A NOTE ON HORIZONTAL PENDULUMS.

By John Milne.

The principal object of the following note is to describe a form of horizontal pendulum which the writer finds easy to construct, and which is easy to manipulate.

Many years ago the first observations on earth pulsations and changes in the vertical undertaken in Japan were made by observing a spot of light reflected from a mirror with a bifilar suspension,—one fibre, as in the Çavendish experiment, being attached to an ordinary pendulum and the others to a fixed point. This was followed by observation through a microscope of the movements of the style of a pendulum as in the Tromometers of Bertelli and Rossi. Observations on the movements of the bubbles of delicate levels were continued for several years. The first attempt at self-recording apparatus was to discharge at intervals of a few minutes sparks from an induction coil from the end of the pointer of a pendulum-seismograph—the pointer giving a large multiplication of the movements of the same. All of these instruments yielded certain results. Next followed photographic registration of the movement of the spot of light reflected from a small mirror attached to an exceedingly light and small conical pendulum. The booms of these pendulums were made of about two-and-a-half inches of aluminium wire tipped with a needle point which rested in an agate cup, and which were held up from their outer ends by a quartz fibre. Two of these instruments were arranged at right angles, but with their mirrors immediately above one another, so that they both received the same beam of light. This light came from a kerosine lamp, through a vertical slit and a lens, to be reflected back through a horizontal slit into a box. In the box, moving in most cases slowly—but several times for the purpose of making special investigations moving quickly—were photographic plates or films on a revolving drum.

Excellent results have been obtained with this form of apparatus, but the difficulty of manipulation is such that it can only be placed in the hands of trained observers and where it is possible to obtain good installation.

Not being able to fulfil these conditions, the following form of apparatus has been designed; six have been constructed, and they have required but little attention and have given satisfactory results.

The pendulum stand *A*, with its upright, which is 50 c.m. high, is of one piece of cast iron. The distance between the leveling screws working in brass sockets is 23 c.m. The back screw tilts the upright and gives the required degree of stability to the pendulum; one of the lateral screws is used in adjusting and calibrating the pendulum. It carries a pointer moving over a graduated arc. By turning it, for example, one degree, which means raising this corner of the instrument $\frac{1}{360}$ of a millimeter (the screws having a millimeter pitch), the corresponding deflection of the pendulum may be noted. The turning is done by a lever projecting from the head of the screw.

The boom of the pendulum is an aluminium tube 4 feet (120 c.m.) in length, carrying a sliding weight, *W*, and a movable point to which the supporting tie can be attached. This tie, which is of thin brass wire, at its upper end terminates with about 1 inch of untwisted silk. On the inner end of the boom there is a quartz cup which bears on a steel needle projecting slightly upwards from the base of the cast-iron stand. The suggestion that the needle should project from the stand rather than from the boom is due to Dr. Reubeur von Paschwitz. It gets over the difficulty of having anything which may be markedly magnetic in motion, and secondly, in case of violent disturbance the relative verticality of the points of support are less liable to alteration.

The instrument is adjusted so that the needle bears normally on the centre of the quartz cup, or so that the centre of gravity of the system falls about *G*.

At the outer end of the boom a stiff wire rises vertically upwards. Clamped to this at the required hight is a horizontal wire 15c.m. long, carrying a thin zinc plate *p* measuring 6c.m. by 10c.m. In the centre of this, and parallel to the length of the boom, there is a slit about .5 mm. broad and 2c.m. long. As the boom moves to the right and left this slit floats over a second slit about 5c.m. long in the lid of the box covering the drum carrying the recording paper. These two slits are at right angles to each other so that the light from a lamp reflected downwards by a plane mirror only reaches the drum as a spot.

A well defined spot, which means a clear sharp line on the photographic film, can be obtained without fine adjustment. That is to say, the distance between the film and the slit or between the stationary and moving slits may be anything between 1 and 5mm. Projecting an inch or so beyond the moving plate and attached to it is a pointer moving over a scale fixed on the cover of the box containing the clock of the recording drum. This can be inspected and the position of the boom at any time noted by looking through the glass plate at *m*.

