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Short Communications

A New Type of Vertical Gravity Gradiometer

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Key words: Gravimetry — Gradiometry — Vertical Gradient — Earth's Figure — Electronic Microbalance — Geophysical Prospecting.

Gravity gradiometry on moving platforms has found recent interest since airborne gravimetry failed to give satisfactory results. In contrast to such sophisticated instrumentation (Ames *et al.*, 1973) where mainly dynamical measuring principles are applied static measuring principles are well adapted to less sophisticated instruments which can be used for geophysical and geodetic field work at the earth's surface. The construction of such vertical gradiometers is an idea which has incited in vain the numerous attempts of physicists and technologists for more than a century. Since ten years high precision gravity meters which yielded relative accuracy of $\pm 10^{-9}$ or, in absolute terms, $\pm 10^{-9}$ g gave way to measuring vertical gravity differences so approximations for $\partial g/\partial h$ were available. Even though the ultimate limit of accuracy for static instruments seems to be of the order of $\pm 10^{-13}$ depending on Brownion motion and *stationary* gravimeters yield accuracy of better than $\pm 10^{-10}$ under favorable conditions gravimeter systems on *moving* platforms might have reached their ultimate accuracy in field work between $\pm 10^{-9}$ to $\pm 10^{-10}$ because of transportation drift and small jumps in the drift curve when the meter is clamped.

A previous attempt to use an electronic microbalance for vertical gradiometry failed mainly because of deficiencies of the read-out-systems at that time (Kibler, 1969). By the balance using the well known principle after Gast (for description see, e.g., (Gardner and Smith, 1972)) having an inductive read-out-system previous deficiencies have been overcome so that a highly sensitive vertical gradiometer based on this principle became available. A torsion tape suspension of the balance system together with zero reading instead of deflections measurements gives way to relatively high accuracy.

There are several advantages of such an ultramicrobalance system in comparison to spring balances like gravimeters where the measuring systems are directly affected by temperature effects etc.

Some details of the new gradiometer as well as the first experiments have been described in Groten (1974). In order to measure the gravity difference along the plumb line the balance is mounted on a steel rack (Fig. 1). A small mass ($\approx$20 grams) is suspended in an evacuated tube on a thin platinum iridium fiber at two different levels having a separation of about 80 or 30 centimeters. The weight difference corresponding to the difference in gravity along the plumb line is compensated by the

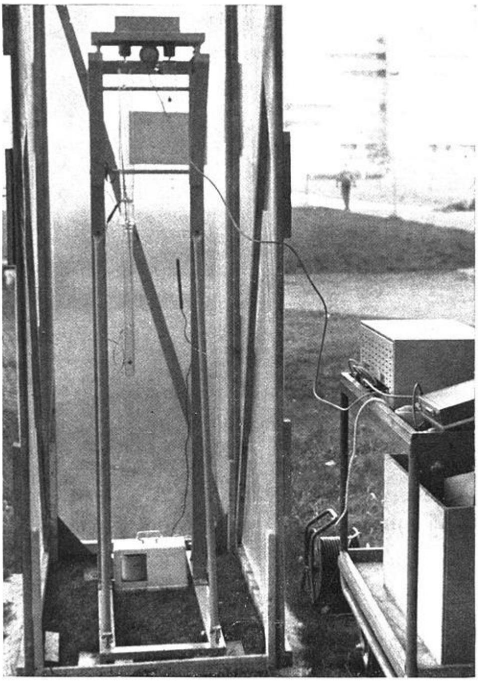

Fig. 1. Measuring system (after removal of insulating material, tube of evacuation etc.) with glass tubes, control box and additional electronics (strip chart recorder, digital voltmeter, additional filtering equipment etc.)

feed-back-system of the balance. The inductive read-out-system used for nulling the measuring system yields relative accuracy of the order of $\pm 10^{-9}$ when the temperature is kept constant within ± 0.01 °C which is easily achieved by modern thermistors and electric heating as used in gravimeters. In a well sealed or evacuated tube within a well insulated box variations of buyoancy, fiber length, volume of small masses (of gold etc.) etc. are negligible so that field work is feasible.

