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Editeur : Dr Paul MELCHIOR
Observatoire Royal de Belgique
3, Avenue Circulaire
U C C L E

B elgique.

THE USE OF THE MILNE -SHAW SEISMOGRAPH FOR THE OBSERVATION OF EARTH TIDES

G.W. Lennon

(The Liverpool Observatory and Tidal Institute)

At the Brussels meeting in April 1957, when arrangements for the observation of earth-tide phenomena during the International Geophysical Year were reviewed, some concern was expressed over the large areas, continental in size, in which no observing station is proposed. Part of the difficulty lies in the fact that instruments designed especially for the purpose are both expensive and difficult to obtain; consequently it is thought that the situation could be considerably improved if some of the several seismographs which must be in existence in these areas could be used for tilt measurements. Seismographs of the Milne-Shaw type have been used for this purpose at Bidston for several years and accordingly the writer was asked to outline the minor modifications required and the manner of operation which experience has shown to be effective.

In one respect, certain advantages are to be gained in the use of a Milne-Shaw seismograph for tilt measurements, in that all parts of the instrument are readily accessible and are comparatively robust, the instrument can be dismantled and reassembled without detriment, rapidly and with a minimum of labour, and, moreover, only moderate workshop experience is required to effect the small modifications which are required. Disadvantages must, however, be acknowledged, the major criticism being the form of suspension which is of the single pivot type. Modern practice is to avoid that degree of mechanical friction which such pivots introduce, but this objection must be examined alongside the nature of the movements to be observed. Superimposed upon the tidal effects there is always present, to a greater or lesser degree, an embroidery of small movements of a microseismic nature with a period of few seconds. Experience shows that this disturbance overcomes the effect of the boom pivot and also of the pivots of the mirror linkage, at least so far as the longer period movements are concerned, and ensures that the mean position of the constantly swinging pendulum is at all times correct. In other respects, in particular sensitivity, the instrument, as will be seen, is quite adequate.

MODIFICATIONS

I. The rotation of the recording drum

The seismograph, designed for the observation of earth-movements with a period of a few seconds, is arranged to give one rotation of the recording drum in one hour. With the considerable change in the period of the observed phenomenon quite obviously some modification must be effected here. The way in which this is to be accomplished depends to a great extent upon local conditions. Geological stability, in so far as this effects drift, the interval over which the instrument must be left unattended, desired sensitivity, and the availability or otherwise of an electricity supply with a stable frequency must all be considered. At Bidston two systems have been used, one with a drum rotation of once per day and a second, once per week. The latter system is the one which has been finally adopted.

Figure I shows the Bidston modification using a synchronous electric motor drive, of clock type, through a simple two-stage worm reduction. This gives in fact one rotation in 8.8 days but this figure follows from the gears which were available at the time rather than from choice. To emphasise the simplicity of the attachment it can be stated that the gears came from a toy construction outfit, Meccano by name. With such slow rotation it is essential to eliminate backlash as far as possible. Worm gears help in this respect but it has been found essential to secure the drum to its cradle by fixed bearings. This results in little or no inconvenience in fitting the photographic recording paper. There is no lateral movement of the cradle assembly along the rack and in fact the cradle is secured in a central position in the recording box by means of a finger-tight screw.

II. The provision of a time mark each hour

Adequate timing of the record can only achieved by providing for a time mark each hour. This is most conveniently arranged by placing a low voltage lamp in the instrument case alongside the mirror linkage at mirror height. If arrangements are made for this to be lit for a short interval on the hour, then upon developing the record, each hour will be marked by a line across the width of the chart. In order to ensure that the lines are as sharp as possible for accurate reading, the lit interval each hour should be less than 10 seconds. Again there are several ways in which this can be effected depending upon local facilities, but figure II illustrates an attachment which can be fitted to a conventional clock. This clock can be in a suitable position, some distance from the instrument,

convenient for frequent checking. In the attachment suggested, two switches are placed in series : A using the conventional hour hand spindle and B using the second hand spindle. Both switches make use of flexible strips, marked a, b, and c, preferably of insulating material, thin plastic being the ideal. Switch A should be adjusted so that contact is made for a period less than a minute whereas the overall period of contact can be adjusted precisely to the second by fixing the length t in switch B.

