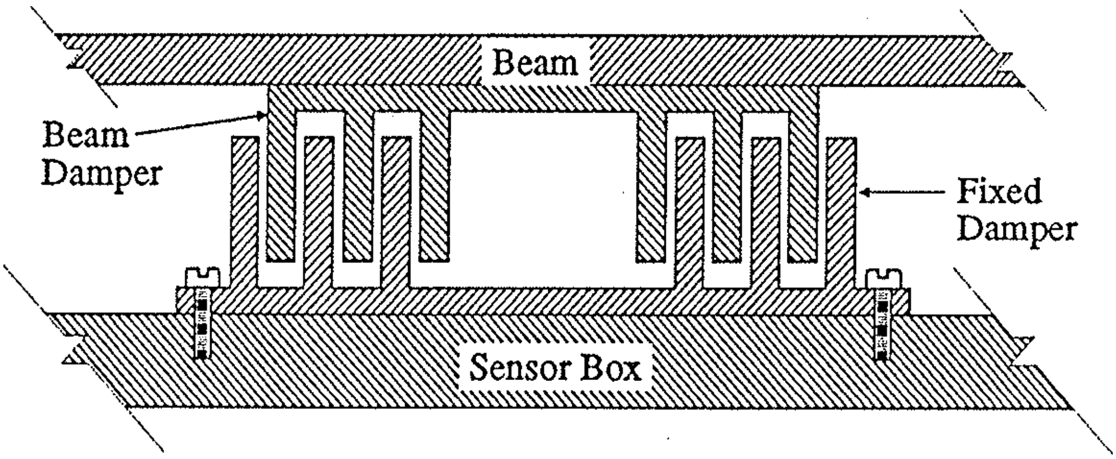
- Disconnect the 12-volt power.
- Remove the black lid, as described earlier.
- Pull the galvo upward out of its pocket in the meter insulation.
- There are two soldering lugs at the base of the galvo. One has a small resistor covered with shrink tubing.
- Make a note of the wire colors and the orientation of the galvo.
- Unsolder the wire that does not have the resistor
- Carefully remove the shrink tubing from around the resistor.
- Unsolder the resistor from the lug.
- Resolder the first wire to the new galvo lug and the resistor to the other lug, paying attention to the orientation of the galvo and wire colors.
- Wrap the resistor with a little tape or shrink tubing.

- Replace the galvo in its pocket.
- Replace the black lid.
- Connect the 12-volt power
- When the meter comes up to thermostated temperature, verify the galvo moves in the same direction as the beam image.
- Check the sensitivity and zero settings of the galvanometer.

Development is in progress of a liquid crystal display (LCD) that will replace the galvo as well as perform other functions.

VARIABLE DAMPING

Normal beam damping is about 70% of critical damping. The variable damper allows normal beam damping to be increased by a factor of 25. Normal damping is accomplished by two air dampers located on the bottom of the beam. There is a small damper near the back of the beam and a main damper near the front or mass end of the beam. Each damper consists of a set of concentric inverted cups on the bottom of the beam and another set of concentric cups fixed to the bottom of the sensor box. The beam cups and fixed cups interfinger. To pull the cups apart, air must flow up and down several times to reach the inner cup of the damper. Meters with variable damping have extra cups in the main damper and a simple rotary valve to open some of the cups when full damping is not desired.



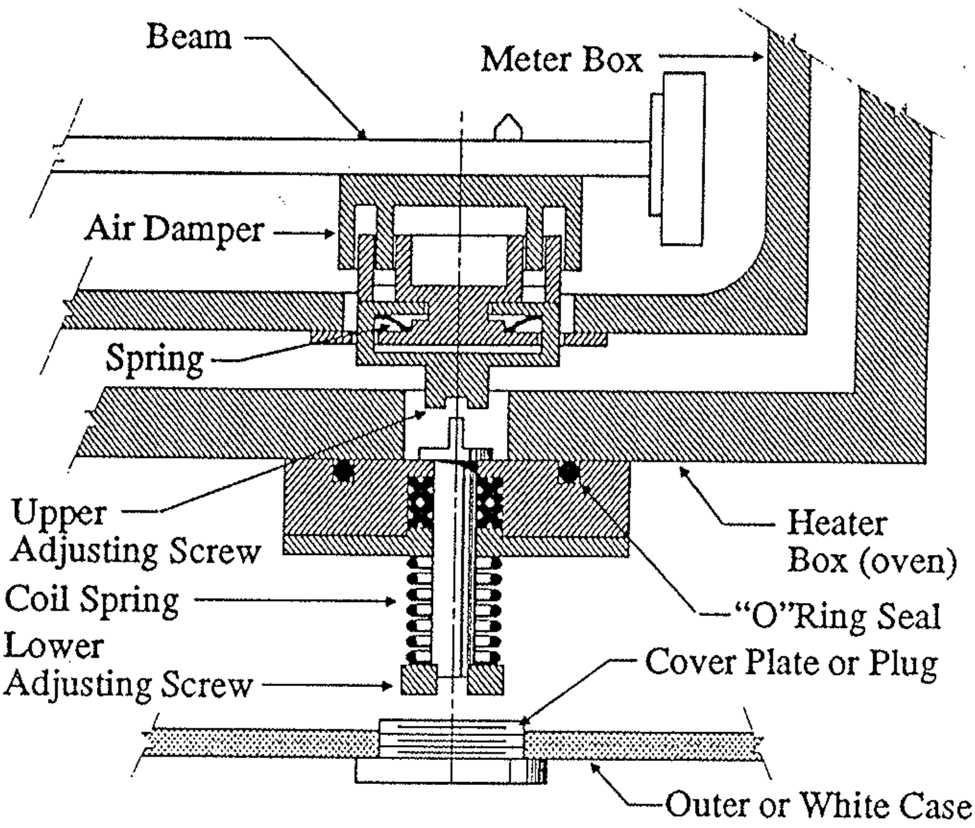
ADJUSTING DAMPER

To adjust the damping, turn the meter on its side and remove the nylon screw on the underside of the white case. Some early models have an aluminum cover plate.

The screwdriver slot of the lower adjusting screw will then be visible. Note on the drawing that a coil spring keeps the lower screw in the downward position. With a screwdriver in the slot of the lower adjusting screw, push inward and engage the slot of the upper adjusting screw. For maximum damping the screw is turned clockwise about one eighth revolution (three quarters of a turn on some earlier meters). A very small amount of torque will be required to turn the adjusting screw and a positive stop can be felt.

As the screwdriver is removed, the coil spring should force the lower adjusting screw away from the upper screw and back to its original position.

For minimum damping (that of a standard gravity meter), the above procedure is reversed. When maximum damping is engaged the damping will be approximately 50% that of the *L and R* underwater gravity meter and about 25 times that of a standard land meter.



ELECTROSTATIC POSITIONER

So that faster readings may be obtained when maximum damping is engaged, an electrostatic beam positioner is provided. The beam positioner switches are the momentary switches located on the operator side of the top of the gravity meter. These switches are also called "cheater" switches. To move the beam (crosshair or galvo) upscale, the switch on the right is pressed, to move the beam downscale, the switch on the left is pressed. The beam is positioned at the reading line with a touch of the left or right switch. If the crosshair then drifts to the left, the nulling dial must be rotated clockwise to a higher reading. Again the beam is positioned at the reading line and the process repeated. The slower the crosshair moves away from the reading line the less the meter is away from the null (balanced) reading. The beam positioner will also operate when the meter is set for standard damping but will generally not be needed.

A solid state power supply provides the voltage (about 60 volts) for the beam positioner.

In using the beam positioner, it is important to keep in mind that the electrostatic force can only overcome approximately 75 milligals of spring tension. therefore, if the meter is set more than 75 milligals from the value of gravity, the beam positioner will not move the beam. It will then be necessary to use the spring tension adjustment (nulling dial) in conjunction with the beam positioner initially to get the meter in range of the reading. It may be necessary to tap the meter gently if the beam is slightly sticking on a stop. This may help avoid an excessive amount of dial turning.

For the gravity meter to operate properly it is important that the lower adjusting screw is down and away from the upper adjusting screw (See the cross sectional view).

CAUTIONS:

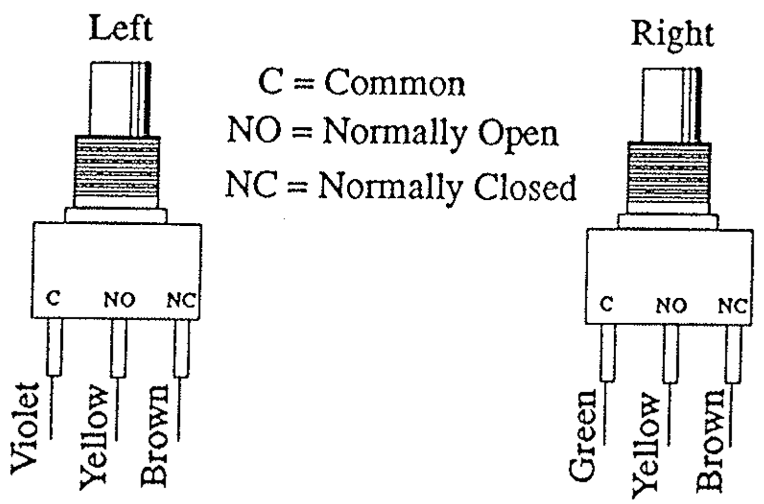
- Too much force on the damper adjustment can shear set pins and render the gravity meter inoperative.
- After changing the damping, be sure the lower adjusting screw has moved down to its original position.
- Make sure the beam positioning switches do not become "stuck" in the down position. Your results will be grossly in error and useless.
- Dust, dirt and moisture are major causes for failure of the beam position switches.
- When reading the gravity meter, be aware of these switches. Do not accidentally depress them.

REPLACING THE CHEATER SWITCHES

Meters with variable damping have two switches on the black lid on the side toward the operator. They are for electrostatically pushing the beam to the null position. These switches can fail when subjected to excessive dust, mud or water. If this occurs in a location where replacement is not available, it is possible to remove the switch, and connect the wires in such a way that will allow the meter to function.