The recording drum, on which the photograph-paper is fixed with a spring clamp, as in a recording barometer, is of thin sheet brass 5.c.m. wide and 105c.m. in circumference (some are much less). It is turned at the rate of 15c.m. per 24 hours, and a film therefore lasts one week.

The clocks, which are of the American type intended to run 8 days, have fitted to the slowest moving arbor four wheels the last of which turns a disc with slots round its edges, once a week. The recording drum, which can be dropped into its bearings, carries a large crank. When in position the clock is slid in a groove until one of the slots catches the outer end of the crank arm; after this the cover is put over the clock and drum and the whole is pushed on grooves into the end of the case covering the pendulum.

Hollow wooden drums, which are easily driven by the clock-work, have a tendency to warp, and this may result in a want of uniformity in the motion.

Brass drums in the damp atmosphere of a cave in a month or so tend to rust, and this rust may act upon the photographic film to such an extent as to render it illegible.

Up to the present ordinary kerosine lamps have been used, but as they require attention at intervals of from 8 to 12 hours they are being replaced by lamps such as are used in magnetic observations, burning benzine.

Every day from 12 noon to 1 p.m. the lamps are removed and a reading is taken, so that time intervals are marked on the photographs and scale values are obtained.

It does not seem necessary that the boom should be made of aluminium, as I obtain what appear to be equally satisfactory records with booms of brass or even wood. The most delicate pendulum I have has a boom made of varnished bamboo with brass fittings. It is about 5 feet in length and when last rated had a period of 55 seconds. I say last rated, because I find that this pendulum, like all others I work with, changes its period and therefore its sensitiveness from week to week. I notice that this source of error when computing results is also found in the infinitely better constructed and better installed apparatus used by Dr. Rebeur von Paschwitz.

When the pendulum has its 55 second period, one millimeter deflection on the photographic plate is equivalent to a tilt of 0.08 seconds of arc. With this degree of sensitiveness a 14lb. weight placed on the column, which is old and massive, at a distance of 2 feet from the instrument, causes a deflection of .5 mm. My weight on the floor *at the outer end* of the boom produces no visible effect.

In this condition the pendulum is, however, often too sensitive, as it will, from time to time, wander an inch or so to the right or left of its mean position, and the spot of light fall outside the film. A sensitiveness of 1 mm. motion per 0".5 arc is usually quite sufficient, and I do not think that apparatus like that of Wolf, Abbadie, Darwin, or Paschwitz capable of recording tilting of from $\frac{1}{100}$ to $\frac{1}{300}$ of a second could be used on the alluvium of Tokyo even when installed on a concrete bed underground.

Such apparatus might however, be used on the solid rock which crops out round the Tokyo plain.

An attempt to test the accuracy of one of the horizontal pendulums was made by placing it on an iron plate resting on a plank 18" broad $1\frac{3}{4}$" thick, which in turn rested on supports near its ends six feet apart. It was then adjusted so that trials with the test screw indicated that turns of 10° gave an average deflection of 11.5 mm.