III. The adjustment of the recording illumination

With the slower movement of the photographic paper past the lens slit, it will be necessary to reduce the illumination considerably. The cylindrical lens attached to the lens box is designed merely to concentrate the light and so is no longer required. Moreover, unless the lens is in perfect adjustment considerable trouble is caused in obtaining an even hour mark. It has been found advisable to remove the lens completely while retaining the lens box with its slit. Even so it will be necessary to further reduce the illumination, preferably with a dimming resistance in series with the lamp. Provision should be made to switch out this resistance when attending to the instrument, in order to check the position of the light spot on the recording paper.

IV. The introduction of a scale

Although by no means essential, it is of considerable assistance if a centimetre scale is drawn on a thin strip of celluloid fixed to the lens box between the slit and the drum. This has the effect of putting centimetre marks on the hour lines which are invaluable in reading off the records. Their use will automatically eliminate any distortion in the paper during photographic processing.

V. Efficiency

It is very important that the instrument should be functioning with maximum efficiency. The boom point should be kept sharp and the agates clean. Great care should be given to the points in the mirror linkage. If the iridium points are old or worn, it has been found successful to replace these by sapphire needles of gramophone type. The overall efficiency can be tested by swinging the pendulum and noting the ratio of the range of one swing to the subsequent one. This ratio should be small and not greater than 1.05:1 when the pendulum is undamped.

GENERAL REMARKS

MOUNTING

Pillars, unless they have been standing for a number of years are inclined to be unstable, introducing spurious drift and sudden tilts resulting from minute temperature and chemical changes in the structure. Modern practice is to mount instruments designed for earth-tide observation directly upon the rock, perhaps surrounded by a narrow trench filled with loose sand. It is possible to set up the Milne-Shaw in this way, but if a pillar is to be used it should be noted that an earthenware pipe of suitable diameter, say 3ft., capped by a slate slab has long been found to be the most stable.

CALIBRATION

The method of calibration by means of imparting a known tilt to the frame of the instrument through a fine screw, leaves much to be desired. It is unreasonable that the calibrating screw should be made to support the whole weight of the instrument during the operation, and experience has shown that some distortion of the metal does occur, affecting the results. When the instrument is at operating sensitivity, considerably outside the range for which it was originally designed, it becomes somewhat unstable from a calibration point of view, so that it is highly desirable to devote great care to the determination of the fundamental law of the pendulum before putting it into operation.

In this task every assistance is more than welcome and the attachment illustrated in figure III is suggested as a more efficient means of rotating the calibrating screw smoothly through the infinitely small steps required with a minimum of backlash trouble. The attachment originally provided in the instrument is barely adequate for the purpose.

It is helpful if slight damping be applied during this operation, of the order of 1.4:1. With this degree of damping the pendulum is reasonably steady for the actual calibration while it is still possible to determine its period. The damping can be retained at this level later for recording purposes.

Calibration should begin with a pendulum period of the order of 10 to 12 seconds, in which range results can be regarded with some confidence. The pendulum period should be increased in steps at least up to the operating sensitivity, measuring damping ratio and damped period carefully at each stage along with the calibration. The damping ratio is obtained

by setting the pendulum in motion by means of the solenoid and noting the turning points on the centimetre scale. The ratio of successive amplitudes, or more conveniently, successive ranges, is calculated and a mean value taken. For the period, with the suggested degree of damping, one should deflect the pendulum by 5 cms. or so whereupon two complete oscillations should be timed beginning and ending at the mean position. This should be repeated several times both at the commencement and at the end of each calibration stage. For each calibration it is essential to work uniformly by tilting equally in both directions to combat the distortion mentioned earlier. It has been found advisable to tilt in small steps of 0·2" at a time successively in one direction, differencing all pairs of values which are five readings apart, to give the displacement for a 1" tilt. In this way any irregularity is immediately apparent. Before reversing the direction it is essential to ensure that backlash is taken up and also that distortion is freed, or alternatively maintained at a steady level, by making minute tilts until the light spot satisfactorily follows the movement of the screw.

Figure IV shows the calibration of one of the Bidston pendulums together with a least squares fit of the separate results to give the fundamental law. It will be noted that here the plots are referred to the square of the free period of the pendulum to give a linear law. A small correction is required to the damped period in order to obtain the free period, by the application of the factor μ.

$$\mu^2 = \frac{1}{1 - 0{\cdot}5372L^2}$$

WHERE L = log. to base 10 of the damping ratio

During subsequent operation it is merely necessary to make a weekly check of the pendulum period in order to determine the sensitivity of the record.