Perturbations by thermodiffusion as, e.g., the Knudsen effect, as well as corresponding disturbances are dodged whenever instead of perfect vacuum a constant slight air (or CO_2)-pressure exists in the tube. Absolute gradiometry is feasible when the weighted mass is determined with a relative accuracy of the order of $\pm 10^{-4}$ or $\pm 10^{-5}$. Relative gradiometry is feasible when the unknown mass is kept constant and the apparatus is calibrated against a laboratory instrument. As the vertical gravity gradient is of the order of

$$-0.31 \text{ mgal/m}$$

(where 1 mgal $= 10^{-3}$ cm/sec^2) measuring weight differences of about $\pm 10^{-7}$ grams yields the above mentioned accuracy in vertical gradients. Using the damping effect of the "not perfect" vacuum slight centrifugal and similar forces are checked by precise observations of the damped fiber-oscillations through a window in the tube. Presently available electronics do permit output of sufficient linearity for those measurements. Electrostatic perturbations are avoided by using metallic tubes instead of glass tubes. The shift of the mass from one level to the other is done automatically by a fork-system. By recording the output of the balance for a time span of about 20 to 30 minutes random perturbations can be averaged out. Wind and other environmental effects can be dodged by setting up the apparatus in a tent. In general, the balance was found to behave in field work like a long-period seismograph. The whole electronics are operated by battery power so geodetic and geophysical field work in open air is indeed feasible. The time necessary for observing at one station is less than the time necessary for observing the horizontal gradients by torsion balances. Potentialities of balance gradiometers are within the 3 Eötvös accuracy or even better.

Moore and Farrell (1970) have described difficulties and improvement of a capacitance transducer used together with an electrostatic force transducer (Weber *et al.*, 1966, Block *et al.*, 1961) in a LaCoste and Romberg feed-back gravimeter where quadratic terms arise. With inductive read-out-system where the torque of a magnetic coil is used in the feed-back-system serious linearization problems do not arise. As the measured quantities do not depend on time the dynamic behavior is not of basic interest.

As the resonance frequency of the apparatus is outside of the main frequency range of microseism and since we are only interested in the zero frequency part the electronic read-out-system with low time constant does not imply any technical difficulties. The accuracy of the feed-back-system and of the electronic output is basicly a problem of costs; a relatively simple system yields ±1 microgram. The inductive read-out-system where variation of output voltage is proportional to the weight difference and to the torque of the magnetic coil is consequently simpler than feed-back-systems having capacitance transducers with electrostatic forces (Weber *et al.*, 1966; Block *et al.*, 1966; Moore *et al.*, 1971) where quadratic terms are dominant as applied in gravimeters.

Mechanical vibrations imply one-sided centrifugal forces which are, however, less disturbing than was first anticipated. One sided electronic effects due to nonlinear output in case of large amplitudes were not found to be remarkable. Fig. 2 gives damped vibrations showing mainly mechanical one-sided effect where the mechanical part can be separated from any electronic one-sided disturbance. Fig. 3. shows the output as recorded on a strip chart recorder.

As the torque needed for "nulling" the measuring system is relatively small, temperature variations around the magnetic coil are not disturbing with quartz beam. Long term variations of the output as seen in Fig. 3 are partly correlated with temperature variations and partly (not fully explained) reversible features of the order of ± 0.5 μgrams.

The tape suspension used in the microbalance applied by us seems to be a reliable tool in field equipment. On the other hand, knife edge and similar supports which have long been considered as a primary error source in pendulum measurements have found partial rehabilitation by recent experiments (Graf, 1973). As the position of the knife edge does not vary much in case of feed-back measuring systems used in laboratories very high accuracy ($\pm 10^{-9}$) is now achieved with knife edge supported balances (Kochsiek, private communication).

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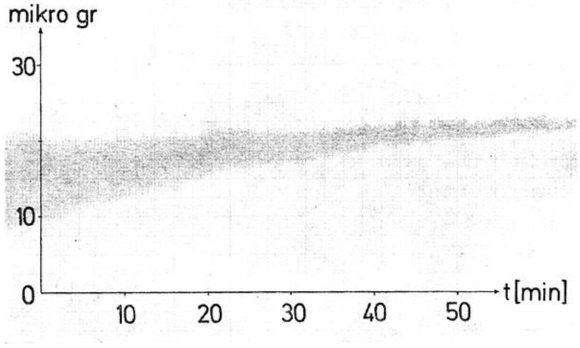

Fig. 2. One sided effect due to centrifugal force

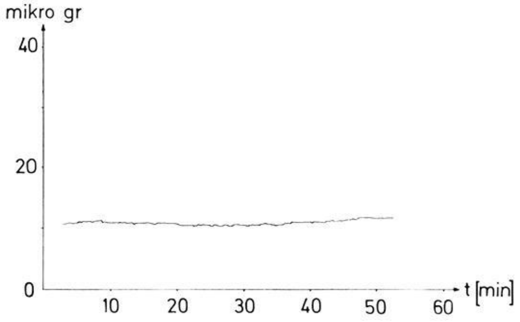

Fig. 3. Example of strip chart record

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