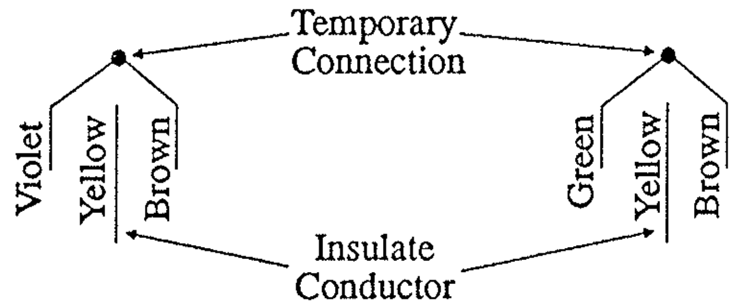
TO SERVICE THE SWITCHES

- Disconnect the 12-volt power.
- Remove the black lid.
- Remove the switch by removing the two screws on the outside of the white box that hold the switch bracket.
- Pull the switch and bracket upward to expose the wires.
- Make a note of wire colors and position.
- Unsolder the wire.
- Follow the diagram.



CHEATER SWITCH REMOVAL

To remove the cheater switch temporarily, connect the brown wire to the green or violet wire, depending on which switch is removed. Do not connect the yellow wire to any other wire. Insulate the conductor of the yellow wire with tape.



REPLACING THE NULLING COUNTER

The nulling counter is like an odometer on a car. Failure is very rare. If it does occur, it is best to send the meter to *L and R*. However, if this is difficult, it can be replaced in the field.

NOTE:
This procedure can cause major damage to the instrument if the counter synchronization with the measuring screw is lost. That is the reason the two counters must be set to the same value and the stalk shaft not turned while the counter is not engaged.

- Disconnect the 12-volt power.
- Remove the black lid.
- Make note of the counter reading.
- Remove the dacron insulation from around the counter and the upper part of the nulling stalk.
- Set the new counter to the exact same reading as the old counter.
- Remove the two brass nuts and washers on the side of the nulling stalk opposite the counter.
- Slide the counter away from the stalk until the gear and the two studs clear the stalk.
- Do not turn the vertical shaft.
- Replace the old counter with the new.
- Note that the holes for the counter studs are slotted. This will allow for adjustment of the gear mesh.
- While tightening the nuts, feel the mesh of the counter gear with the stalk gear by turning the vertical shaft a small amount. The mesh should not be to tight or it will cause excessive bearing wear nor to loose or it will cause excessive gear wear.

REPLACING THE HEATER CONTROL MODULE

Prior to mid 1966, a mercury thermostat controlled the heater. From G-125 and D-1 onward, a thermistor bridge has been used. Most of the mercury thermostats have been replaced with thermistor bridges

There are two common heater control modules: the standard module and the optional semiproportional module. The standard module is a brown or black cube about 2x2x2.5cm in size. It has two electrical connectors and red LED light. It is located under the Dacron insulation and rests atop the meters inner aluminum lid. Replacement is straightforward.

- Disconnect the 12-volt power.
- Remove the black lid.
- Remove enough Dacron to expose the module.
- Replace the module.
- Temporarily connect to 12-volt power to verify the red LED lights.
- Replace the Dacron and black lid.
- Connect the 12-volt power.
- Watch the thermometer and verify the temperature comes up to the correct amount.

To check the thermistor heating circuit:

Text to be added here.

The semiproportional heater module is a long irregular tube. It has two connectors the same as the standard module. The module should stand upright in the left near corner of the meter. This module can be replaced with the standard module but the reverse is not usually true. See the Options section for more details.

CHANGING OPERATING TEMPERATURE

THEORY

The temperature control system associated with the *Thermistor-Transistor Heating Circuit* is solid state. A temperature-sensing thermistor bridge operates an amplifier and power transistor to control the current to the heating element.

The thermistor bridge contains two legs of thermistors and two legs of balancing resistors. One of the resistor legs normally consists of one 10kΩ resistor. This leg is known as the "fixed-leg". The second resistor leg, with a resistance of 10kΩ ±2kΩ, is known as the "selected-leg".

In our laboratory the operating temperature is set by choosing the resistor within the selected-leg. It is, therefore, necessary to change the selected-leg resistor(s) to change the temperature of the instrument. Temperature is an inverse function of resistance. A resistance change of 800Ω results in an approximate inverse temperature change of one degree centigrade.

Because the gravimeter has an optimum operating temperature, we do NOT recommend changing the temperature, however, under extreme environmental conditions, operating at the optimum temperature may result in erratic readings and drifts. In cold conditions this would be caused by the heater not being able to provide enough heat. In hot environments this would be caused by the instrument heating above the optimum temperature. (This would be more noticeable in extremely hot climates than in extremely cold climates.) Temperature adjustment of ±5°C or more should be avoided if possible. There are field techniques described in another section of the manual that can reduce the effects of extreme ambient air temperatures. These other techniques should be exhausted before considering a change in the operating temperature.

PROCEDURE

To change the operating temperature less than two degrees, it is necessary only to change the selected-leg resistance. (See exception below) Remove the black lid of the instrument and enough dacron insulation to expose the heat control module next to the thermometer well.

Gently remove the selected-leg resistor(s) mounted on a green and yellow twisted pair of wires (green and red in some older meters). Remove power to the instrument when cutting or soldering any wires.

To decrease the operating temperature, add (in series) resistance at the rate of about 1000Ω/°C. Resistors must be precision film type (RN-55D). Do not change by more than 2000Ω resistance.

To change the operating temperature more than 4°C, or if the desired instrument temperature is not within 4°C of 50°C, it is necessary to change the fixed-leg resistor *before* changing the selected-leg resistor. This fixed-resistor (normally 10k or 11kΩ) is changed to maintain the balance and equal thermistor sensitivity.

To change the fixed-leg resistor, remove power from the instrument and find the brown and purple twisted wires and components. Carefully cut away the outer tube of shrinkable tubing. There will be exposed one 10kΩ resistor (the fixed-leg resistor). Remove the fixed-leg resistor and replace it with one of appropriate value (see the table below). Resistors should only be RN-55D metal film. Use shrinkable tubing to cover bare wire and to form the outer tube shield.

FIXED-LEG RESISTOR	DESIRED OPERATING TEMPERATURE (°C)
15kΩ	40.1-44.0
12kΩ	44.1-48.0
10kΩ	48.1-52.0
9.1kΩ	52.1-56.0
7.5kΩ	56.1-60.0

At this stage, the selected-leg resistor(s) must be balanced. The resistance should be within about 3000Ω of the fixed-leg resistor. This is more or less a trial and error selection. Begin with a resistor equal to the fixed-leg resistor. Add resistance for a lower temperature; use less resistance for higher temperature.

GENERAL NOTES

Because of resistor and thermistor tolerances, and because thermistor temperature-resistance curves are non-linear, the exact resistance is difficult to predetermine for a specific temperature.

It is sometimes necessary to "tune" the resistance in the selected-leg with one or two smaller valued resistors to get the exact desired temperature.

A few older Thermistor-Transistor Circuit bridges use two watt wire-wound resistors. These resistors are perfectly satisfactory but are larger than the precision film resistors now used.

For further information or assistance contact our laboratory.

NOTE: Whenever drastic operating temperature changes are made of more than a couple of degrees, the internal pressure/vacuum must be released. Between the gear box, the arrestment stalk, and the eyepiece stalk, there is a seal cap retained by three 2-56 screws. Loosen all three screws and lift the seal cap. After the temperature change has been made and the temperature stabilizes replace the seal cap and tighten the screws. Caution, be sure there are no dacron fibers on the seal cap nor on the mating surface of the gravity meter sensor lid. If the seal cap is left open, the inert dry gas may be lost from the inside of the meter. This voids the warranty.

BIMETALLIC THERMOSTAT

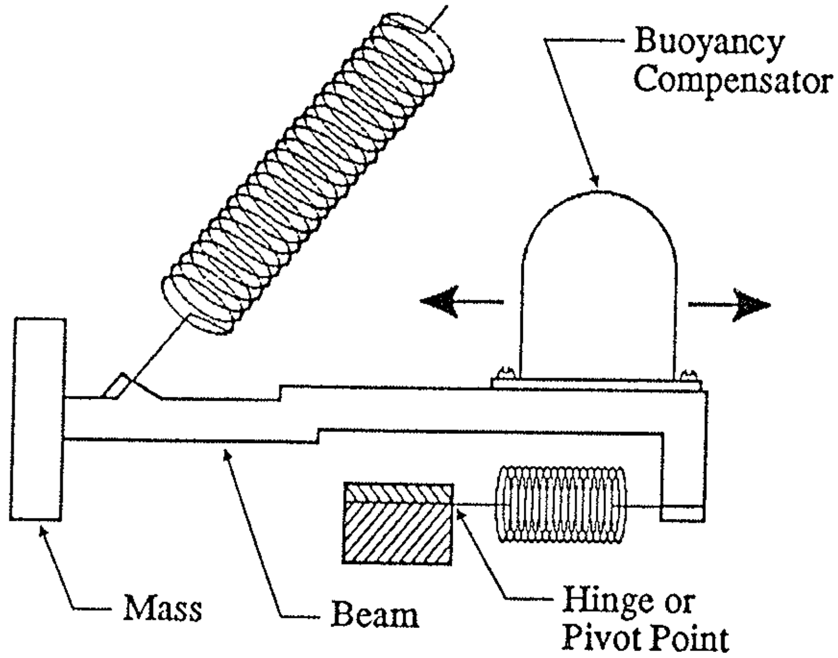
A small sealed cylinder containing a bimetallic thermostat is located on the side of the heater box. It is in series with the heater wire. If the meter is about to overheat, the bimetallic thermostat will open the circuit and stop the heating before thermal damage can occur.

The most likely cause of the overheating has been the inadvertent reversal of the 12-volt DC power to the meter. This causes the heater control to command the heater to be on, regardless of the temperature sensed by the thermistor bridge. When the bimetallic reaches 69°C, it will open and the temperature will decrease. At some temperature the bimetallic coil will close, power will flow into the heater wires, the temperature will rise to 69°C and the cycle will repeat.

On meters with the AT0-3 fuse and reverse polarity protection, the AT0-3 will prevent the reversed 12-volt polarity current from entering the meter.

CHECKING THE METER SEALS

The meter is sealed. This increases the accuracy of the meter. If the meter were not sealed, a change in atmospheric pressure would cause a change in the buoyancy of the beam mass and would give the false appearance of a change in gravity. In case one of the seals did leak, there is a buoyancy compensator on the meter's beam. It is a large fixed volume of light mass located in back of the beam hinge or pivot point. During construction of the meter, the compensator is positioned on the beam to remove at least 98% of the effect of atmospheric pressure changes, should a leak develop in the sensor enclosure.



If the sensor develops a leak, The compensator will allow an accuracy as good as other gravity meters in good working order. However, the accuracy will be less than optimal and less than desired for careful gravity observations.

