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A sensitive water-level tiltmeter

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A sensitivity approximately equal to that of a horizontal pedulum is obtained in a 50 m long water-level tiltmeter. A crapaudine-type calibrating device is described.

Introduction

Development of the tiltmeter described here was prompted by the need in 1969 to observe experimentally tilting of the crust due to the Earth and ocean tides at several points throughout Britain, and the need at about the same time to monitor secular tilting due to loading of a dam reservoir in Canada. Attempts to carry out these programmes with horizontal-pendulum tiltmeters were unsuccessful, basically because of the short base line and lack of zero stability in this type of tiltmeter. Both these difficulties are overcome, at least in principle, by water-level tiltmeters, but it was uncertain whether the high sensitivity required in tidal and secular studies could be achieved. In order to investigate this a visually read, water-level tiltmeter of the Eaton (1959) type was modified to use displacement transducers of the differential-transformer type and tests were carried out at high sensitivity. In the light of these preliminary tests a new tiltmeter was built and recently tested in an underground site near Ottawa. This new tiltmeter is described here.

Description

The principal features of the tiltmeter are illustrated in figure 1. Stainless steel was chosen for the material of the float because it provides a permanent surface and is not wetted by water or most other fluids. The preliminary tests had shown that the angle of contact of the water on the float is most stable when the water does not wet the float. This stability is important because the contact angle determines the capillary force acting on the float. The float is of large diameter (12.5 cm), also to minimize capillary effects, and the bottom surface is inclined to prevent the trapping of air bubbles. A large mass is used (850 g) because a low natural frequency of the float in heaving motion seems to favour free movement of the armature in the transducer core; perhaps because of greater excitation by ambient noise. The tiltmeter vessels are of brass which was cast as one piece, with special care taken to avoid a porous surface, and sealed with a baked-on fluorocarbon coating after final machining.

The transducer is fitted to the bottom of the vessel which is only 1.5 mm thick and can be deflected upwards elastically by a threaded shaft bearing on a hub located at the centre of the under side in the manner indicated in figure 1. This shaft can be turned through a series of precision gears by a multi-turn dial installed on the side of the vessel. This permits trimming the position of the transducer armature through a range of about 0.1 mm, either for the purpose of matching the two transducers to each other or as a secondary calibration of the transducer sensitivity.

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* Contribution no. 440.

The primary means of calibrating the tiltmeter system is through a change in the volume available to the fluid. This is accomplished by a device patterned after the crapaudine (Verbaandert & Melchior 1958) used to calibrate horizontal pendulums. It consists of two sealed disk-shaped chambers having a diameter of 20 cm and separated by a 1.5 mm thick wall. One chamber is connected to the fluid line of the tiltmeter system; the other chamber is filled with mercury from a reservoir supported above the chamber. The wall separating the two chambers is caused to deflect slightly by varying the height of the mercury reservoir. This varies the volume available to the hydrostatic fluid and causes a corresponding variation in water level in each vessel. The volume displaced in this manner can be measured precisely by arranging the apparatus to produce the same volume change in a small diameter pipe and measuring the deflexion of the meniscus; this calibration has not yet been attempted however.

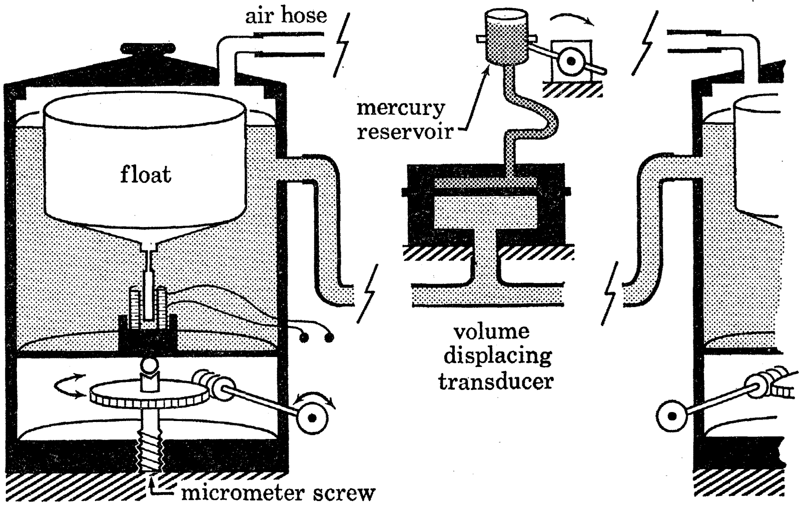

Figure 1. Illustrating design features of the water-level tiltmeter.

The tiltmeter was installed in a 50 m long adit in an underground site near Ottawa in March 1972. Each vessel was placed on a stainless steel shelf secured to the wall of the mine at three points by bolts and expansion nuts. The shelves were designed to tolerate misalinement of the mounting studs and to permit levelling adjustments to be made without distortion due to stress. The water line was kept as level as possible by supporting it along a taut steel wire.

PERFORMANCE

Before beginning the recording of tilt it was intended to investigate the response of the system to tilting at various frequencies. This was to be done by mounting the mercury reservoir on the end of a lever which could be rotated to raise and lower the reservoir sinusoidally at any given frequency. The site, however, proved to be unexpectedly noisy and the artificially produced signal, which was only a fraction of that produced by the Earth tide, could not be accurately measured. A step change, on the other hand, caused by raising and lowering the reservoir manually over a vertical range of 1.2 m, produced a float displacement of about 5 μm which could be repeated with an accuracy of better than 1 %. A sample record showing the effect of this step change at each vessel is reproduced in figure 2. This signal could not be used to calibrate the system, since the volume displacement constant for the crapaudine device has not yet been determined but it did facilitate the precise matching of the sensitivities of the two transducers. As a temporary measure the micrometer adjustments at each vessel were used to calibrate the sensitivity of the system.