SENSITIVITY

It must be acknowledged that unique conditions exist at Bidston where, due to marine loading, the amplitude of the tidal effect is of the order of 0·1". Here it is the practice to work with a pendulum period of approximately 17 secs. which gives a tidal range on the record of nearly two centimetres. At other sites the tidal effect will normally be much less, perhaps only of the order of 0·01", but to counter this it is possible to increase the sensitivity considerably where local drift allows. The Bidston

pendulums have been operated quite successfully at periods of 23 to 24 seconds giving a 60 % increase of sensitivity and there is every reason to suppose that even further increases can be made with advantage in certain cases. Sensitivity should not be the cause of concern for it is interesting to note that with careful reading, records have been successfully analysed where the recorded effect was of the order of only 0·1mms. in amplitude. In such cases, a clean trace is all-important and assistance in achieving this can be had by increasing the damping and ensuring that illumination is at a minimum.

There is ample evidence to confirm the view that the lack of a specially designed instrument presents no bar to participation in the programme of earth-tide observation during the International Geophysical Year where a discarded seismograph of the Milne-Shaw, or indeed of other horizontal pendulum types, is available. With minor modification and careful application, such instruments could be given a new lease of life and provide results of great significance in this field.

Station HOHER LIST

ALLEMAGNE R.F.

Eifel Univ.Sternwarte

Latitude 50°10' N
Longitude 6°51' E
Altitude
Profondeur cave 1 à 2 m

Adresse Postale

Institut für theoretische
Geodäsie der Universität
Meckenheimer Allee 172
BONN
R.F. Allemagne

Directeur Prof.Dr. Ing. Helmut WOLF

Station temporaire

Equipement

1 gravimètre Askania GS11 avec enregistreur automatique.

Station NEUNKIRCHEN

ALLEMAGNE R.F.

	pendules horiz.	gravimètre
Latitude	50°47' N	50°46'N
Longitude	7°56' E	7°60'E
Altitude	221 m	360 m
Profondeur cave	140 m	

Adresse Postale.
Institut für Angewandte Géodäsie
Forsthausstr.151
Frankfurt a.M
Rép.Féd. Allemagne

Directeur Dr.h.c.Erwin GIGAS

Personnel scientifique Dr.rer.nat. Rudolf BREIN
Dr.Ing. habil. Karl GERKE

station temporaire à partir du 15 juin 1957
permanente à partir de septembre 1957

au gravimètre, toujours un mois par trimestre.

	pendules horiz.	gravimètre
Nature du sol	roche	béton
sous-sol	roche	roche

Des couches sous dévoniennes avec des failles parfois. Les stations d'observation, sans vibration par la circulation, sont situées dans un terrain peu microséismique.

Equipement.

une paire de pendules horizontaux type Zöllner
(sensibilité 0"001 (mm/5 m)

un gravimètre North-American
enregistreur photographique
vitesses de déroulement : 11,5 mm/h ou 2 mm/h
sensibilité 1 microgal.

(24-14-57)

Station TIEFENORT

ALLEMAGNE D.D.R.

Latitude 50°52' N
Longitude 10°57' E
Altitude -33 m NN
Profondeur cave 285m

Adresse Postale
Institut für Theoretische Physik
und Geophysik
Bergakademie
Akademiestrasse 6
Freiberg
Rép. Dém. Allemagne

Directeur Prof. Dr. W BUCHHEIM

Personnel scientifique Dipl. Geophys. G. UHLIG

station en fonction pendant l'A G I
début des observations projeté pour le 1/VIII/1957

sol et sous-sol : sel (mine de potasse)

Equipement:

une paire de pendules doubles type Lettau
(aluminium et laiton, fils d'acier au tungstine)
sensibilité 0"001/mm pour une distance à l'enregistreur
de 3 m.

(s) Prof. Dr. W. Buchheim (24-IV-57)

Lettre du Prof. Louis B.SLICHTER ,Director INSTITUTE OF GEOPHYSICS
Los Angeles 24,California
(UNIVERSITY OF CALIFORNIA)

au Dr. Melchior en date du 10 avril 1957.