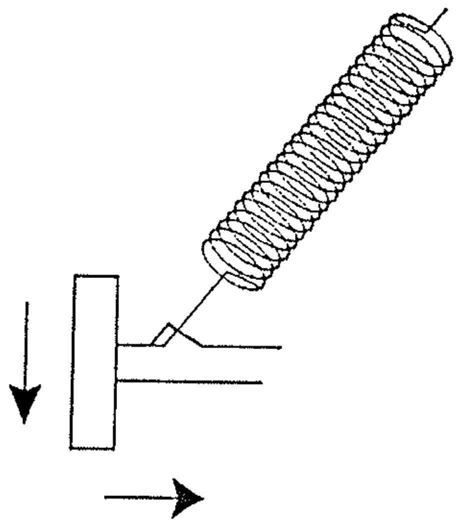
On the average, seals begin to fail after eight to ten years. They become hard and brittle. *L and R* recommends "long term servicing" every eight to ten years. (See the section on servicing.)

It is easy to test for a seal failure if a large change in elevation is available. A change in elevation will cause a change in atmospheric pressure. Taking a series of gravity readings after a recent change in the meter's elevation will be revealing. As air leaks into or out of the meter, there will be a change in the readings. The rate of this change will depend on the size of the leak, the magnitude of the recent change in ambient air pressure and how accurately the buoyancy compensator was set during construction of the meter. Remember, at any one location, gravity is changing due to earth tides. This change is at most one microgal per minute. If observations are made every two to five minutes, corrected for earth tides and plotted against time, the resulting curve should be fairly straight and horizontal. If it is not horizontal, it is probable that a meter seal is leaking.

CHECKING FOR MECHANICAL HYSTERESIS

When the beam is clamped, it is pushed down against the adjustable bottom stops. These are set to limit the travel of the beam to 7½ small optical divisions of downward travel from the null reading line. Clamping stretches the main spring, compared to its length when the beam is unclamped and at the reading line. There is a mechanism in the meter that pushes the beam backwards as it is clamped and that "push" is exactly the amount necessary to shorten the main spring back to its length when it was unclamped and at the reading line.

Were it not for the dual movement of the clamping mechanism, the spring would be stored elongated. It would relax in this stretched position and when unclamped for the next reading, reverse creep would occur. It would take ten to twenty minutes for the meter to stabilize for a reading.



DUAL MOVEMENT OF BEAM CLAMPING

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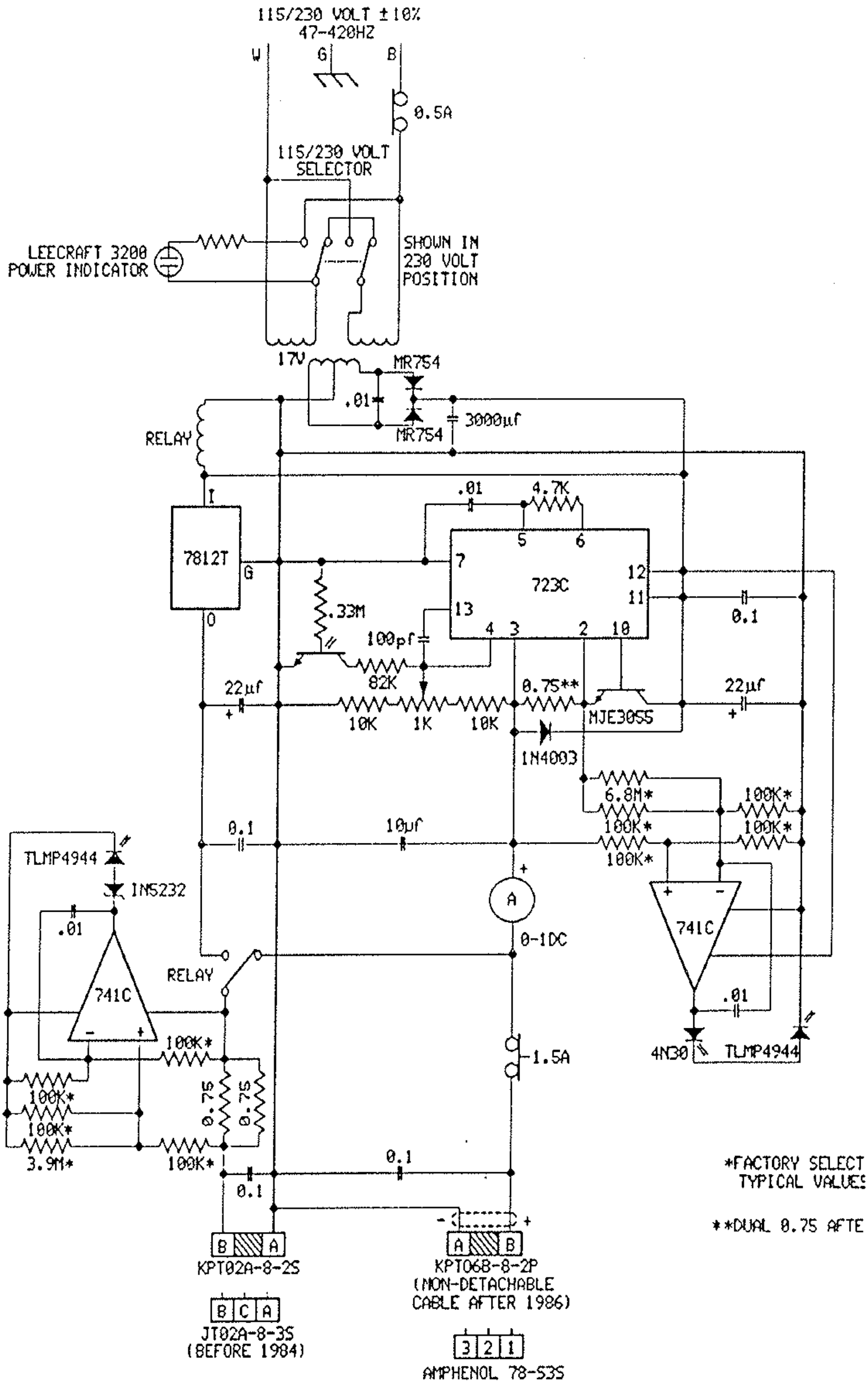


TWO-LED GEL/CELL BATTERY CHARGER/ELIMINATOR

STANDARD CHARGER/BATTERY ELIMINATOR

There have been four major designs of the *L and R* charger/eliminator:

Early chargers were for NiCad batteries: These were provided as original equipment for meters up to G-323 and D-12 or about 1973. Almost all of these have been replaced by newer designs and the NiCad batteries replaced with gelatin stabilized lead-acid batteries.

Next were the early gel-cell battery charger. They are distinguishable by an amp meter, a red power indicator lamp and a single red LED lamp that indicated when the meter was receiving heating power. These chargers were built in 1973 and 1974 and many are still in service.

The more recent charger is similar in appearance to the above, except there are two LED's: one to indicate when the meter is receiving heating power and one to indicate when the battery is receiving more than a trickle charge. These were built between 1974 and 1989.

The present charger no longer has an amp meter. This was the most expensive component on earlier chargers and the part most frequently damaged by mechanical abuse. The amp meter has been replaced by an LED ten-element colored bar display.

When using any of the gel-cell battery chargers, if the AC power source is intermittent, the meter will not go off heat as long as the charger has both a battery and the meter connected to it. When AC power is lost, a relay changes position. It disconnects the battery from the charging circuit and connects it to the meter. When AC power returns, the relay returns to its original position.

The circuit breakers within the chargers can be tripped by a sharp blow as well as excess current. A blow may occur during transportation. If the charger is not working after shipment, first check the breakers. There are two breakers, one on the incoming AC power line and one on the outgoing charger line. Both are 1.5 amp rating. To reset the breakers:

- Disconnect from the AC power
- Turn the charger upside down
- Remove the bottom of the charger (four screws)
- Press in the plungers of the two breakers
- Replace the charger bottom.

If the recepticals for the bottom screws are loose, they may be tightened by pressing the aluminum together a small amount with pliers.

Chargers before 1987 had a separate battery charging cable with a round Amphenol 3-pin fitting at the charger end of the cable. When disconnecting a battery from the charger, this cable always should be disconnected at the battery end first. If the other end of the cable is disconnected first, there are two exposed pins with unfused 12-volt power across them. Severe damage could occur if these were shorted by brushing across a metal surface.

Chargers built after 1986 (with nondetachable charging cable) have a small modification which provides smoother power for those meters using the electrostatic nulling options when their gravity meter is plugged into the charger/eliminator. Earlier charges that have had this modification can be identified by opening and examining the PC board. The modification can be identified by two 0.75 ohm resistors in parallel located close to the relay, or by the small XREG label on the bottom of the charger housing.

HIGH SPEED CRANK

The high speed crank can expedite gravity reading when there are large gravity differences between gravity stations. It is a small cylindrical gear box with a ratio of 9.5 to 1. There is a small crank at the top for turning while the housing is held by two fingers. At the bottom is a yoke with two pins that fit into matching holes in the top of the meter's nulling dial.

OPERATION

To use the crank simply place it on the top of the nulling dial, matching the two holes in the dial and the two short pins on the gear box.

We strongly urge the operator to use discretion in the rate of speed the dial is turned as it is possible that the life of the counter may be shortened if the dial is rotated too fast. Also, caution should be exercised when approching the end of travel of the counter (0000.0 and 7000.0 for the Model G and 0000.0 and 2000.0 for the Model D).

The operator will prefer to use the device to bring the counter to an approximate gravity reading, then lift it off the dial and complete the final gravity reading in the usual manner.

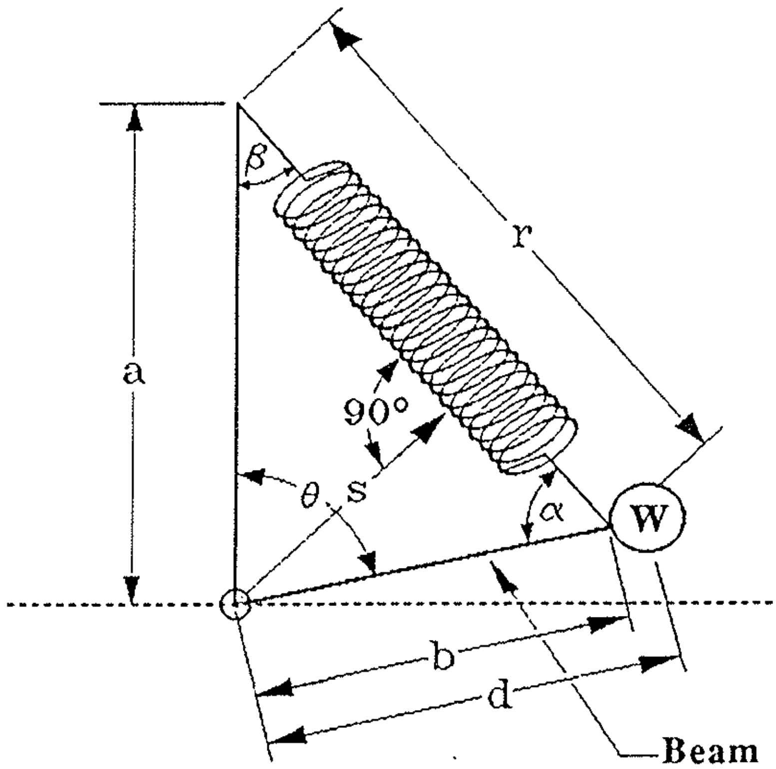
The device is a precision product with high quality gears and bearings throughout. Care should be taken to protect it from dust and dirt as much as possible and to handle it carefully. Its usefulness can be decreased by dropping it and bending the shafts or housing.