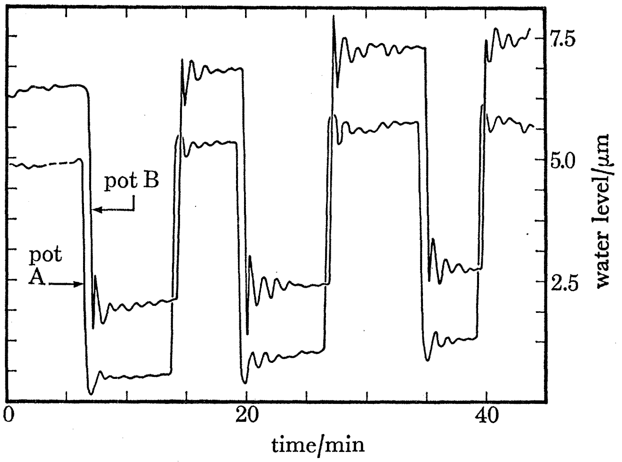

Figure 2. Water level change at vessels A and B due to vertical displacement of mercury reservoir through range of 1.2 m.

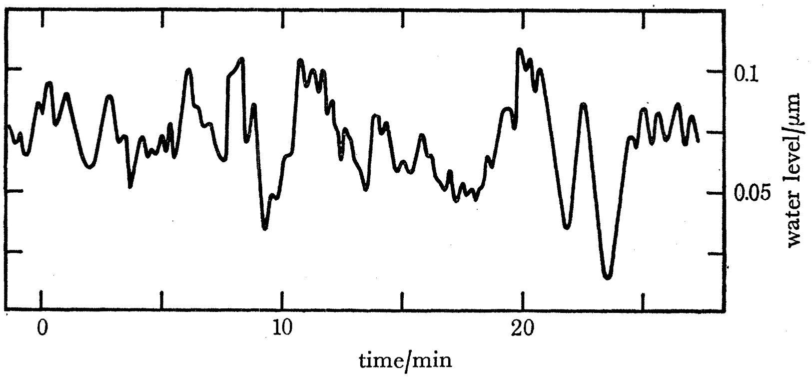

Figure 3. Typical water-level variations observed at either vessel.

The noise referred to above is demonstrated in figure 3 which is a reproduction of a typical output from one transducer. The outputs of the two transducers are largely coherent and of opposite phase, indicating that the noise is due to real tilting of the system rather than independent random motion of the floats. Figure 3 demonstrates too the absence of sticking or friction effects which were observed in the preliminary tests of the modified Eaton-type tiltmeter.

A record of the difference between the two transducers outputs is reproduced in figure 4. No drift or tares are evident in the few weeks of measurements recorded to date.

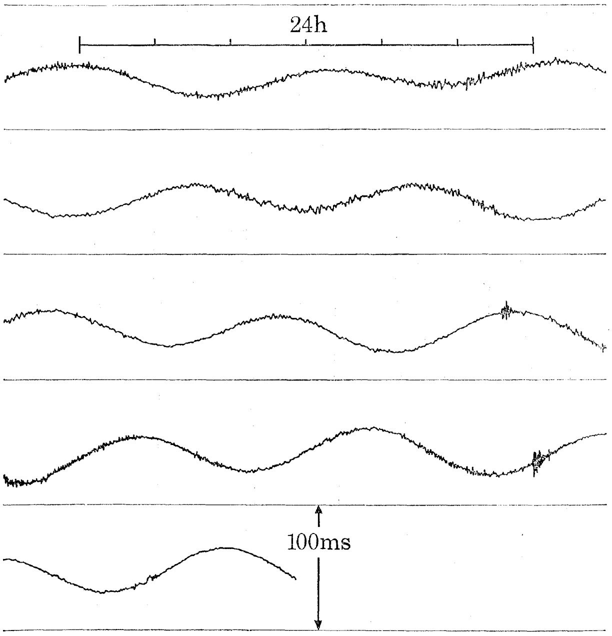

Figure 4. Tiltmeter record for Ottawa, 20 April to 25 April, 1972. (Difference in water levels of vessels A and B.)

Discussion

The tiltmeter appears to be free of systematic effects which would result in drift and the usable sensitivity is approximately equal to that of a short-based tiltmeter. The crapaudine device intended to be used for calibrating the tiltmeter, and for testing its dynamic response, is an effective but low-signal device which should be used with both tiltmeter vessels placed side-by-side on the same pier. Although water was used for the tests it may not be the ideal fluid because of its high vapour pressure and surface tension. An apparent leak observed in the tests may be due to evaporation from the water surface and subsequent condensation on the walls of the vessels and on the floats. This might be avoided by using a low vapour pressure, low-viscosity silicone liquid.

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References (Bower)

Eaton, J. P. 1959 *Bull. seism. Soc. Am.* **49**, 301–306.
Verbaandert, J. & Melchior, P. 1958 *Communs. Obs. r. Belg.* no. 142. (*S. Geopht.* no. 47, 114–115.)