



Operating Principles of the Superconducting Gravity Meter



Observatory Superconducting Gravimeter (OSG), electronics package
and 4K refrigeration system shown above

Why is it named the SG?

A spherical superconducting mass is levitated using a magnetic force that exactly balances the force of gravity. The superconducting property of zero resistance allows the currents that produce the magnetic field to flow forever without resistive loss as long they are kept below a critical temperature. This explains the extreme stability of the sensor and hence the name – Superconducting Gravimeter (SG).

Working Principles of an SG

Other relative gravimeters and seismometers are based on a test mass that is suspended by a spring attached to the instrument support. A change in gravity or motion of the ground moves the test mass and this motion generates a voltage that becomes the output signal (velocity or acceleration). Even in a thermally well-regulated environment the mechanical aspects of a spring suspension causes erratic drift that is difficult to remove by post processing. The SG solves the drift problem by replacing the mechanical spring with the levitation of a test mass using a magnetic suspension.

The figure (opposite top right) shows a diagram of the GSU; the three major superconducting elements are the levitated mass (sphere), the field coils, and the magnetic shield. The displacement transducer is formed by a capacitance bridge that surrounds the sphere and is sealed with a partial pressure of helium gas in a separate cavity inside the coils.

The field is generated by two niobium wire coils (superconducting below a temperature of 9.2 °K) that carry, in principle, perfectly stable and persistent superconducting currents to provide an extremely stable magnetic field. The stability depends on the zero resistance property of superconductors – after the currents are “trapped” no resistive (ohmic) losses are present to cause them to decay in time. The test mass is a small 2.54 cm diameter sphere, also made of niobium, that weighs about 5 grams. The coils are axially aligned; one just below the center of the sphere and one displaced about 2.5 cm below the sphere. When current is trapped in the coils, currents are induced on the surface of the sphere. As with the currents in the coils, the induced currents are perfectly stable in the absence of any ohmic losses.

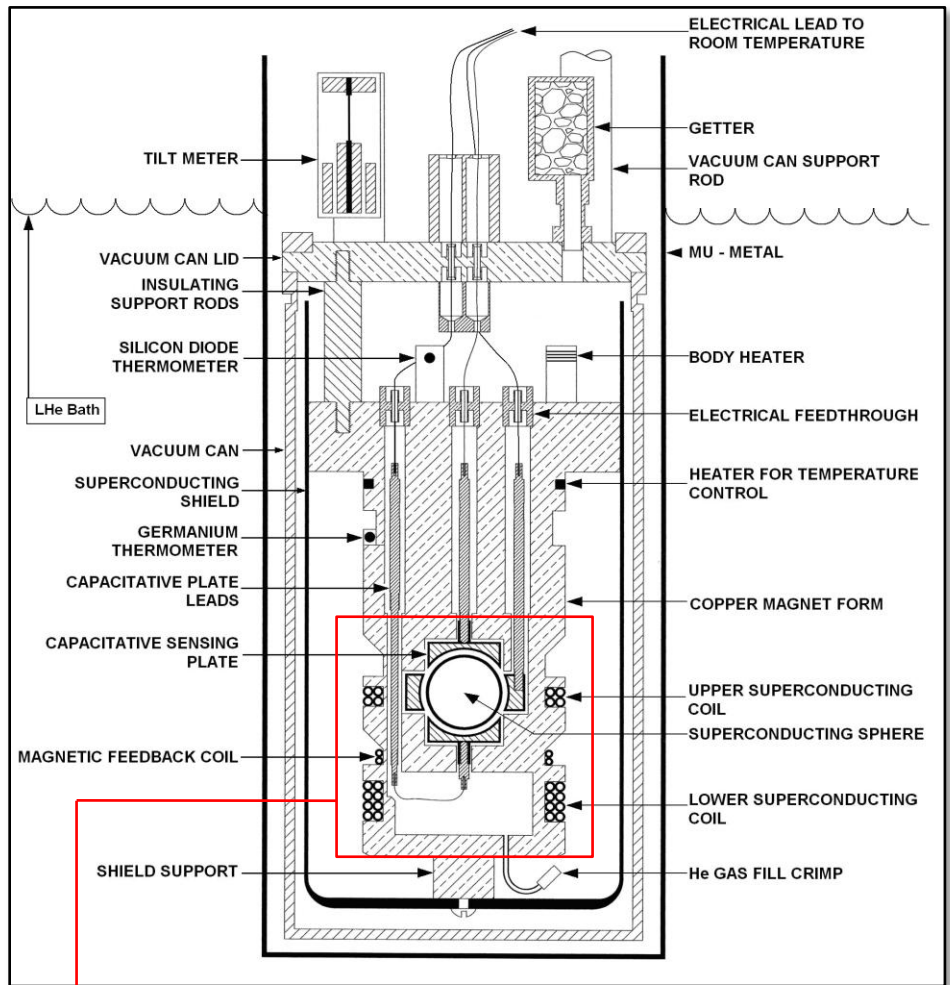


A view of an OSG Dewar, vibration isolation frame and coldhead cryogenic refrigerator

The levitation force is produced by the interaction between the magnetic field from the coils and the currents induced on the surface of the superconducting sphere. The figure below shows a schematic of the sphere, coils, capacitance bridge, and magnetic flux lines induced on the surface of the superconducting sphere.