PHYSICS OF THE SENSOR

In the early days of earthquake seismology, long period horizontal motions could be measured with the horizontal pendulum seismograph. As the axis of rotation became closer to vertical, the period became longer. Theoretically, if the axis is vertical, the period is infinite.

Dr. Romberg posed the question to his student, Lucien LaCoste, how to design a vertical seismograph with the characteristics as good as the existing horizontal pendulum seismograph.

In the illustrated suspension, there are two torques: gravitational and spring. If these two torques balance each other for any angle of the beam, the system will have infinite period. The smallest change in vertical acceleration (or gravity) will cause a large movement.



The torque due to gravity is:

$$T_g = Wd \sin \theta$$

Where W is the mass and d is the distance from the mass to the beam's hinge.

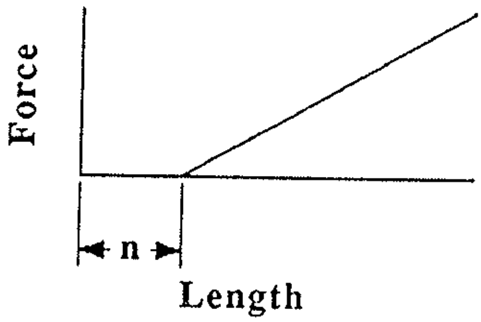
The torque due to the spring is the product of the pull of the spring and the springs lever arm, s.

$$s = a \sin \beta.$$

The length of the spring is r and by the law of sines:

$$r = \frac{b \sin \theta}{\sin b}$$

If the spring constant is k and the length of the spring without force is n, The spring force is illustrated by this graph.



The torque due to the spring is then:

$$\begin{aligned} T_s &= -k(r-n)s \\ &= kns - krs \\ &= kns - k\frac{b \sin \theta}{\sin \beta} a \sin \beta \\ &= kns - k\ a\ b\ \sin \theta \end{aligned}$$

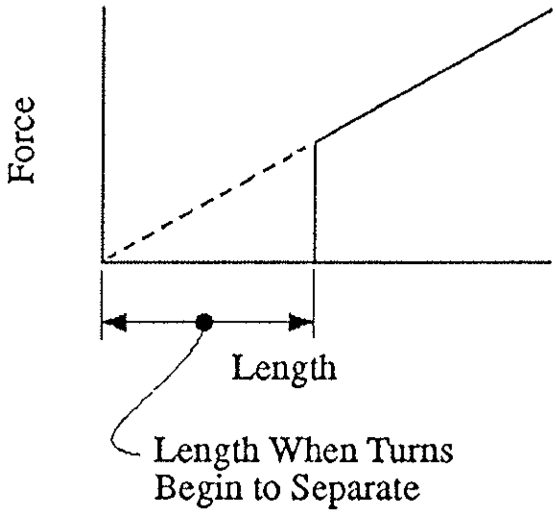
The total torque is:

$$\begin{aligned} T_o &= T_g + T_s \\ &= Wd \sin \theta + kns - kab \sin \theta \\ &= kns + (Wd - kab) \sin \theta \end{aligned}$$

This equation would yield zero torque and would be satisfied for all angles of θ if:

$$n = 0 \quad \text{and} \quad Wd - kab = 0$$

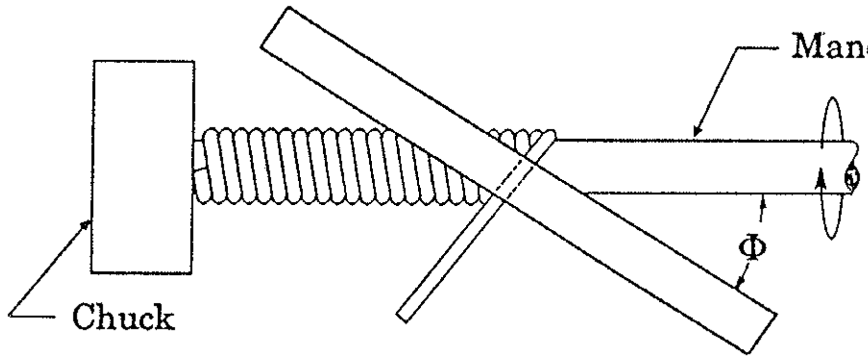
For n to equal zero, we must have a "zero length spring". That is , a spring whose force-length graph passes through the origin or, at least, points toward the origin. The turns of a helical spring of zero unstressed length would bump into each other before the spring actually reached zero length. By making a helical spring whose turns press against each other when there is no force on the spring, a "zero length spring" can be made.



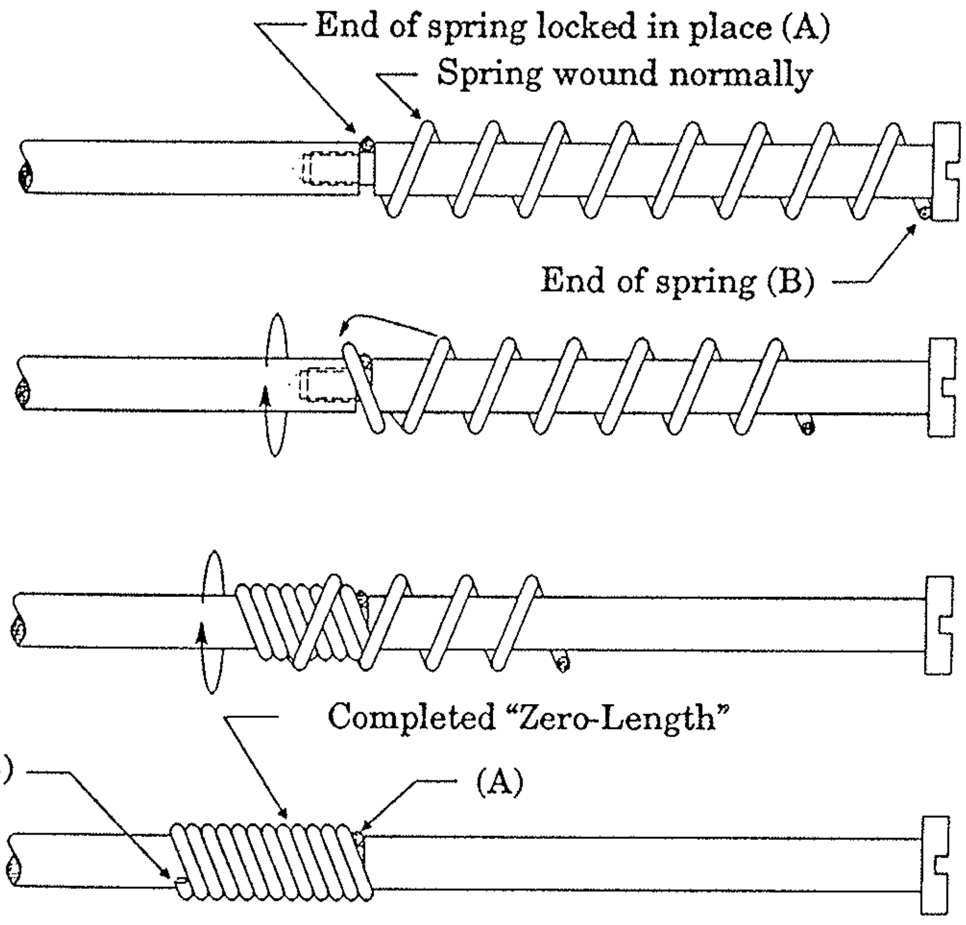
Zero Length Spring

There are several ways to make a zero length spring. A simple zero-length spring is a flat spiral spring. The mechanical properties of a spiral spring are not as convenient as a helical spring.

To make a zero-length helical spring, the spring wire can be wound onto a mandrel. As the wire is wound, it can be twisted.



Another method is to hold the wire at an angle and with tension while winding it on a rotating mandrel.

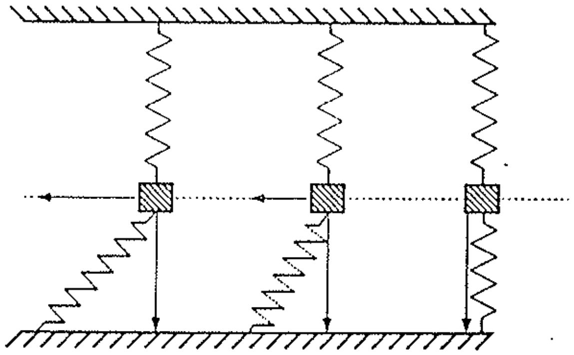


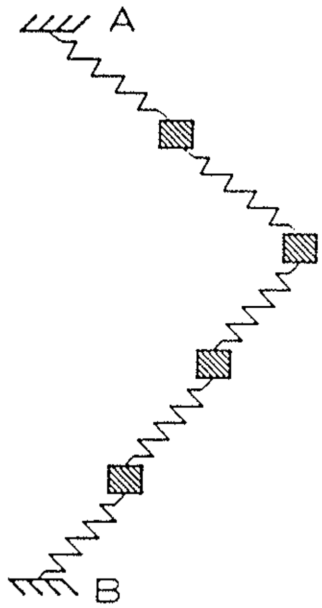
Still another method is to "turn the spring inside out".

The actual spring used in the *L and R* meters are "negative-length". The spring wire is large enough and stiff enough that the spring would not act like an ideal spring if the spring were to be clamped at both ends. Thus, a very fine but strong wire is attached to the top end of the spring and another to the bottom of the spring. The top wire is clamped to the lever system and the bottom wire is clamped to the beam. The effective length of the spring is the combined length of the helical spring and the two fine wires. That combination is "zero-length". The helical spring by itself is "negative-length".

