PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

A Technique for the Precise Calibration of Continuously Recording Gravimeters

H. D. Valliant

Phil. Trans. R. Soc. Lond. A 1973 **274**, 227-230
doi: 10.1098/rsta.1973.0047

Phil. Trans. R. Soc. Lond. A. **274**, 227–230 (1973) [227]
Printed in Great Britain

A technique for the precise calibration of continuously recording gravimeters

By H. D. Valliant
*Gravity Division, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Canada**

A prototype device to calibrate recording Earth tide meters of the TRG-1 variety has been constructed and demonstrated to operate satisfactorily. The calibration is effected by subjecting the gravimeter to an external sinusoidal acceleration of approximately 3 $\mu m/s^2$. The magnitude of the applied acceleration, which is determined from a record of the gravimeter's displacement, is compared directly with the gravimeter's response. The prototype was limited to a driving frequency of 0.01 Hz. The reconstruction of the calibrator to permit operation at frequencies down to 0.001 Hz is discussed. A calibration precision of 0.1% was achieved with the prototype.

Introduction

The need for precise calibration of continuously recording gravimeters is becoming increasingly urgent for studying the response of the Earth at tidal and free oscillation frequencies. As the magnitude of ocean tide loading effects amount to about 5% of the observed Earth-tide a 0.1% calibration accuracy yields tidal loading information accurate to only 2%. Similarly, studies of the tidal effects due to the dynamic behaviour of the Earth's core require a comparison between measured and theoretical gravimetric factors accurate to 0.1%. Furthermore, a precise knowledge of the gravimeter transfer function at frequencies from 10^{-2} to 10^{-4} Hz also becomes important with the recent development of amplitude theories for terrestrial line-spectra (Ben-Menaham, Rosenman & Israel 1972).

Although techniques to monitor relative calibration with this accuracy are available, their employment has been limited by the lack of a sufficiently precise absolute calibration. The best reported calibration so far (Moore & Farrell 1970) claims a calibration accuracy of 0.3%, but is applicable only to servo-nulled instruments.

As a result the Earth Physics Branch undertook to develop a device for calibrating recording gravimeters with a 0.1% accuracy. To be a useful standard the calibrator must be universal in nature and readily reproducable. In the method under investigation an external sinusoidal vertical acceleration of tidal amplitude is applied to the gravimeter. By observing the amplitude and frequency of the displacement the applied acceleration is computed and compared with the gravimeter response. Alternately the gravimeter displacement can be compared directly with the double integral of its response. Although not employed for the measurements made with the prototype instrument, the latter method does not require an accurate knowledge of frequency and automatically corrects for distortion which is assumed negligible in the first method.

Figure 1 is a view of the final instrument as assembled for operation. A prototype similar to the instrument shown in figure 1, but less refined was constructed initially. The gravimeter is hung from the beam of a long period seismometer which is supported by a triad of parallel zero-length springs. By tuning the seismometer to a natural period of around 5 s the

* Contribution no. 439.

motion of the gravimeter is controlled by a 1 N force generated electromagnetically. The purity of motion is determined by the quality of the oscillator employed and the uniformity of the magnetic field. A commercially available oscillator with harmonic distortion as low as 0.01 % at frequencies as low as 10^{-3} Hz is employed. Although beyond the manufacturer's specifications this oscillator has been found to provide a useful signal at frequencies as low as 1.5×10^{-4} Hz. Unwanted modes of oscillatory motion are removed by the use of oil filled dash-pots.