Extrait: Enclosed for your information is a list of tentative locations for our earth-tide stations, outside the U.S.A., for the International Geophysical Year. We are expecting to receive a second La Coste Romberg Gravimeter during next July, and thus will plan to operate two instruments. In addition to the stations listed exterior to the U.S., we are planning to make observations at five or six stations in the United States, including Inyokern, California, Austin, Texas and Geneva, Wisconsin (the latter because of Michelson's tilt-measurements there).

Id. lettre du 14 mai 1957.

Extrait: Enclosed, for your information, and perhaps comments, are proposed timetables for our I.G.Y. Earth Tide Program. This list includes Saigon, Bahrein and Istanbul as additional stations and omits Japanese stations.

Observer: Ronald Forbes

Wake Is.	20 july	- 29 august	1957
Manila	16 sept	- 11 nov.	1957
Saigon	18 nov 1957	6 jan.	1958
New Dehli	13 ,jan	7 march	1958
Bahrein	14 march	5 may	1958
Istanbul	9 may	27 june	1958
England	3 july	11 août	1958

Observer: Ed .Kraut

Bermuda	14 sept	- 2 nov	1957
Azores	9 nov	- 27 déc.	1957
England	3 jan	- 24 feb.	1958
Rome	1 march	- 17 april	1958
Bukavu(Belgian Congo)	28 april	- 16 june	1958

In each station 1°) set up gear and run for one week
2°) 31 days observations.

SEISMOLOGICAL LABORATORY
220, North San Rafael Ave.
Pasadena, California

May 21, 1957.

Dear Dr. Melchior,

The following is a list of the extensometer stations of our network and their characteristics:

1. Dalton Canyon

   Coordinates 34° 10.23' N, 117° 48.55' W.
   Equipment (a) micrometer microscope for secular strain, (b) ink writting recorder for tidal strain and seismic waves with recording speed of 0.75 inches/hr. (1.9cm) and sensitivity 1 mm = strain of 3.7×10^{-10}.
   Length of fused quartz tubing 24.08 meters.
   h = 523 meters.
   Direction W 13.5° N.

2. Isabella

   Coordinates 35° 39.78' N, 118° 28.39' W.
   Equipment same as Dalton.
   Length of fused quartz tubing 30 meters.
   h = 835 meters.
   Direction N 40° W.

3. Santiago, Chile

   Two components NS and EW.
   Equipment (a) micrometer microscope for secular strain, (b) tidal strain recorder not yet installed.
   Length of fused quartz tubing 30 meters.
   Estimated completion date November, 1957.

4. Chosica, Peru

   Tunnels now being excavated. Will consist of two components approximately 30 meters long with measuring microscopes for secular strains and ink-writing recorders for tidal strains.
   Anticipated completion date - November, 1957.

With best wishes,

Sincerely yours,
Hugo Benioff
Professor of Seismology

(65) H. de CASTRO — Variaciones temporales de la pesantez por influjo de la Luna y el Sol. (Ciencia X, n°1-2, pp 29-40 1950, Mexico)

(66) R. LECOLAZET — Enregistrement et analyse harmonique de la marée gravimétrique à Strasbourg (huit mois d'observation). (Annales de Géophysique sous presse)

(67) R. TOMASCHEK — Measurements of Tidal Gravity and Load Deformations on Unst (Shetlands) (M.N.G.S. sous presse)

(68) J. PICHA — Ergebnisse der Gezeitenbeobachtungen der festen Erdkruste in Brezové Hory in den Jahren 1936 - 1939. (Travaux de l'Institut Géophysique de l'Académie Tchécoslovaque des Sciences N° 42 Geofysikální Shornik 1956)

(69) K. GERKE — "Über die Wirkung von vertikalen Erdkrustenbewegungen und Deformationen der Niveaufläche auf Nivellements hoher Genauigkeit." Deutsche Geodätische Kommission bei der Bayerischen Akademie der Wissenschaften, Reihe C, Veröffentlichung Nr.6 (1953) 50 Seiten, 17 Abbildungen.

(70) K. GERKE — "Untersuchung über periodische Lotstörungen im Tidegebiet". Zeitschrift für Vermessunswesen, 79. Jahrg. 1954, S. 294-299

(71) R. BREIN "Photographische Registrierung der Erdgezeiten mit einem Gravimeter - Beitrag zur Libellenprüfung".

