GRAVITY METERS (GRAVIMETERS) USED IN GEOPHYSICAL EXPLORATION [1]

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ABSTRACT

The variation of the Earth's gravitational attraction at different locations was first observed by Jean Richer in 1672 with a pendulum-operated clock, and it was with pendulums that the first relative values of gravity were measured. Gravity meters were developed later, and have been used intensively during the past thirty years for oil exploration. Because gravimeters can measure changes in gravity of less than 1 part in 1 million of the Earth's total gravity, their sensitivity creates many difficult instrumental problems, which are briefly discussed. However, gravimeters used in the more accurate geodetic work today have an even greater reading accuracy of 1 part in 1 billion of the Earth's total gravity, as a result of instrument research and development to meet even more exacting requirements in precision.

The variation in the gravitational attraction of the Earth at different locations on its surface was first discovered by Jean Richer in 1672. He noted that a pendulum-operated clock was slower by about 2½ minutes in Cayenne, French Guiana, as compared to Paris, France. In those days it was known that the period of a simple pendulum is a function of the pendulum's length and the pull of gravity, and Richer concluded that because the pendulum's length remained constant, then the attraction of gravity was not the same in the two places. Later, in the period 1735-1743, another Frenchman named Bouguer was the first to apply the pendulum method to a study of the shape of the Earth, during which he achieved the first relative gravity measurements.

In 1833, Sir John Herschel described the first gravity meter in which the relative pull of gravity was measured by the relative displacement of a plumb bob suspended on a spring. However, it was not until the years 1928-30 that intensive development of gravimeters began, when American oil companies became interested in the use of gravity measurements as an aid in exploration.

The law of universal gravitation was conceived by Newton from a study of Kepler's empirical laws of the motion of the planets, and is expressed by the following familiar equation:

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$$F = k \frac{m_1 m_2}{r^2} \qquad (1)$$

where F is the force of attraction in dynes between two masses m_1 and m_2 separated by a distance r in centimeters and k is the universal constant of gravitation, 6.67 x 10^{-8} cgs units. Newton's second law of motion also states that force is equal to mass times acceleration:

$$F = ma \qquad (2)$$

The weight of a body on the Earth is equal to the force acting on it because of the Earth's gravity; thus, if we let m_1 equal the mass of a body on the Earth, and g equal its "free-fall" acceleration, then the gravitational force acting on the body is numerically equivalent to its acceleration. Thus, Earth's gravitational attraction at its surface is:

$$g = \frac{F}{m_1} = k \frac{m_2}{r^2} \qquad (3)$$

where, m_2 is the mass of the Earth and r is the distance to its center from the point on its surface.

The units of g are expressed in gals (after Galileo), and 1 gal is equal to 1 cm/sec/sec. In geophysical exploration the gal is too large a unit, so the milligal (1/1000 of a gal) is more commonly used.

The gravimeter is essentially an extremely sensitive scale with which relative values of the gravitational attraction of the Earth can be measured directly by "weighing" a constant mass. That is, the weight of an object is equal to its constant mass times the gravitational attraction of the Earth. To illustrate the extreme accuracy needed of a gravimeter, let us recall that 1 milligal is 1/1000 of a gal. As the total gravity of the Earth is about 980 gals, 1 milligal is equivalent to about 1 part in 1 million of the Earth's total gravity.

Nettleton (1940) described the required accuracy of a gravimeter in another way. If a mass is suspended on a spring and the spring is stretched a length of 30 centimeters, then a change of 1 milligal of the Earth's gravity would displace the mass by only 30 x 10^{-7} cm, or about 1/10 of the wavelength of light.

Instrument construction presents many difficulties. One of the major problems, obviously, is the measurements of the minute displacement of mass caused by small changes in gravity. Compound spring systems together with optical systems are used to achieve the required sensitivity. Another major problem is the changes in the spring system that are due to the thermal expansion and instability of elastic materials. The thermal effects are compensated for by a combination of (1) the use of bimetallic materials, (2) the maintenance of constant temperature, and (3) the use of spring materials with low temperature coefficients. Elastic creep and elastic lag are largely overcome with the use of fused quartz, which has very stable elastic properties. Furthermore, it is necessary to enclose the spring systems in a partial vacuum because gravimeters are very sensitive to changes in barometric pressure.

The instrument drift and calibration of a gravimeter must be determined for any gravity measurements. Although spring systems are made of fused quartz which has extremely constant elastic properties, there is, nevertheless, a steady change in the dimensions of the system caused by elastic fatigue. This change, known as the "drift" of the instrument, varies linearly as little as several dial divisions per day. Gravimeter readings taken at the same location several times a day are usually sufficient for plotting drift curves for accurate work.

The gravimeter readings are recorded as figures in dial divisions. In order to be read directly in units of milligals, the dial must be calibrated in the field against known differences in gravity, or in the laboratory by the "tilt" method of adding known masses to the spring system. Because a gravimeter can measure only relative values of gravity, pendulums which measure absolute values of gravity are used to establish known differences of gravity at different locations.

The rapid development of the gravimeter as an extremely sensitive and accurate "weighing" device was due to its application to the exploration of oil. With continuing research and development, gravimeters have been made for use in geodetic work such as studying the figure of the Earth and studying the tidal effects of the Moon and Sun. Such instruments have a reading accuracy of one microgal (1/1,000,000 of a gal) which is 1 part in 1 billion of Earth's total gravity. In addition to geodetic types, gravimeters have been developed for underwater use in off-shore oil exploration such as in the Gulf of Mexico. Gravimeters are precision instruments which can be operated under a wide range of conditions on land or under water.

REFERENCE CITED

1. Nettleton, L. L., 1940, Geophysical Prospecting for Oil, p. 24, McGraw-Hill Book Co., New York.