INSENSITIVITY TO LATERAL VIBRATIONS

An important feature of the zero length spring suspension is its insensitivity to longitudinal and transverse vibrations (Harrison 1960, LaCoste 1967). Consider the spring to be made of identical masses with segments of weightless zero length spring between the masses. The top end of the spring is attached to A and the bottom to B. Since the spring segments are zero length springs, the forces each spring exerts on the adjacent masses are proportional to the spring length. Therefore, if the masses are equally spaced vertically, the vertical component of force exerted on each mass will be zero regardless of its horizontal position or horizontal motion. Also, the vertical components of force are proportional to the vertical component of spring length. (The vertical component of the force vector remains the same.) Also, the vertical force on A and B will be independent of any horizontal motions.





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Harrison, J.C., The measurement of gravity at sea, *Methods and Techniques of Modern Geophysics*, Interscience Publishers, NY, 1960

LaCoste, L., Measurement of Gravity at Sea and in the Air, *Reviews of Geophysics*, pp 477-526, Nov. 1967

CALIBRATION

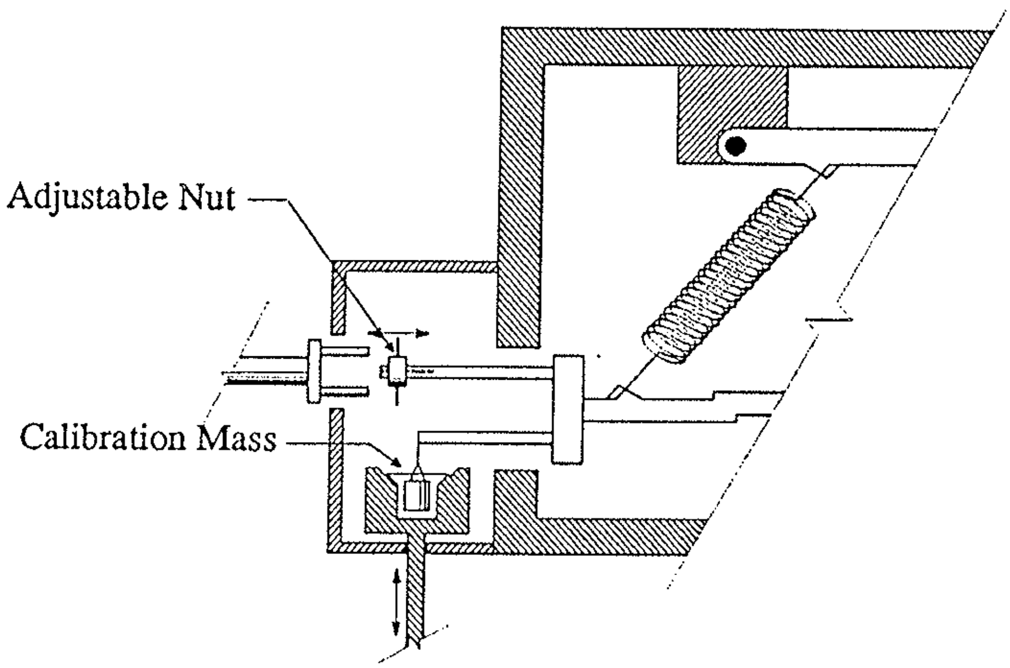
Calibration of the *L and R* gravity meter is accomplished in two states:

- First a relative calibration is obtained at numerous points over the entire range of the meter
- Then the relative calibration data are adjusted to absolute values by field measurements over a known gravity difference

Considering the geometry of the micrometer screw, lever system and suspension, the interval factor curve should be a third-order curve. There will be minute deviations from the ideal third-order curve due to imperfections in the lever system, gear box, micrometer screw and the jewel and pivot where the micrometer screw transfers its movement to the lever system.

To obtain the relative calibration curve, a fixture is attached to the beam mass.

- One part allows a calibration mass to be added and removed from the beam.
- Another part is a long thin screw with a small adjustable nut that allows the meter to be nulled in the lab over the full travel of the micrometer screw.



MODEL G RELATIVE CALIBRATION

First, let us consider the Model G meter with manual observation of the relative calibration data. If the calibration mass corresponds to a change of about 200 milligals and the meter can be read to about 0.01 milligal, then the accuracy of obtaining a relative factor is about one part in 20,000.

The relative calibration is obtained as follows; first the counter is set to 0100.00 then:

- The range adjust nut is positioned so the beam is close to balance
- The counter is adjusted to an accurate null and the counter reading is recorded as an OFF reading
- The calibrating mass is added to the fixture on the beam, the beam is nulled and the counter reading is recorded as an ON reading
- The calibration mass is removed and a second OFF reading is obtained and recorded
- The calibration mass is added and a second ON reading is obtained and recorded.
- The counter is set 200 units higher (0300.00 for the second data point) and the above procedure is repeated at the new counter setting.
- The above procedures are repeated every 200 counter units through counter reading 6900.00.
- Four or five sets of readings are done at arbitrary positions on the screw as independent checks for factor repeatability

The data obtained from the above laboratory observations are processed as follows:

- The two OFF readings are averaged and the two ON readings are averaged for each set of observations

- Let

  C_{off} = average counter reading with the calibration mass removed

  C_{on} = average counter reading with the mass on the beam

  C_{av} = average counter reading
  = $(C_{off} + C_{on})/2$

  M = approximate milligal value of the calibration mass (a constant)

  F_r = relative factor for C_{av}
  = $M/(C_{on} - C_{off})$

- A table of C_{av} versus F_r is generated from the observation data at the regular intervals.

- These data are plotted and a smooth curve is drawn through or close to the data points.

- The four or five sets of data taken at arbitrary points are reduced and these points are plotted on the above graph as a check of repeatability.

- A table is constructed by scaling seventy relative factors from the smooth curve through the data points. The values are taken for counter readings starting at 50, 150, 250, etc. through 6950. Name them F_{50}, F_{150} etc.

MODEL G ABSOLUTE CALIBRATION

To adjust the relative factors to absolute factors, the meter must be read at two or more gravity stations of known gravity difference. A single factor is determined. When the relative factors are multiplied by this single conversion factor, the final calibration table can be constructed.

The greater the gravity difference between the calibration stations, the greater would be the accuracy of the conversion factor. Since the relative factors were determined by the manual lab procedure with an accuracy of about one part in 20,000 or 22,000, then it would be appropriate to have similar accuracy in the determination of the conversion factor.

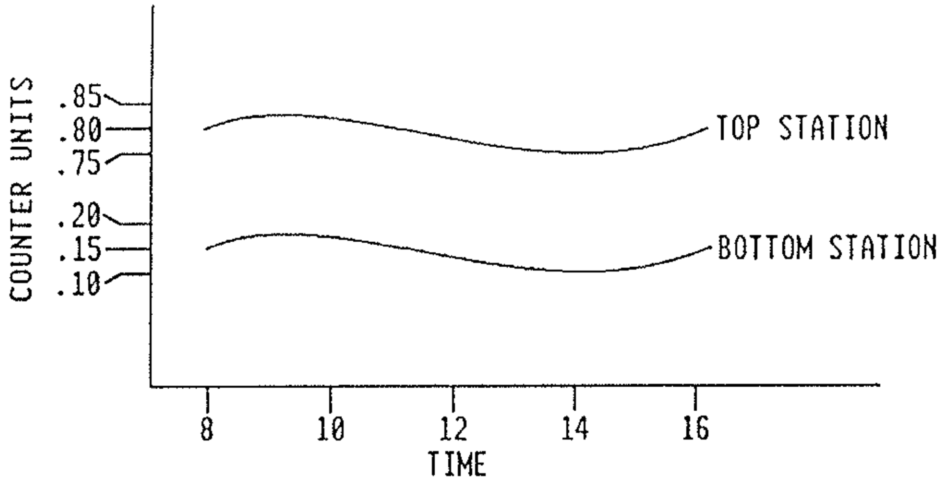
The meter reading can be resolved easily to 0.01 milligal. Therefore a calibration range of 200 or 220 milligals would be appropriate for accuracy consistent with the relative determinations.

The high and low calibration stations should be close to each other to allow the observations to be repeated several times for greater accuracy and a further field check of the meters repeatability under field conditions.

There is little elevation relief and only small gravity changes in the vicinity of the *L and R* laboratory. The closest large change in gravity is 1,000 kilometers to the west, Cloudcroft in the state of New Mexico. Two stations were established accurately. Their gravity difference is approximately 240 milligals.

The field procedure consists of alternately reading the meter at one station then the other station until at least four readings are taken at the top station and four at the bottom station.

The observations at both stations are plotted against times on the same graph. Typical scales would be 0.05 counter unit per centimeter (or 0.10 units per inch) and one hour per two centimeters (or one inch). Two smooth curves are drawn through the upper and lower station data points. The second curve is constructed parallel to the first.



The separation between the two curves is the average counter reading difference ΔC

If the gravity difference between the two calibration stations is ΔG, then the absolute calibration factor over that range of the meter is:

$$F_{abs} = \Delta G / \Delta C$$

The calibration table for the Model G will consist of 70 calibration factors, one for each 100 counter units. The 70 relative factors determined earlier are multiplied by the absolute calibration factor; F_{abs}. The calibration factor to use for counter readings between 0000.00 and 0100.00 is $F_{50} \times F_{abs}$ and the calibration factor for the readings between 0100.00 and 0200.00 is $F_{150} \times F_{abs}$, etc. If F_{50}, F_{150} and F_{250} are 1.02031, 1.02038 and 1.02045 respectively and F_{abs} is 1.00321, then the first portion of the final table would be:

Counter Reading	Interval Reading	Cumulative Value
0000	1.02031	000.000
0100	1.02038	102.031
0200	1.02045	204.069
		206.114

See *Converting the Counter Reading to Milligals* in the first section of this manual.

MODEL D CALIBRATION

The standard Model D has a counter range of 2000.00 and utilizes about 62% of the full range of the lever and micrometer system. This is a small enough portion of the third-order interval factor curve that, for most work, it can be approximated by a straight line. By minor adjustment within the meter, the slope of that line can be made almost horizontal. Thus a single calibration factor can be used for the full range of the meter.

Many of the meters between D1 and D109 have been assigned a single calibration factor. The meters were constructed and the factors determined at three points; one near 0100.00, one near mid range and one near 1900.00. These were determined at a field calibration range of 17 milligals located near the *L and R* laboratory. The meter was adjusted the approximate amount necessary to make the factor curve horizontal and returned to the calibration range. If the repeated tests at 0100.00, 1000.00 and 1900.00 indicated the calibration curve very close to horizontal, factors were also determined for counter readings near 0500.00 and 1500.00. If these also plotted on the horizontal line, a single factor was used for the meter.