Deutsche Geodätische Kommission bei der Bayerischen Akademie der Wissenschaften, Reihe B, Veröffentlichung Nr.21 (1954) 18 Seiten, 9 Abbildungen (Mitteilung des Instituts für Angewandte Geodäsie, Frankfurt/M.

(72) R. BREIN " Die Schwerkraftregistrierungen.Beitrag zur Frage einer Absorption der Schwere."

20 Seiten, 9 Abbildungen. Aus der Veröffentlichung von R. Brein - H.S. Jelstrup - K. Nottarp - H.U. Sandig - R. Sigl : " Beobachtungen zur Sonnenfinsternis 1954 in Südnorwegen."
Deutsche Geodätische Kommission bei der Bayerischen Akademie der Wissenschaften, Reihe B, Nr.26 (1957)
(Mitteilung des Instituts für Angewandte Geodäsie Frankfurt/M.) (im Druck)

(73) R. BREIN "Untersuchung einiger Fehlereinflüsse bei der Messung von Schwereunterschieden und bei der Registrierung kleinster Schwereänderungen mit dem Gravimeter."

Deutsche Geodätische Kommission bei der Bayerischen Akademie der Wissenschaften, Reihe B, Nr.37, 20 Seiten, 10 Abbildungen (1957) (im Druck)

(74) G. JOBERT Influence de la structure de la croûte sur les déformations causées par les marées océaniques. (Annales de Géophysique,12,n°4,pp.290-295, 1956)

(75) H.N.CLARKSON and J.B. LA COSTE Improvements in Tidal Gravity Meters and their Simultaneous Comparison
(Trans. Amer. Geoph. Union 38 n°1 pp.8-16 1957)

(76) Colloque International sur les Marées Terrestres préparatoire aux travaux de l'Année Géophysique Internationale, Uccle 24-26 avril 1957.
(Comm. Obs. Royal Belgique n° 114, S. Géoph n°39, 80 pages , 1957)

(77) P. MELCHIOR — Discussion du procédé de Corkan pour la séparation des effets directs et indirects dans les marées terrestres.
(Comm. Obs. Royal Belgique n° 115, S. Géoph. N° 40, 1957)

(78) G.W.GROVES — Numerecal filters for discrimination against tidal periodicities.
(Trans. Amer. Geoph. Union 36 n°6 1073 1955)

FIG. I

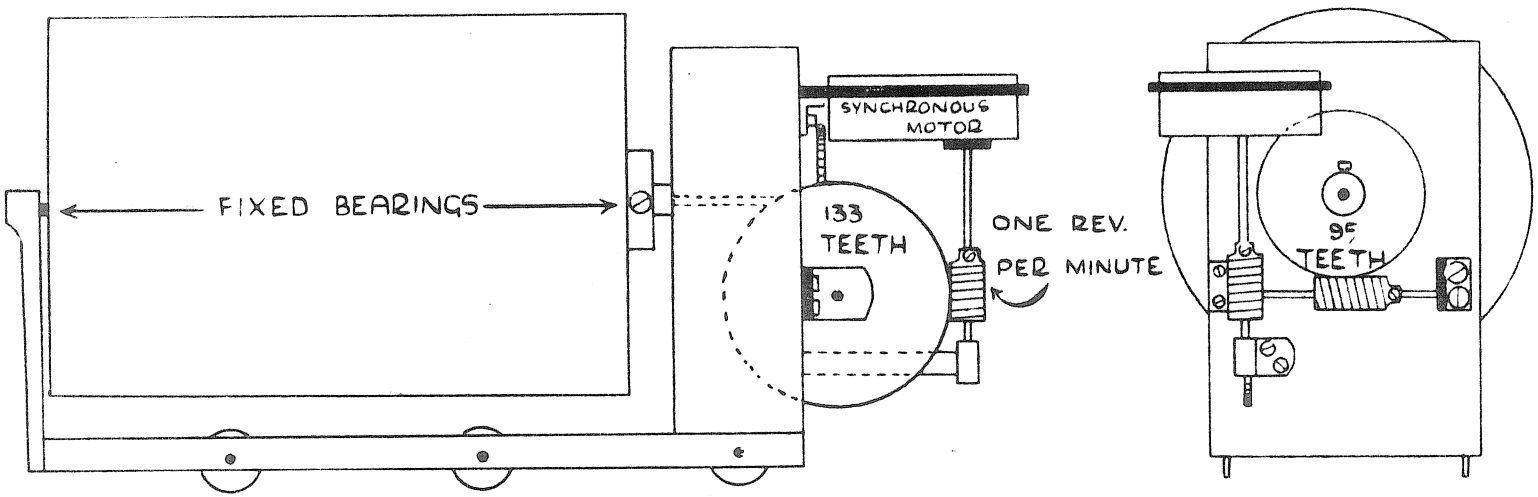
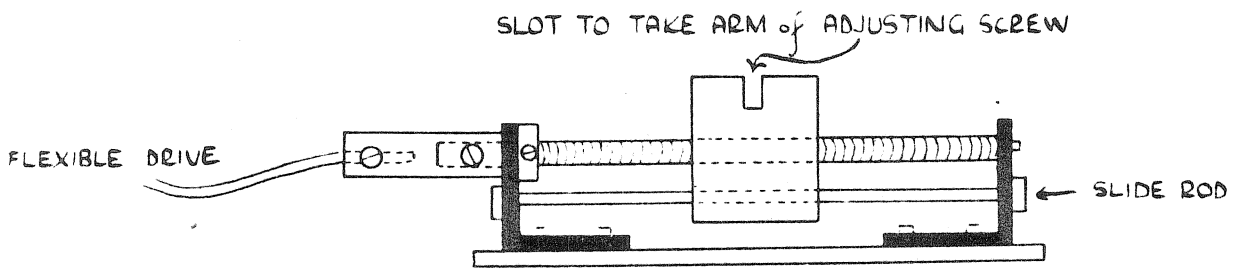