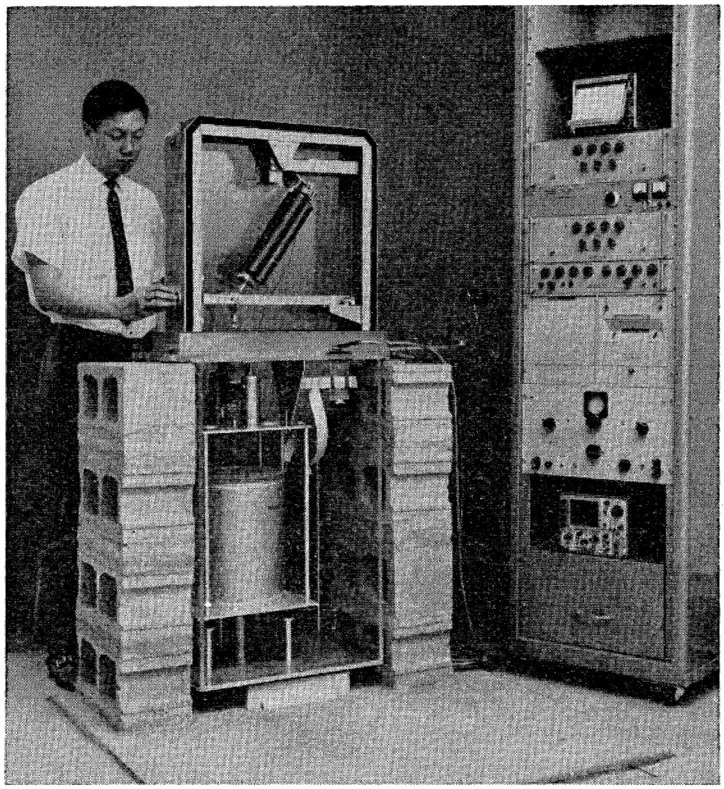


FIGURE 1. The final version of the calibrator being assembled for operation. A gravimeter (similar to TRG-1 gravimeters) is suspended from the beam of a modified long period seismometer.

ERROR SOURCES

(a) *Measurement of gravimeter displacement*

In the present arrangement the displacement is measured with a Photo-Pot† with an accuracy of 0.1 %. This error source is not a limitation as its contribution can be made negligible by employing interferometric techniques. Such a degree of sophistication is not felt to be necessary.

(b) *Measurement of the driving frequency*

Errors from this source are also made negligibly small by using a precision electronic counter to measure period.

† Registered trademark Gianni Corporation.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

(c) *Errors in the gravimeter recording system*

All data are recorded digitally with an accuracy of 0.05 %.

(d) *Effect of the Earth's vertical gradient*

The effect of the local gravity is to add algebraically a small in-phase component due to the gravimeter's displacement through the Earth's field. As this displacement is about 5 cm the magnitude of the effect amounts to 0.15 μm/s² or 5 % of full scale. Therefore a knowledge of the vertical gradient accurate to 2 % is required to correct for local gravity. It is expected that the vertical gradient can be measured to an accuracy of at least 2 % by a linear combination of observations at several frequencies in the range where the gravimeter response is flat.

(e) *Retrieval of the signal*

Retrieval of the signal from background noise represents the basic limitation in accuracy. Background noise is reduced as much as possible by careful mechanization, which includes exclusive use of non-frictional hinges to avoid stiction and oil-dampers to remove horizontal and torsional oscillations. The signal is then recovered by a least squares fit to the equation:

$$z = A + Bt + C \sin (wt + \phi). \tag{1}$$

The retrieval technique which has been tested with results from the prototype device is found to provide 0.01 % accuracy.

(f) *Earth tides*

While negligible at the 0.01 Hz driving frequency used with the prototype the effect of Earth tides at longer periods becomes appreciable. This error source may be minimized by observing during relatively flat portions of the Earth-tide cycle and by including higher order time terms in equation one.

Results

Results so far have been obtained from a prototype device intended only for a feasibility study. The lowest frequency available for the initial test was 10^{-2} Hz. Tests at five different amplitudes are plotted against the gravimeter output in figure 2. The amplitude response of the gravimeter

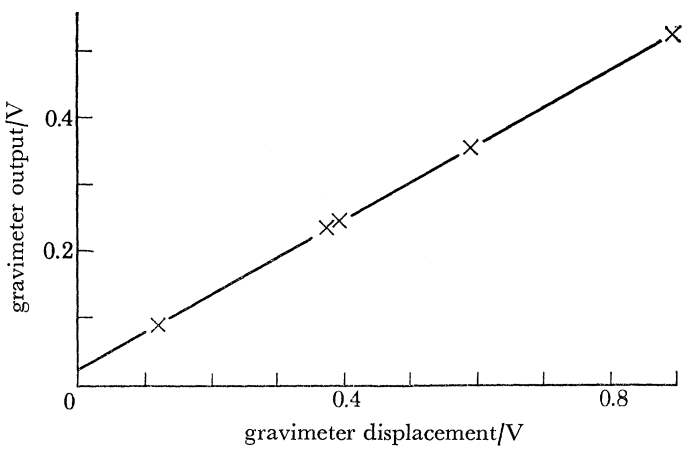


FIGURE 2. Results with a prototype calibrator showing linearity of the gravimeters response with amplitude.