On occasion, it was difficult to obtain a sufficiently straight line over the range of the counter or to adjust the meter so the interval factor line was horizontal. For those meters, a calibration table was prepared using a smooth curve through the five data points obtained at the Austin 17-milligal calibration range.

Starting with meter D110, the laboratory calibration was used to determine relative calibration factors, then the meters were field calibrated over the 240 milligal range to determine the factor necessary to convert the relative factor to absolute factors. A calibration mass equivalent to about 100 milligals was used and five points were measured to determine the calibration curve. Since the meters did not have enough range to be read over the 240 milligal field range, a temporary counter was placed on the meters to allow them to read a little below 0000.00 and a little above 2000.00.

Though this technique was an improvement of the calibration using the local 17-milligal field range, there were two disadvantages: the 100 milligal calibration mass covered too large a portion of the curve and could smooth some of the curvature and the special counter temporarily required for reading over the 240-milligal range was an inconvenience.

Beginning in 1989 (meter D-145) the laboratory calibrations use a 20 milligal calibration mass so the finer structures of the relative curve can be observed. Also, a new field station was installed along the 240-milligal range. It is approximately 160 milligals greater than the top calibration station at Cloudcroft. The standard counter can be used during field calibration over the 160 milligal range.

SELECTION OF CALIBRATION MASS

There are two important factors in the selection of the calibration mass

- It should be large enough to give accurate data (considering the resolution of reading the meter) yet not so large that there would be significant curvature in the calibration graph over the OFF and ON span.
- The milligal value of the calibration mass should not be a value likely to display aliasing with any potential periodic errors in the meter.

The two most likely periodic errors in the meters are once, twice and four times per revolution of the micrometer screw. Selecting a calibration mass of approximately 220 milligals for the Model G gives three revolutions of the micrometer screw between the OFF and ON of the mass. Selecting a calibration mass of approximately 20 milligals for the Model D gives approximately six revolutions between the OFF and ON of the mass.

Future Improvements in Calibration

We know that the 240-milligal Cloudcroft calibration range value is slightly low. When the *L and R* meters are used on calibration ranges determined by modern absolute gravimeters, the values determined by the Model G meters are usually low by a few parts in 10,000. We hope to have an absolute meter to observe gravity at the Cloudcroft range in Fall of 1989.

It would be desirable to improve the accuracy and detail of the laboratory portion of the meter calibration. It is possible to do this manually but it would result in a higher meter cost. The same could be done by computer automation without an increase in the cost of the meter. *L and R* plans to have this automation completed during 1989.

HISTORY

The *LaCoste and Romberg* land gravity meter is based on the zero-length spring suspension. It allows an instrument to be very sensitive to small changes in gravity yet be very compact in size. The size of the basic element is a cube about 5 centimeters on each side. The concept of the zero-length spring was developed by Lucien LaCoste as a graduate student at the University of Texas in 1932. He and his faculty advisor, Dr. Arnold Romberg utilized the concept first to construct long-period vertical seismographs. Their instrument exceeded the period of existing instruments by an order of magnitude (LaCoste 1934).

While teaching at the University of Texas, Drs. LaCoste and Romberg developed the first two gravity meters during 1937 and 1938. The first weighed about 125 pounds (57 kilos) and the second about 100 pounds (45 kilos). Following spring semester in 1939, they took leave of absence from the university to develop and build gravity meters on a full-time basis.

The first production meters weighed about 75 pounds (34 kilos). About 45 were produced from 1939 through 1941. These meters were not barometrically sealed but were compensated for buoyancy effects of changes in air pressure. Their range was 100 milligals and they could be reset to work anywhere on the surface of the earth.

Next came the "25-pound" meters (11 kilos). They had a range of 200 milligals and about 80 were built between 1941 and 1957. There are a few of these that are still in service.

The geodetic meter was first built in 1957. These meters had a world-wide range without resetting. Eight were constructed using the 25-pound meter size and several of its parts. Their range was 6,000 milligals.

The meter was miniaturized and several improvements made. Thus the Model G meter was born in 1959 . Since there were a few places atop the Andes not reachable by a 6,000 milligal range, the meters were designed to have a 7,000 milligal range. Their weight was about 8 pounds (3.6 kilos). They were mounted in white fiberglass boxes with rigid foam insulation and their power consumption was reduced. They were sealed so barometric pressure changes could not effect the buoyancy of the mass. By 1989, over 950 Model G meters were constructed and almost all are still in service.

The Model D meter uses many parts in common with the Model G: the same spring, beam and mass. However, there are two screws for nulling the meter: a coarse reset screw with worldwide range and a fine reading screw with a 200 milligal range. The first Model D was built in 1968 and over 150 were constructed by 1989.

Both the Model G and Model D meters have undergone gradual evolution in design details. As sources of error or potential difficulties were recognized, solutions were gradually developed and implemented. Several changes are under way at this time. Recently linear electrostatic feedback nulling has been added as an option. Model D meters are available with both fine and coarse screws calibrated, allowing greater accuracy in geodetic work. Development is under way for an internal microprocessor to work in conjunction with electronic levels, shaft encoder, calibration factors in memory, temperature sensor, clock and a data memory.

ACKNOWLEDGEMENTS

The *L and R* gravity meter has gone through some major changes and numerous minor changes during its evolution. Dr. LaCoste is the inventor and source of most of the important ideas that make the meter work so well. His partner, Dr. Romberg, was a resourceful contributor that worked at the firm till he was 85 years old.

In recent years others have contributed significantly. Larry Burris contributed the air damped pendulum level design, Herb Valliant contributed the analog and digital electrostatic nulling systems. Dan Hemingson contributed much of the electrical design including the capacitance beam position indicator, the standard and semi-proportional heater control modules, and AC and DC chargers. Carol Montigue's careful work on micrometer screws has been crucial. Finally, the patience and care of the meter builders has been essential.

COMPUTER PROGRAMS

GRAVPAC DATA PROCESSING

This program is designed for the convenient entry, display, and processing of land-survey gravity data. It accommodates different survey and timekeeping systems, different types of gravity meters, and a broad range of user-selected options. The data may be entered and processed in one block or in segments as they become available. The processed data are both printed and written to a readily-accessible disk file for further processing.

GRAVPAC requires an MS-DOS compatible computer (version 2.0 or higher) with line printer and at least one 5 ¼ inch or 3 ½ floppy drive (plus a second floppy or hard-disk drive for data). To initiate GRAVPAC, insert the disk in an active drive and type GRAVPAC. Alternately, the program files may be copied onto a hard disk and the programs run from that drive. You may wish to run a short trial data set before entering your actual data.

If you have questions or comments please contact Larry Barrows at *L and R* (512) 346-0077. Some specific notes about GRAVPAC follow:

1. The GRAVPAC disk contains ten chained programs and one short file used to pass information between programs. The disk is full, so either the files should be copied to a hard disk or the user must specify a second drive which will contain the data files. Multiple surveys may be processed by using separate disks for the data files.

2. "Stations" refer to the locations at which meter readings are made. Stations are identified by their i.d's (six character, alpha-numeric variables). "Observations" are the individual meter readings and are identified by the numbered sequence in which the observations are made.

3. Station coordinates may be entered as:

- Decimal degrees of latitude and longitude
- Whole degrees + decimal minutes of latitude and longitude
- Feet or meters North-South and East-West of a reference point.The latitude and longitude of the reference must be specified.

Sign conventions are:

- Latitude: + for North, - for South
- Longitude: + for West, - for South
- Feet and Meters: + for North, - for South

  + for East, - for West
- Elevations may be in feet or meters

4. Observation times are needed for both tide and drift corrections. Timekeeping options are: local standard time, daylight savings time, or Greenwich mean time. For the first two, the local time zone must be specified. Time is entered as whole hours plus whole minutes on a 24-hour clock (0-23 hours).

5. The user must specify a factor that converts meter readings into milliGals (mGal/unit). For non-linear meters, the user can create a disk file of multiple meter factors (see the L and R Gravity Meter Operators Manual for further details). With the *L and R* analog electrostatic feedback system, the user specifies the sensitivity of the electrostatic system and the locked mechanical setting.

6. There are prime base stations at which absolute gravity (for example 980,000 mGals) is known or assumed and secondary base stations which are tied to primary bases. The program lists absolute gravity at secondary bases implied by ties to prime bases. After reviewing the ties to prime bases the user must determine the optimum absolute gravity at secondary bases and advance the secondary bases to prime status before the survey data are processed.

7. Instrument drift is linearly prorated between base station ties. However, field stations can be tied to a single base station reading by assuming zero drift. Also tares can occur within a series of readings if the meter is inadvertently bumped. Both situations are handled by identifying the times of breaks in the drift control. Zero drift is assumed between the breaks and the times of the nearest base station readings. A break should not coincide with a meter reading.

8. Metered gravity is the meter reading converted to milliGals and corrected for solar plus lunar tides. Tides are calculated for a rigid earth, the method described by I.M. Longman (J.G.R., v.64, n.12, p.2351-2355). The rigid earth tide then is multiplied by 1.16 to account for the earths deformation due to the earth tide. Drift in the metered gravity is prorated between base station ties and the difference in gravity between stations and bases is added to the absolute gravity at the bases to give observed gravity.

   Bouguer gravity follows from:

   BougGrav=ObsGrav - (g_0 + free-air + slab + terrain)

   where:
   g_0= sea-level gravity on a reference spheroid (IGSN71 as modified for the 1967 GRS or the 1930 International Gravity Formula)
   free-air(mGal) = -0.09406 * elevation(ft)
   = -0.3086 * elevation (m)
   slab(mGal) = +0.01277 * σ(gm/cc) * elevation(ft)
   = +0.04190 * σ(gm/cc) * elevation(m)

9. Output includes: observed gravity, free-air gravity, and Bouguer gravity for four selected slab densities. The Bouguer slab effect may be split by specifying one regional elevation and deep density plus a shallow density for the local topography.

10. The program is currently dimensioned for up to 1000 observations at up to 800 stations, 20 prime base stations, 20 secondary base stations, and 20 breaks in the drift control.

11. The program will print earth tide tables with calculated values in microGals for every five minutes.

GMODEL INTERACTIVE MODELING

GMODEL supports construction of gravity models using combinations of: infinitely-long horizontal polygons, finite-length horizontal polygons, vertical prisms, and spheres. Calculations may be made along a profile or on a horizontal surface. For profile calculations, observed gravity may be entered and displayed along with the modeled gravity. The user may then modify the model or print the results. Surface calculations are made on a 51 by 51 element rectangular grid and stored on disk file for subsequent contouring. A separate subprogram automatically inverts an observed gravity profile into a model of a single, irregular interface.