FIG III



SLIDE ROD PREVENTS SCREW BLOCK FROM ROTATING

FIG II

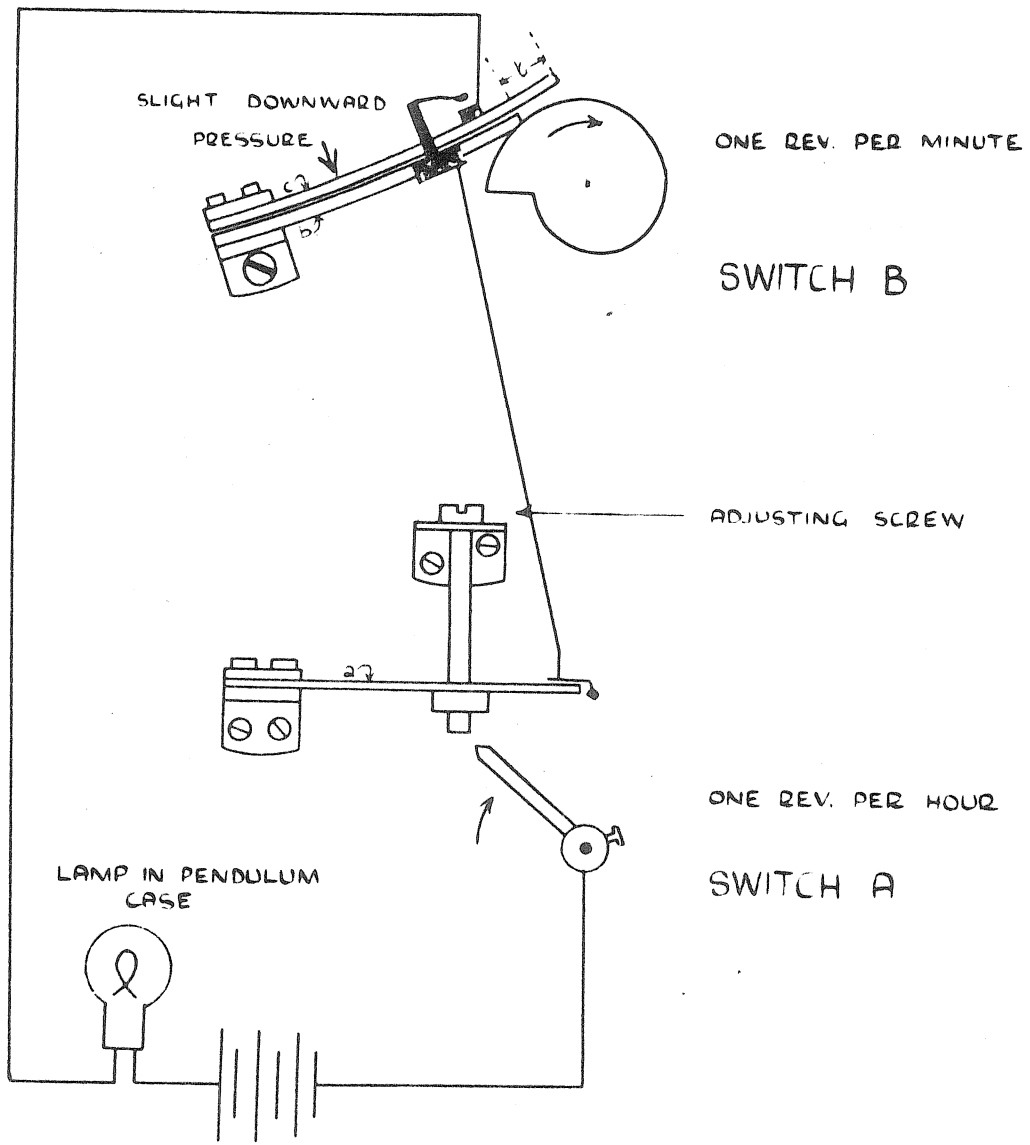
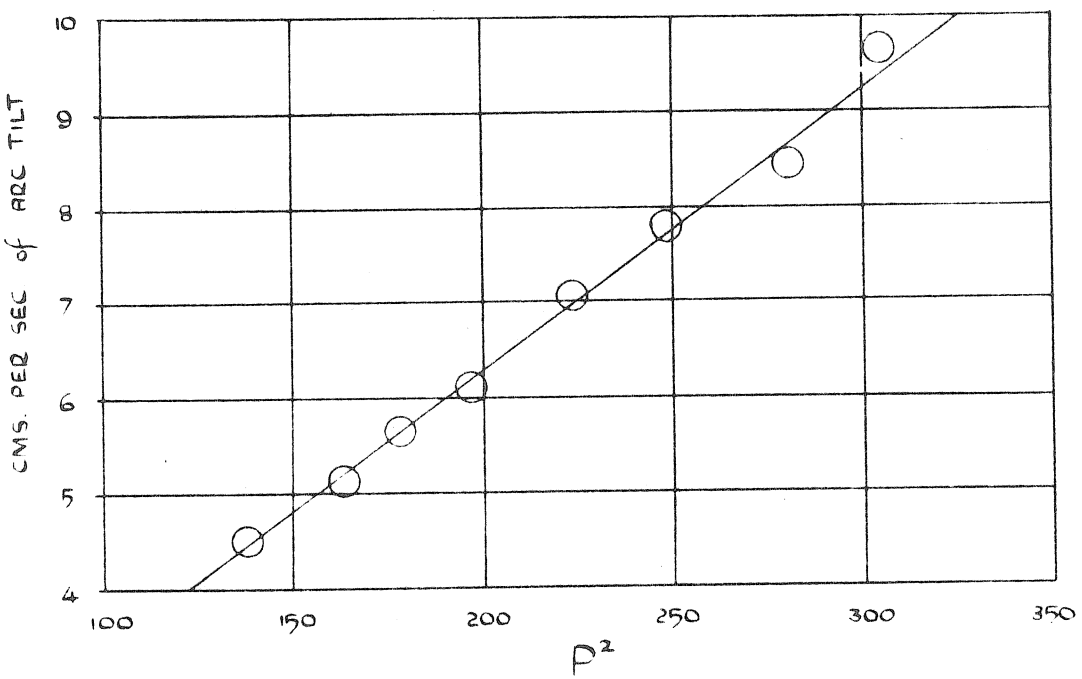


