Terrestrial Gravity Instrumentation In The 20th Century: A Brief Review

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At the turn of the century, only pendulum apparatuses and torsion balances were available for general exploration work. Both these early techniques were cumbersome and time-consuming. Although portable, torsion balances weighed up to 72 kg (160 lbs) (Steiner, 1926) and required an observing hut for protection from sun and wind. They were extremely sensitive to close-by terrain effects which had to be measured with painstaking detail to a radius of 100 m (30 ft) around the instrument (Heiland, 1933). Often the terrain had to be physically smoothed to a distance of 10 m (3 ft). Accuracy of pendulum measurements suffered because time standards of the day were pendulums themselves. The period of the roving pendulum could only be compared with that of another pendulum at a fixed site, or with a spring chronometer calibrated against a pendulum at a fixed site. This requirement was one factor that gave rise to the need for broadcast time signals and partly accounts for the early association between astronomy, time standards and geophysics. Vening Meinesz (1929) developed the technique of making shipboard observations with pendulums.

It was no wonder that the development of the gravity meter was welcomed with a universal sigh of relief. By 1935 potential field measurements with gravity meters supplanted gradient measurements with torsion balances. The invention of the so-called zero-length spring mechanism by Dr. Lucien LaCoste (1934) has been the basis for gravity meter (and long period seismometer) design for more than fifty years. Gravity meters of this type were erroneously labeled "astatic" because they were capable of achieving infinite sensitivity. Astatic gravity meters soon replaced "static" gravity meters and were developed through the years for a wide variety of applications, including: measurements on land, in bore-holes, under water, on the sea-surface and in the air. Measurements from a moving platform were made possible with the discovery by LaCoste (1967) that an overdamped, infinitely sensitive gravity meter could provide an instantaneous response and large dynamic range. With the help of modern electronics "static" gravity meters were also developed (Jacoby, 1970) for less precise dynamic applications and within the past five years (Hugill, 1984) for precise stationary observations.

Potential field measurements are generally characterized by three types:

1) Absolute: Measurements are made in fundamental units, traceable to national standards of length and time at each observation site.

2) Relative with absolute scale: Differences in gravity are measured in fundamental units traceable to national standards of length and time.

3) Relative: Differences in gravity are measured with arbitrary scale.

The free-fall apparatus is an example of the first type. Pendulums offer an example of both types 1 and 2, depending on how they are used. If the length of the pendulum is determined, the measurement is absolute; if the length of the pendulum is assumed to be constant, the measurement is relative with absolute scale. The gravity meter is an example of type 3. As gravity meters require a known gravity difference for calibration, various relative (type 2) pendulum apparatuses, capable of precisions up to 20 ppm, were employed until around 1970. The longevity of pendulums was made possible with the development of broadcast time signals and later with portable precise crystal clocks. Measurements performed on the North American and European Gravity Standardization networks with the Gulf Pendulums (Gay, 1940), USA, Cambridge Pendulums (Jackson, 1961), UK, and the Canadian Pendulums (Valliant, 1971), amongst others, continue to contribute to the adjusted values of these gravity networks.

Absolute gravity measurements were originally performed as laboratory experiments at fixed sites. Sakuma (1963) in France, Preston-Thomas (1960) in Canada, Cook (1967) in the UK and Tate (1966) in the USA were among the early contributors in this field. A major breakthrough came when Faller and Hammond (1974) developed a portable free-fall apparatus in the early 70's. This apparatus not only improved upon the accuracy achieved with pendulums, but also provided absolute observations. The free-fall apparatus soon superceded pendulums for establishing gravity standards.

Improvements in the design of gravity meters since their introduction has led to a significant reduction in size and greatly increased precision. Weight decreased from 34 kg (75 lbs) in 1939 to about 3.6 kg (8 lbs) in modern instruments. As the precision increased from about 100 μGals to a few μGals, applications expanded to include the measurement of crustal motion, the search for non-newtonian forces, archeology, and civil engineering. The development of peripheral devices (Valliant et al, 1986) to automatically null the gravity meter contributed to this increased precision. Apart from enhancements to the "astatic" gravity meter, few developments in hardware were achieved. One of these was the vibrating string gravity meter (Gilbert, 1949) which was developed in the 1950's and was employed briefly for marine and borehole applications. Another is the cryogenic gravity meter (Goodkind et al, 1968) which utilizes the stability of superconducting current to achieve a relative (type 3) instrument with extremely low drift suitable for tidal and secular gravity measurements. An advance in performing measurements from a moving platform was achieved with the development of the straight-line gravity meter (LaCoste, 1983). In this invention, the proof-mass of the gravity meter is constrained to move in a vertical straight line, thereby eliminating the cross-coupling of horizontal accelerations into the vertical; a problem inherent in beam type gravity meters. The latter part of the century also saw the rebirth of gradient measurements which offers advantages for observations from a moving platform. Definitive testing of the Bell gradiomenter was recently reported (Jekeli, 1988).

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