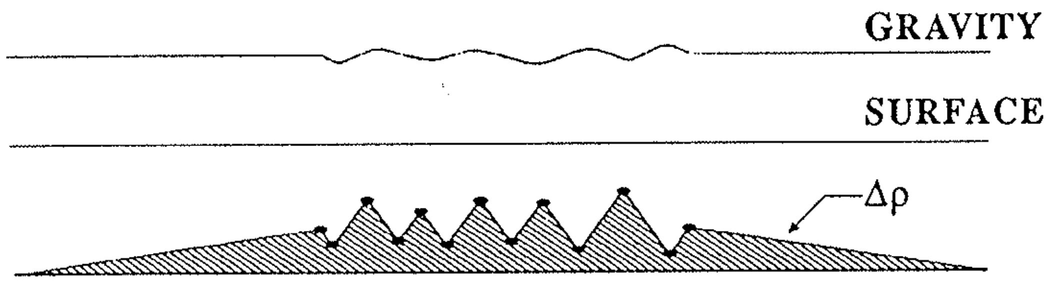
HARDWARE REQUIREMENTS

GMODEL requires an MS-DOS compatible computer (version 2.0 or higher) with an Epson-compatible line printer. (If no printouts are needed the program can be run without the printer.) The program uses black & white graphics and an 80 character by 25 line screen format. Hardcopy prints of the screen graphics are obtained with the PRINTSCREEN key on your keyboard. If your system uses either an Enhanced Graphics Adapter (EGA) or Color Graphics Adapter (CGA), the program sets the screen mode and activates the PRINTSCREEN key. If it does not have an EGA or CGA, you will be asked to specify the graphics mode and will have to activate the PRINTSCREEN key yourself. GMODEL will not run with a Hercules adapter.

DESCRIPTION

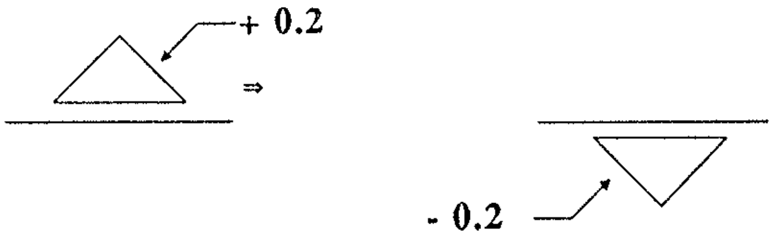
GMODEL uses a right-handed coordinate system with the +X axis to the right, the +Y axis towards the viewer, and the +Z axis positive downward (depth). All calculations are on the Z=0 plane. Horizontal polygons parallel the Y axis and are defined by the X,Z coordinates of the vertices. For finite-length horizontal polygons the Y coordinates of the two ends must be specified. Vertical polygons are defined by the X,Y coordinates of the vertices plus the depths (Z) to the top and bottom of the body. For all polygons, vertices are numbered clockwise around the body. Spheres are defined by the X,Y,Z coordinates of their center plus the radius. Density contrasts are in gm/cc. Dimensions may be in meters, feet, kilometers, or kilofeet.

Complex situations may be modeled with these simple bodies. For a profile over an irregular interface place the first and last vertex of an infinitely-long polygon at long distances beyond the ends of the profile and slightly deeper than its deepest point. The remaining vertices are used to shape the surface. This approach can also be used to model a fault step.



To model bodies above the Z=0 plane, enter the vertices as if the body is below the plane and reverse the sign of the density contrast.

(Bodies which penetrate the Z=0 plane must be split into two parts.) Vertical and horizontal cylinders can be approximated with hexagonal polygons. Spheres can be used as point source approximations of irregular bodies at large distances.



PROFILES

The location of profiles is specified by the X,Y coordinates of the end points. If Y(start)=Y(stop)=0 then the profile coincides with the X axis and is perpendicular to the strike of any horizontal polygons in the model.Gravity observations are entered as their distance from the start of the profile plus the gravity value in milligals. Observations outside the profile range of the modeled gravity are not plotted. You may elect to have the program find a linear regional which ties the first and last observations to the modeled gravity. This regional is removed from the observed gravity before it is plotted.

SURFACE CALCULATIONS

The grid for surface calculations is specified by its minimum and maximum X coordinates and its minimum and maximum Y coordinates. The X,Y coordinates and gravity value of each point are written to GSURF.DAT or some other user-specified file. These may be loaded directly into a contouring program (such as SURFER). You can use the following BASIC language program segment to bring these data into your own contouring or data-processing programs.

```
OPTION BASE 1
DIM X(51,51),Y(51,51),G(51,51)
OPEN "GSURF.DAT" FOR INPUT AS #1
FOR II=1 TO 51
FOR JJ=1 TO 51
INPUT #1,X(II,JJ),Y(II,JJ),G(II,JJ)
NEXT JJ
NEXT II
CLOSE #1
```

AUTOMATED INVERSION

Automated inversion fits a single interface to a profile of up to 100 gravity observations. Observations must be ordered from left to right along the profile but do not have to be uniformly spaced. In addition to the observed gravity, the user specifies the depth to the interface at the two ends of the profile and the density contrast. Generally it is desirable to model several densities and depths to determine the range of structures which will satisfy the data.

Automated inversion uses an infinitely-long horizontal polygon with fixed vertices below the ends of the profile and vertically-free vertices at each of the other observation points. The inversion program uses the linear regional to tie the end observations to the modeled gravity. During each program iteration, the depths to the vertically-free vertices are adjusted to reduce the difference between the modeled and the regionally-adjusted observed gravity. For computational purposes there are two additional model vertices located 100 profile lengths beyond the ends of the profile at depths of one-fifth the profile length.

GMODEL is dimensioned for:

- maximum number of bodies: 20
- maximum number of polygon vertices: 30
- maximum number of observations: 100
- values on a modeled profile: 101
- values on a modeled surface: 51 by 51

REFERENCES

Infinitely-long horizontal polygons	Talwani, 1973, Computer usage in the computation of gravity anomalies in Bolt, Methods in Computational Physics: Academic Press, pp 343-389
Finite-length horizontal polygons	Rasmussen and Pedersen, 1979, End corrections in potential field modeling: Geophysical Prospecting, v.27, pp 749-760
Vertical polygons	Plouff, 1976, Gravity and magnetic fields of polygonal prisms and application to magnetic terrain corrections: Geophysics, v.41, pp 727-741

TIDECV

TIDECV uses the Hewlet-Packard HP-41CV or CX to compute gravity changes on the earth due to lunar and solar attraction. It uses the formulas presented by I. M. Longman in the Journal of Geophysical Research, Volume 64, No. 12, December 1959, pages 2351-2355. After computation of the attractions, the values are multiplied by 1.16 to account for the earth compliance to the gravitational forces of the moon and sun. This is a good approximation for continental areas well away from the coast. Near the coast the amplification may be slightly greater and there may be a slight phase shift due to oceanic loading of the earth's crust.

Depending upon what is already stored in the memory space of your HP41, it may be necessary for you to repartition the program and data storage memory space using SIZE before you can load the tide program. TIDECV consumes 4 memory registers and uses storage registers 00 through 38.

After loading the program, be sure the keyboard is in "user" mode and XEQ [alpha] TIDECV [alpha]. The following page contains a sample input for Austin Tx. and what the answer should be.

DISPLAY	INPUT	COMMENT
HR	12 R/S	The program uses local time or Greenwich time.(Use 17 R/S for Greenwich time.)
MIN	30 R/S	
LAT	35.45 R/S	35° 45' is entered 35.45. (Use "-" for south latitude.)
LONG	112.15 R/S	(Use "-" for east longitude)
ELEV	500 R/S	The computation is not sensitive to elevation.
MO	6 R/S	
DAY	12 R/S	If Greenwich hour is used , remember to use the day in Greenwich, England.
YEAR	83 R/S	Omit the "19" from the year.

ZONE	6 R/S	The time zones in the U.S. are EST=5, CST=6,MST=7, PST=8.(Use 0 for Greenwich.)
DST :0,1	1 R/S	Use 1 for Daylight SavingsTime and 0 for Standard Time (Use 0 for Greenwich.)
FACTOR	.112233 R/S	The gravimeter calibration factor.
	. . . . .calculating for about 40 seconds	
T.C.: 69.4		Tidal correction in microgals
	R/S	
READING	1000.00 R/S	Input meter reading
RAW G = 112.233		Raw gravity in milligals.
	R/S	
RG+T = 112.302		Raw gravity plus tidal correction

If only the tidal correction is needed, another calculation may be started by pressing the COS key. You do not need to reenter all the parameters each time. If the parameter remains the same, press the R/S key without reentering. If the remainder of the parameters are the same, press the Σ+ key and computation will start.

If storage registers from 00 through 38 have been used since TIDECV was last run, start computation with XEQ TIDECV as the first part of the program loads several constants into storage to reduce computation time of repeated calculations.

A laminated instruction card is provided with the program. It is sized to fit into the HP41 carrying pouch.

GMOD

GMOD determines the vertical component of the gravitational attraction of four simple geometrical bodies: the sphere, horizontal circular cylinder, thin semi-infinite horizontal plate and the thick vertical "fault" that extends to the surface. The units can be feet or meters with the answers in microgals or kilofeet or kilometers with the answers in milligals.

Be sure the keyboard is in the USER mode when loading or using the program.

The program puts the HP-41 in the radian mode if it is not already in that mode. Prompts guide you through the execution of the program. You select feet or meters (kilofeet or kilometer if you read the results in milligals). You then select the type of body, the density , the diameter or thickness, the depth and the horizontal coordinate of the observation point.

If you have already run the program, there are several shortcuts that may be employed. Pressing keys A, D and I will do the following:

A: returns to ask for a new X coordinate and redoes the calculation with the other parameters remaining the same.

D: returns to ask for a new diameter or thickness.

I: returns to the beginning of the program. If you make a data input error, this key provides a quick way to start over.