DIAGRAM of MECHANISM TO GIVE TIME MARK

FIG. IV

CALIBRATION of EAST-WEST PENDULUM, BIDSTON MAY 1957

INSTRUMENT - MILNE-SHAW SEISMOGRAPH



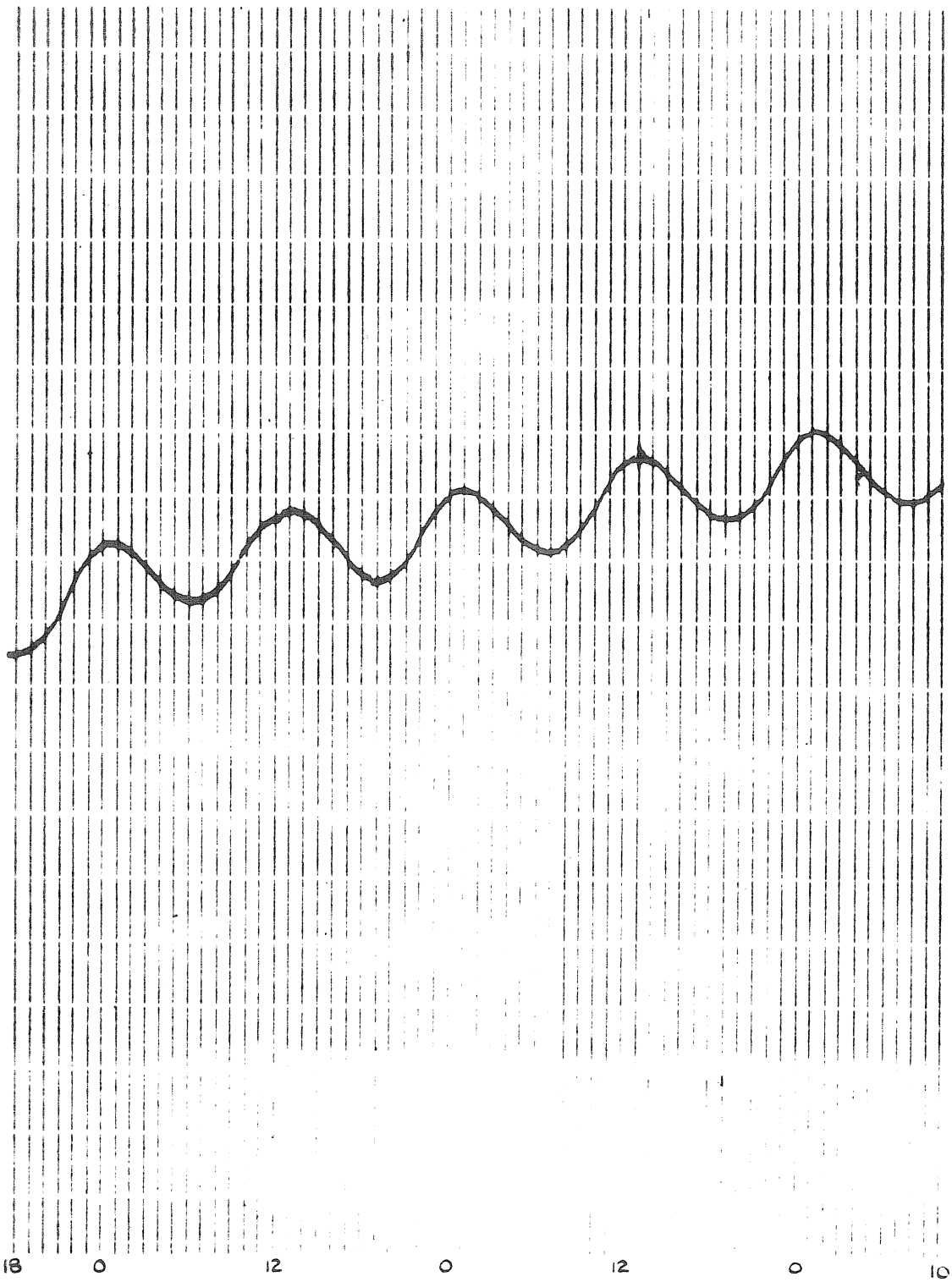
P = FREE PERIOD of PENDULUM IN SECS.

LEAST SQUARES FIT GIVES SENSITIVITY IN CMS PER SEC. of ARC TILT

$0.029525\,P^2 + 0.403$

IC V

SPECIMEN RECORD



EAST WEST PENDULUM, BIDSTON. 3rd. - 6th. MARCH 1957

SENSITIVITY:- 8.152 cms. per sec. of arc tilt.

Station
Appareil
Azimuth
Calibration

Document
envoyé aux centres
Date d'envoi

MOIS: juin 1958 TABLEAU : Ia

Feuillet: 1

heures / jours TU	0	1	2	3	4	5	6	7	8	9	10	11
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