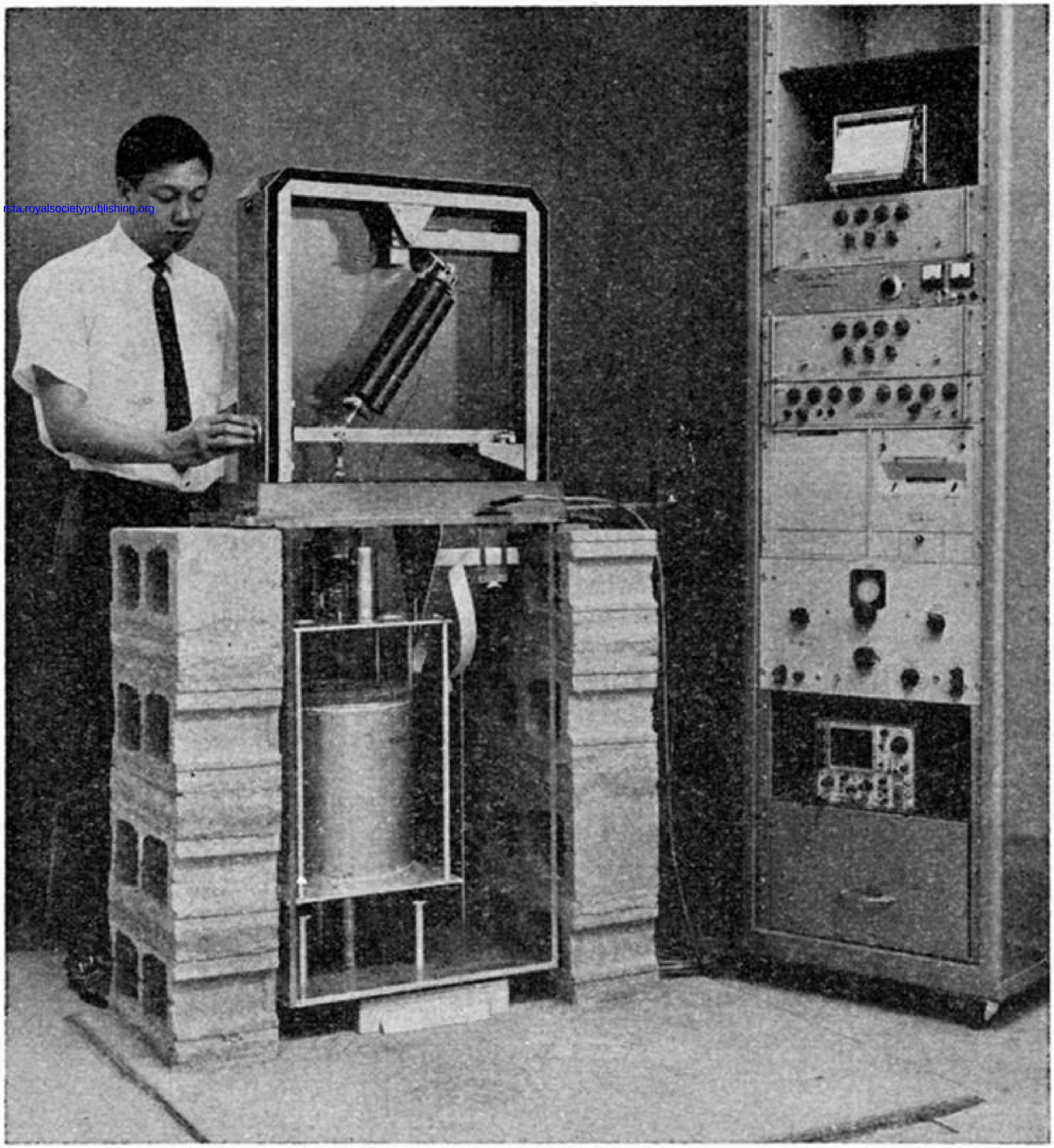
is found to be quite linear (correlation coefficient 0.99) with the slope (calibration constant) defined to better than 0.1 %. The non zero intercept is believed due to translational motion of the seismometer hinges; this fault has been corrected in the final model. Phase response is also obtained so that the complete transfer function may be determined for frequencies between 10^{-2} and 10^{-3} Hz. Results from measurements with the prototype indicate that a calibration accuracy of 0.1 % is readily available. When combined with static methods the dynamic technique will provide calibration at frequencies which bracket the band of tidal frequencies.

References (Valliant)

Ben-Menaham, A., Rosenman, M. & Israel, M. 1972 *Phys. Earth Planet. Int.* **5**, 1–29.
Moore, R. D. & Farrell, W. E. 1970 *J. geophys. Res.* **75**, 928–932.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES



IGURE 1. The final version of the calibrator being assembled for operation. A gravimeter (similar to TRG-1 gravimeters) is suspended from the beam of a modified long period seismometer.