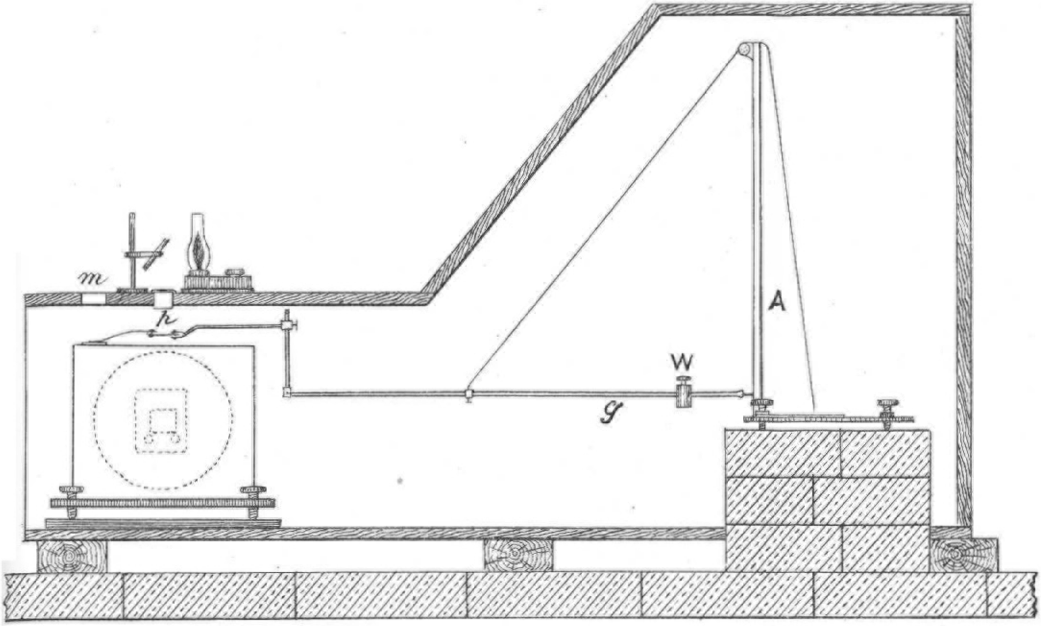
Side by side with the pendulum, a transit having a good telescope was placed, and this read on a scale fixed on a brick wall at a distance of 720 feet. The supporting plank was then loaded at its middle until the telescope showed a deflection of 14 in. on the scale and the pointer of the pendulum moved 93 mm. From this it seems that the pendulum indicated a tilt of 1 in 562, while the angular tilt of the telescope was 1 in 616.

These are the means of a series of experiments, and assuming that the readings through the telescope were correct then the pendulum indications are about 10 per cent. below their true values. On the other hand, assuming that the readings through the telescope were one inch too small, and it was difficult to read within that quantity, then the pendulum indications are 2.3 per cent. short of their true value. A great source of error no doubt resides in the test screw of the pendulum.

The instrument described will be recognized by those engaged in similar investigations as coarse in construction, roughly approximate in its records, and because it is large as being in all probability subject to convection currents, unequal heating in its parts, and other interferences. In spite of these objections, I find it satisfactory. It is cheap, easily put up to read from 1″ to 0″.5, easily worked, while the light is near the film and therefore in the best position to use with ordinary bromide paper.

With more delicate apparatus, on the Tokyo plain at least, no matter what the size of the foundations might be, the result of my experiments shew that such instruments continually require readjustment in order to keep the light on a film of managable breadth, while if installed on the rocks in the mountains I fancy that owing to earthquakes or the gradual yielding of the column that there would be a constant change in the meaning of the deflections. In two of my pendulums I notice that sometimes they gradually become more sensitive and sometimes less sensitive.

The columns I am using underground are of brick, 2 ft. high and 2 ft. square, put together with pure cement. On the top of these, at first, I placed a slab of marble, but because I noticed that in a damp atmosphere there was a marked chemical action taking place between the brass screws and the stone on which they rested, the marble has been replaced by slate.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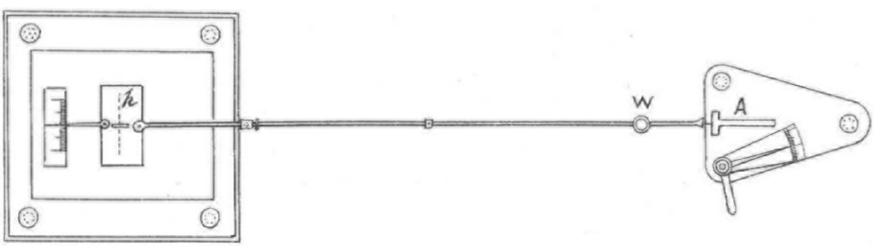
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