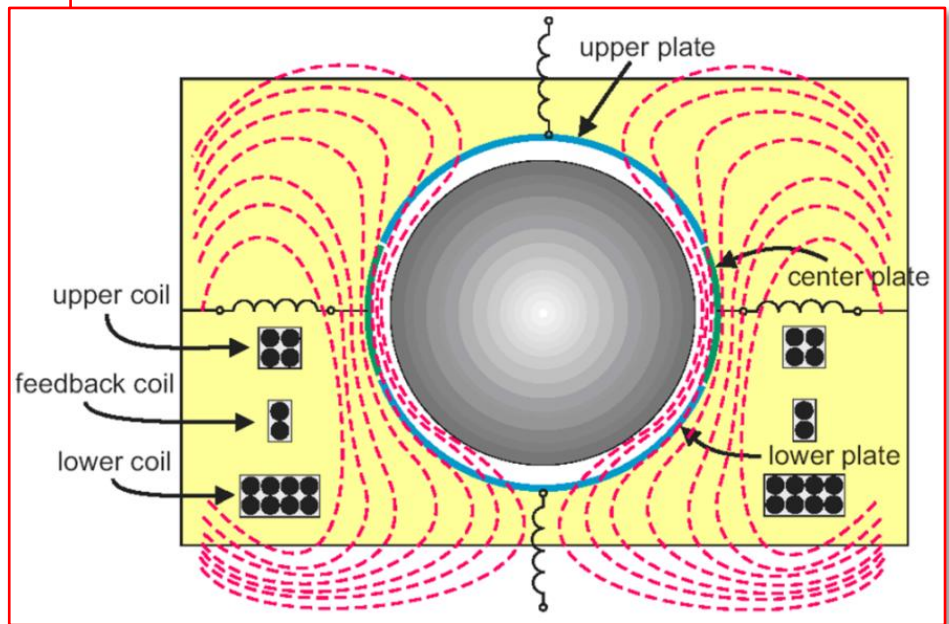
The current in the coils can be precisely adjusted to balance the force of gravity on the sphere at the center of the displacement transducer. The ratio of currents in upper and lower coils is adjusted so that the magnetic force gradient (spring constant) is very weak. As a result, a very small change in gravity (acceleration) gives a large displacement of the test mass. This allows for the instrument to achieve very high sensitivity.

Because the levitation is magnetic, changes in the Earth's magnetic field would seriously degrade its stability. A superconducting shield is used to exclude the earth's magnetic field from entering the space where the sensor is housed.



Sectional drawing of Gravity Sensing Unit (GSU)

- To maintain superconductivity, the SG sensor operates in liquid helium at 4 Degrees Kelvin inside a highly efficient vacuum insulated Dewar.
- An OSG uses a 4 °K refrigeration system that uses only 1.3 kW to operate. The 4 °K coldhead liquefies helium gas in the Dewar neck and returns it to the Dewar storage volume.
- The Dewar-Coldhead operate as a “closed cycle system” that can operate indefinitely without the need for refilling. No Liquid Helium refills are needed! New advances in the iGrav™ Dewar allow for cool down from room temperature in a matter of days!
- At cryogenic temperatures all materials are extremely stable and the sensor can be temperature regulated to a few micro-Kelvin. Therefore, material “creep” and sensitivity to local temperature and humidity changes are totally eliminated.



Conceptual drawing of flux lines, plates and Nb sphere



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About the Company:

GWR Instruments, Inc., located in San Diego, California is the sole manufacturer of the Superconducting Gravimeter which provides a stable, extremely precise long term gravity record. The Superconducting Gravimeter (SG) was invented by J. Goodkind and W. Prothero at the University of California, San Diego in the mid 1960's. In 1979, GWR Instruments was formed as a partnership by J. Goodkind, R. J. Warburton and R. C. Reineman. The company was incorporated in 1992 and Richard Warburton and Richard Reineman actively manage the company and take pride in their long term relationships with customers. The SG has continuously evolved over the years - including reducing its size by increasing Dewar efficiency and improving signal stability and precision; however the core working principles of levitating a sphere in a superconducting magnetic field remain the same. The present GWR Observatory Superconducting Gravimeter (OSG) provides unprecedented nano-Gal resolution across a broad frequency band and stability approaching a few $\mu\text{Gal}/\text{year}$. The GWR OSG provides the finest possible measurement of long term gravity signals over periods of years to decades.

The Superconducting Gravimeter is used in observatories throughout the world in the Global Geodynamics Project^{1,2} for measuring the broad spectrum of gravity signals ranging long period seismic (1000 s) to crustal tectonic motion over years to decades. To encourage measurements that include volcanoes, geothermal reservoirs, and hydrological applications, GWR Instruments introduced the new **iGrav™** in 2010. This new simplified system maintains the same operating features as the traditional Observatory Superconducting Gravimeter, but is built into one stand-alone "package". The complete $\frac{1}{2}$ sized Dewar houses all the redesigned electronics and data system within the top portion of the Dewar. The modernized electronics simplifies setup and preserves the sensor characteristics. The smaller Dewar can be automatically cooled on demand in only a few days. The results in a modular design that simplifies setup and allows for easier relocation to new sites.

To ease the process of field installations, complete field enclosures are being designed and soon will be available. These enclosures will include air conditioning, power management, lightening protection and integration with GPS and will be suitable for rapid deployment in rugged field environments.

Visit www.gwrinstruments.com for product information and/or to request a quotation.

References:

1. Global Geodynamics Project (<http://www.eas.slu.edu/GGP/ggphome.html>)
2. Hinderer J and Crossley D (2004) Scientific achievements from the first phase (1997-2003) of the Global Geodynamics Project using a worldwide network of superconducting gravimeters. *Journal of Geodynamics* 38:237-262.