

ON NEW PRECISION-SEISMOGRAPHS

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Introduction.

In the present paper a description of a new kind of Seismograph is given which is specially designed to produce greater precision and reliability than has so far been obtained. Modern seismometry lays great stress on the instrumental side of seismology, whereas in former times the principal research consisted in determining as accurately as possible the single moment of occurrence of the various phases.

Since the time of Prince B. Galitzin the aim of seismometry has been considerably enlarged. It has become possible to calculate the geographical co-ordinates of the epicentre of an earth-quake from the data of a single seismic station. If occasionally deviations occur, they may very often be caused by the inaccuracy of the time-distance relation, which may even be different for each centre.

A second important object of research for which Prince B. Galitzin has laid a sure foundation, is the determination of the angle of emergence of the seismic rays for all groups of longitudinal waves. From such determinations can be drawn conclusions as to the stratifications in greater depths below the crust of the earth.

Both these aims of seismometry demand a very exact mensuration of the three components of dislocation of the earth-surface at the locality of observation. Whereas the measurement of the moments of occurrence themselves depends on the sharpness of the commencements of the signals and the uniform motion of the registering apparatus, this task is facilitated very considerably by the choice of Seismographs which possess the same inherent period, the same amount of damping and the same degree of sensitiveness.

Some Notes on Seismic Registrations.

As to the sensitiveness of Seismographs, the purely mechanical registration method depends on the size of the pendulum weight, in so far as for counteracting the friction the pendulum weight must be made large when greater sensitiveness is required.

The optical registration method is not subject to this drawback, but it requires fairly long optical levers, which presuppose strong and expensive sources of light.

Combinations of mechanical and optical levers allow all desired degrees of magnification, as has lately been accomplished by Prof. Wiechert with his highly interesting Million-Seismograph. The mechanical and the optical registration methods, however, both evince a considerable drawback in their application. They presuppose a room of absolutely constant temperature. If this condition is not fulfilled, the zero-position of the Seismograph fluctuates, so that with great sensitiveness the lines of the registration-drum cross. This circumstance gives an unsightly appearance to the registrations and their utilization is thereby often rendered difficult. These criticisms do not apply to the galvanometric registration method.

An aperiodic galvanometer of the Deprez-d'Arsonval system possesses an undeviating position of rest which, if not disturbed by currents from the earth, will remain motionless for years. The infinitesimally small fluctuations of the zero-position of the pendulum are imperceptible, for which reason the distances between the lines on the registration-drum remain unaltered.

This circumstance is a very important advantage of this registration method. A second, which is of equal importance in many places, is the following. If it is desired to dispose of a very high sensitiveness for the periods of longitudinal waves, as is required in the determination of the geographical co-ordinates of the epicentre and the angle of emergence, the galvanometric method is the one which is indifferent to very short wave-periods ($< 1^{\circ}$).

It is very rarely possible to find a place for a seismic station which is altogether free from artificial disturbances. The working of engines, the movement of vehicles etc. produce effects at a distance of many kilometres, causing short periodical movements

which are recorded above the seismic registrations and which give a finely serrated character to the line. On account of the above mentioned peculiarity of the method, these serrations are very insignificant in the galvanometric registration and present no hindrance to the measuring of amplitudes and exact moments of occurrence. The most popular and obvious advantage of this method is of course this, that the registration may be accomplished in a different room from that in which the pendulum is placed, and removed from it as far as may be desired.

The objection, which is sometimes raised, that in the case of disturbances the galvanometer-coil, which represents a short pendulum, will oscillate in its own period, need not be considered in the case of registrations of distant earthquakes. The galvanometer-coil is a bifilar one or, which comes to the same thing, it is suspended by a little ribbon and only might possibly be seriously disturbed by action, if there is resonance and if the supporting parts should be subjected to regular disturbances within the period of the suspension of the galvanometer-coil, as is to be noticed sometimes in towns, in buildings affected by noisy traffic.

The question now arises what kind of suspension would be the most advantageous in the case of horizontal pendulums, the motions of which are to be registered by means of a galvanometer.

Prince B. Galitzin introduced the suspension method of Zöllner which has now been adopted in many seismic stations. This suspension is no doubt preferable to all point-suspensions, because the points are liable to become blunt under the action of large pendulum-weights and thus to render it impossible to obtain an incontestable registration. The suspension of Zöllner is free from this defect and in addition to this possesses a very weak mechanical damping, so that at the limit of aperiodicity the magnetic damping exerts its full effect. But it is a drawback which may not be neglected, that the suspension-wires are too long and elastic, in consequence of which the mobile system may execute not only revolving movements, but also parallel dislocations.

The supporting pivot which Prince B. Galitzin recommends is probably intended to render these displacements harmless, but thereby the oscillating system becomes "rather imperfect mechanically."