To start the program:

XEQ [alpha] GMOD [alpha]

A test run of the program is as follows:

DISPLAY	INPUT	COMMENT
FT,MT:0,1:	0 R/S	Feet or meters [kilofeet or kilometers]
S,C,P,F:1.2		
.3.43.4:	1 R/S	Sphere, cylinder, plate or fault?
DENSITY:	1 R/S	Density contract
DIAMETER:	1 R/S	For plate or fault, THICK is prompted
DEPTH:	1 R/S	Depth to center sphere, cylinder or plate
STA X:	0 R/S	Coordinates X=0 is above the center of the sphere and above the edge of the plate or fault. Position X is over the plate or fault.
G:SP=1.065		
	A	
STA X:	1 R/S	
G:SP=0.377		
	D	
DIAMETER:	2 R/S	
DEPTH:	1 R/S	
STA X:	0 R/S	
G:SP=8.520		

The formulas used to calculate the gravitational attractions are presented in several texts and references. See:

Nettleton, Elementary Gravity and Magnetics for Geologists and Seismologists, 1971, pp 48-52

Nettleton, Geophysical Prospecting for Oil, 1940, pp 102-115

Nettleton, Geophysics, Vol 7, 1942, pp 57-58, pp 68-69, p 69

Sphere : $\frac{8.52\,\sigma R^3}{Z^2}\,(1 + X^2/Z^2)^{-3/2}$

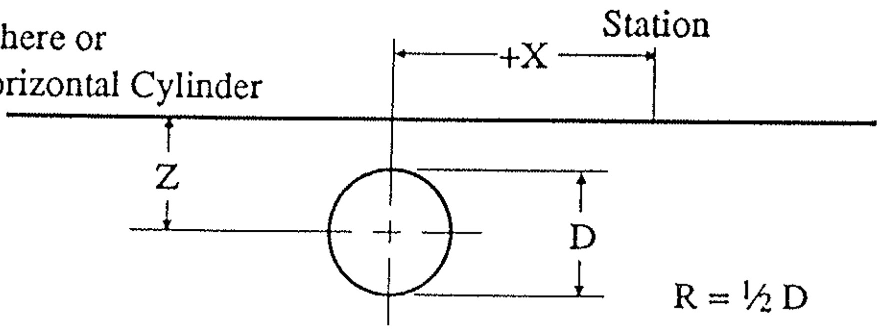
Horizontal Circular Cylinder : $\frac{12.77\,\sigma R^2}{Z}\quad(1 + X^2/Z^2)^{-1}$

Plate $12.77\,\sigma\,T\,(\frac{1}{2} + \frac{1}{\pi}\mathrm{atan}\,\frac{X}{Z})$

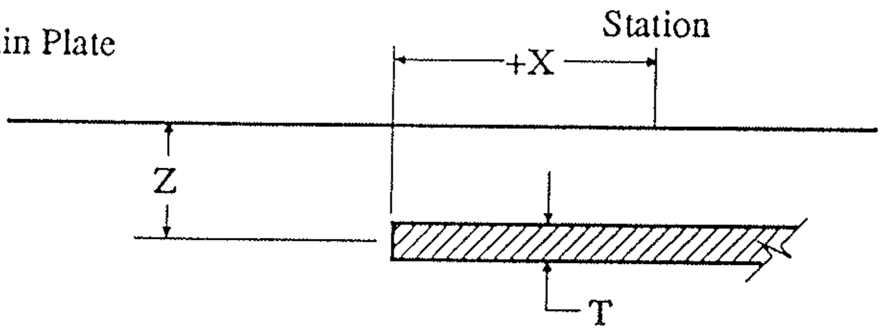
Thick Fault :

$$12.77\,\sigma Z\,(\frac{1}{\pi}\frac{X}{Z}\ln\,\frac{(1 + X^2/Z^2)^{\frac{1}{2}}}{X/Z} + \frac{1}{2} + \frac{1}{\pi}\,\mathrm{atan}\,X/Z)$$

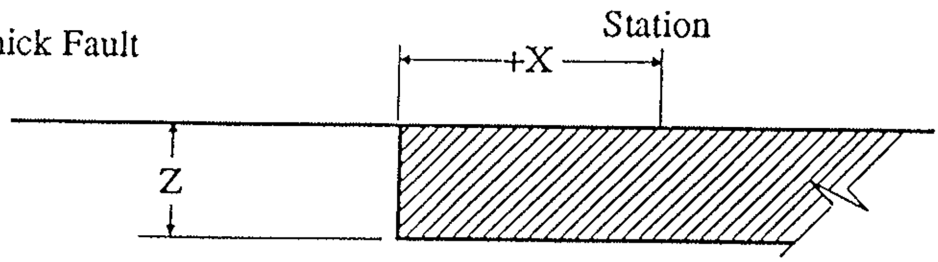
Sphere or
Horizontal Cylinder



Thin Plate



Thick Fault



SHIPPING PRECAUTIONS

Probably the largest risk to a gravity meter occurs when it is shipped. A few simple precautions can reduce the risk significantly. When the instrument arrives at your job, we want the meter to be in good operating order. When the instrument is returned to us for service, we want the cost to be as low as possible. Several times meters have been returned to us for minor repairs and major damage has occurred during return. Most of the risk during shipping can be reduced if you follow these suggestions:

TAPE CLAMP

Place tape around the clamping screw and the eye piece to prevent the clamp from vibrating loose or curious people from tampering with it.

RETRACT LEVELING SCREWS

Retract the leveling screws until they are flush with the bottom of the meter.

I.D. INSIDE CASE

Place a business card or some identification inside the carrying case in case the box and its labels are damaged or separated in customs.

NO BATTERIES WITH METER

Do not pack batteries with the meter. Acid has come out of them in hot climates. Also, minor damage could cause a short and incinerate a gravity meter.

KEEP LIGHT WEIGHT

Do not pack anything heavy with the meter. Keep the"Transafe" shipping box as light as possible so people will tend to handle it with more care.

FOAM ATOP METER

Place a piece of foam rubber atop the instrument so it can't vibrate up and down inside the carrying case. Be sure there is nothing to rub on the instrument.

USE TRANSAFE

Use the specially designed "Transafe" shipping box for the carrying case. Plan ahead: if it has been lost or severely damaged, send for a new one. If the "Transafe" is not available, use a large cardboard container, well padded with SOFT foam rubber. A wood or metal box is not advisable as it does not absorb impact as well as cardboard.

FRAGILE SIGNS

If the large DELICATE INSTRUMENT sign is damaged or obliterated with labels or airbill envelopes, there should be a spare sign taped to the top of the inside "Transafe" cover. Be sure there are FRAGILE signs on all four sides of the box. If a fragile shipment is not adequately marked, the insurance company may reject a claim for damages.

PACKING ACCESSORIES

Pack the accessories in a separate box. Always place the batteries right-side up. Protect them and other accessories from damaging each other by using plenty of packing in a thoughtful way.

TELEPHONE

Telephone the person the instrument is being shipped to and give the airbill number, the shipping company, and the expected arrival time. If the meter does not arrive, an early search can be initiated.

DOMESTIC

From the US, return to : LaCoste and Romberg Gravity Meters, 4807 Spicewood Springs Rd., Bldg 2, Austin, Texas 78759, phone (512) 346-0077. Federal Express is preferred. Their phone is (800) 238-5355.

FOREIGN

Return to: LaCoste and Romberg Gravity Meters, Inc., Austin, Texas USA, c/o Robert F. Barnes, Customs Broker, Austin International Airport. Be sure to attach to the outside of the box a certificate of "U.S. goods being returned for repairs". An example follows.

RECEIVING SHIPMENT

Upon receipt of a shipment, it should be inspected promptly and any damage should be reported at once. For an insurance claim to be valid, it must be reported within the limited time prescribed by the insurance company. Save the packing material to prove to the insurance inspector that the shipment was properly packed and adequately labeled.

SHIPPING BOX SELECTION

The proper selection of a shipping box and padding material can save much frustration, money and lost time. A soft box (cardboard for example) will crush and absorb much of the jar of a drop. A hard box (wood or metal) will transmit most of the jar of a drop to the inside of the box. If the packing within the box is dense (dense foam rubber, styrofoam or solid sprayed-in-place plastic) then the jar of a drop will be transmitted to the contents. Very soft foam rubber can absorb several times more jar than dense rubber.

When more than one item is in a single box, it is important to protect the items from bumping or rubbing against each other.

Don't even consider shipping the meter in the bare aluminum carrying case.

Weights & Dimensions

Meter

Length	7¾ inches	19.7 centimeters
Width	7 inches	17.8 centimeters
Height	9⅞ inches	25.1 centimeters
Weight	7 pounds	3.2 kilograms

Battery

Length	6 inches	15.2 centimeters
Width	2⅝ inches	6.7 centimeters
Heigth	4⅝ inches	11.7 centimeters
Weight	5 pounds	2.3 kilograms

Carrying Case

Length	9¾ inches	24.8 centimeters
Width	16 inches	40.6 centimeters
Height	16 inches	40.6 centimeters
Weight	10 pounds	4.5 kilograms

Meter w/Battery & Carrying Case

Weight	22 pounds	10 kilograms

SHIPPING WEIGHTS & DIMENSIONS

BOX 1

Length	21 inches	53.3 centimeters
Width	15 inches	38.1 centimeters
Height	18 inches	45.7 centimeters
Weight	25 pounds	11.3 kilograms
Volume	3.3 cubic feet	0.093 cubic meter

CONTENTS

Meter

Carrying Case

Level Adjusting Tool

Spare Fuses

Spare Lamps

Manual

BOX 2

Length	16 inches	40.6 centimeters
Width	16 inches	40.6 centimeters
Height	10 inches	25.4 centimeters
Weight	20 pounds	9 kilograms
Volume	1.5 cubic feet	0.042 cubic meter

CONTENTS

Two Gel Type Batteries

Charger / Battery Eliminator

Power Extension Cable

Aluminum Baseplate

Recording Cable (if meter has CPI option)

FOREIGN SHIPPERS DECLARATION
COVERING THE RETURN OF UNITED STATES MERCHANDISE

Required: When value of goods exceeds $1,000.00 UScy

I, ________________________ DECLARE THAT THE ARTICLES SPECIFIED HEREIN ARE, TO THE BEST OF MY KNOWLEDGE AND BELIEF, THE GROWTH, PRODUCE OR MANUFACTURE OF THE UNITED STATES. THAT THEY WERE EXPORTED FROM THE UNITED STATES FROM THE PORT OF________________ ON OR ABOUT________________ THAT THEY ARE RETURNED WITHOUT HAVING BEEN ADVANCED IN VALUE OR IMPROVED IN CONDITION BY ANY PROCESS OF MANUFACTURE OR OTHER MEANS.

Marks	Qty	Model No.	Description	S/N	Value in U.S.$
	One	Model G	Lacoste & Romberg Gravity Meter and Parts		

SHIPPED VIA ______________________ DATE ______________________

DATE: ______________________ SIGNATURE ______________________

TITLE ______________________

ADDRESS ______________________

U.S. Customs regulations, Sec 10, 1, revised as of October 1957 provides that shipments of returned U.S. Goods valued over $1,000.00 requires foreign shippers declaration for FREE ENTRY into the United States.

Customer ______________________