Even supposing that no serious apprehensions need be enter-

tained on this account, yet there is another circumstance which might be much more dangerous: this suspension-method makes it necessary to give the apparatus itself a fairly elongated shape. This might lead to the result that the whole construction executes sympathetic movements which would introduce ambiguous elements into the registration. The experiments carried out at Pulkovo with a heavy steel-bell, which in an air-tight chamber contained a pendulum suspended by the Zöllner-method, have proved that the so-called micro-seismic motions of the second order were not absent on windy days.

One might have thought that all these remaining motions illustrate real motions of the soil. But experiments with artificial air blasts in the room itself gave the peculiar result¹⁾ that in the case of variations of atmospheric pressure and slight air currents the steel-bell, which was placed on 3 adjustable screws, started to rock, which may have occurred in this manner that the points of the screws were deforming the plates of the pedestal. It is therefore of little use to cause a pendulum to register in an airtight room, and this is also a rather complicated problem, because to render such a chamber absolutely airtight at atmospheric pressure is very difficult. Besides the chamber with the exhausted air may behave to changes of pressure like an Aneroid-capsule. In the underground station²⁾ one expected to find smaller microseismic motions of the 2-nd order than in the former diagrams, as these localities were nowhere exposed to a direct wind-pressure. Here the pendulums were mounted in a somewhat different way, namely the sheet-iron hooks were in no direct connection with the basis of the pendulum framework, the result of which was that a current of air in the pendulum-room could not exert any influence upon the pendulums by its pressure on the hooks.

Nevertheless the microseismic motions of the 2-nd order remained in considerable strength and at the periods of strong wind proved to be very troublesome in the working up of the earthquake diagrams. It is well known that then one could af-

1) Изв. Пост. Центр. Сейсм. Комиссии, т. IV, вып. 2. 1911.

J. Wilip: On the Influence of Air-Currents on Highly Sensitive Horizontal Pendulums.

2) Изв. Пост. Центр. Сейсм. Комиссии, т. V, вып. 2. 1912.

J. Wilip: The Central Seismic Station at Pulkovo.

ford the luxury of having every component registered photographically twice, and it was just this circumstance which allowed a more comprehensive insight into the real facts to be obtained.

2 exactly parallel horizontal pendulums, only mounted on different columns, showed microseismic motions of exactly opposite direction. Undoubtedly there must have been air-currents at work which had a different direction near the walls of the room and in the middle of it. At the moment when the air was pumped out of the room the weight of the horizontal pendulum pointing to the middle of the pendulum-room could be deflected more towards the door than that of the other pendulum which pointed to the wall opposite.

This character of the air-motion was illustrated with special distinctness by the two E—W components which were parallel to each other at equal distances from the corners of the room¹⁾ and which indicated exactly opposite motions.

It is the sucking effect of the wind which appears at all chinks and gaps of closed rooms and causes air-currents and differences of pressure in these apertures corresponding to the character of the wind. This direct influence of the air-currents due to storms in the pendulum-room is nowadays causing difficulties in the working up of many earthquake diagrams and in the measurement of real surface-dislocations. The disturbing action takes place firstly by a direct pull upon the swinging system, secondly, also by the pressure upon a high pendulum-structure, which owing to the subsidence of the adjusting screws may cause slight inclinations to occur.

It is also possible that even in quiet weather when in the open air a considerable fall of temperature is occurring, air-motions round the seismograph may be produced by the unequal cooling of the walls and the ceiling of the station-building, as well as by colder air-currents penetrating through chinks and pores; those air-motions cause deviations of the zero-position of the pendulum possessing a long period. This circumstance renders more difficult an incontestable investigation of the microseismic motions of the frost which have often been watched.

It may be sometimes possible under certain conditions at a station to find a so-called neutral point, where the sucking

1) l. c.

effect does not appear at all; but this would in any case be a very uncertain way out of the difficulty.

With larger pendulum-weights, as they are used in the cases of the Wiechert and Mainka pendulums, a direct influence of air-currents should be less noticeable. Yet even in such cases the separation of real surface-movements from air-deflections is hardly possible. It is true that greater stability is manifested by the vertical Seismograph; at Pulkovo it very seldom showed greater disturbances, chiefly, it may be supposed, because this apparatus does not react to inclinations. Lighter seismographs, if they are designed for high sensitivity, are always very liable to this defect, especially if the inherent period is made very long (25^s).

As to the inherent period of a seismograph which could be recommended, the following general remarks may be made in this place.

At Pulkovo on each strip of paper two pendulums were made to register galvanometrically in parallel lines, one with 25^s and the other with about $13^{s.5}$ as inherent period. It appeared that the pendulums with shorter inherent periods were capable of giving more details than the former pendulums with a long period and with a high factor of transmission. Nowadays the most important and most interesting part of an earthquake registration is the very first beginning with its different groups of longitudinal waves, and with an inherent period of $12-13^{s.5}$ it is just the wave-periods occurring most frequently in these preliminary phases, which possess the highest sensitivity. The inherent period of 25^s recommended in the beginning by Prince B. Galitzin gives an excellent sensitivity for wave-groups of the principal phase, which is very strongly represented as it is and exceeds the scale in the case of greater tremors.

The inherent period of $12-13.5$ possesses the further great advantage that it makes it possible to register the horizontal components with apparatus of the same inherent period, which can easily be given to a Vertical Seismograph. This is an important condition for an incontestable determination of the angle of emergence. In a resultant of all the 3 components I should recommend the inherent period of $12-13^s$, because with an inherent period of $13^{s.5}$ the Vertical Seismograph is even more stable than with longer periods.

New Horizontal Pendulums with Hermetic Exclusion of Air.

The experiences which I was able to gather as the constant collaborator of Prince B. Galitzin and as director of the Seismic Central Station at Pulkovo, have induced me to study more closely the above-mentioned circumstances and to try to discover how more incontestable registrations of earthquakes and microseismic motions could be obtained. It was therefore necessary to work out for the horizontal pendulum a more stable and less elongated system than that of Hengler-Zöllner and to make it independent of the injurious effects of all air-currents. The solution of this problem has been much facilitated by the fact that the ingenious constructor of the Pulkovo Seismographs, the mechanician Mr. H. Masing, has transferred his domicile to Tartu (Dorpat) and is executing orders for all kinds of scientific apparatus with the greatest precision.

Estonia itself is not yet in a position to establish a Seismic Station, although there are subterranean rooms under the Cathedral Hill which could be adapted for it.

Another small country, Denmark, has forestalled Estonia, as Prof. N. E. Nörlund has ordered from Estonia a full set of pendulums with galvanometric registration and three registration-apparatus, that is to say a complete first-class outfit for a Seismic Station¹).

Let us next turn to the new type of Horizontal Pendulums which were made on my suggestion by the mechanician Mr. H. Masing.

On fig. 1 there is a vertical cross-section through the apparatus on a reduced scale of 7:1.

On the bed-plate AA of 48—52 cm in length and 35—44 cm in breadth a pendulum-structure BB is erected which is composed of cast-iron frames with lattice work.

To this structure 2 contrivances are attached; first, a complicated brass-casting EE, very little inclined, the other cross-section of which is represented in the adjoining picture. This serves for the suspension of the mobile system. Second, a brass-frame RR, placed in front of the part just described, which contains the regulation-mechanism of the couples of magnets

1) In addition to this 2 Horizontal Pendulums of the new type have been ordered from Potsdam by Professor E. Kohlschütter.

$M_1 M_1$, for the galvanometric registration, and $M_2 M_2$, for magnetic damping.

The oscillating part is formed by the frame LL with the principal weight G of ca. 4.5 klg, the coil-system J for cutting the lines of force, and the damping-plate H. Two screws KK allow a small rotation of the frontal part of this system about a horizontal axis, in order to place the winding-plane of the coils and the damping plate vertically to the lines of force, should this be desirable.

This mobile system is suspended from the slightly inclined part EE by means of the plate-springs FF, in this way, that it

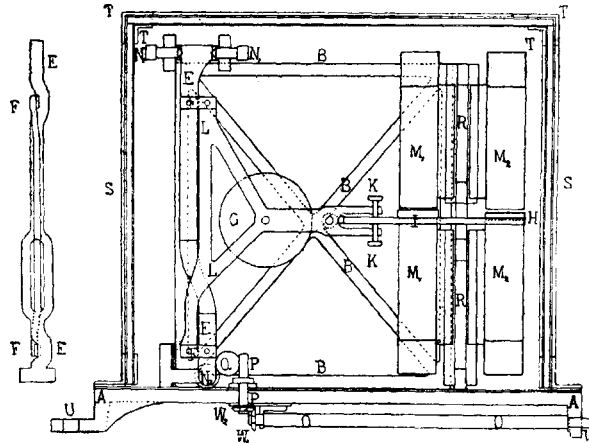


Fig. 1.

draws the spring at the upper point of suspension forward and pushes back the one below, as is easily understood from the figure.

The inherent period of the pendulum is roughly adjusted by means of the two upper screws, $N_1 N_1$, by screwing out one of these and screwing in the other and then by tightening them both.

In the bed-plate AA there are 3 fastening screws each with 2 nuts. (In the figure the boring should be noted at U.) The lower of these may at the same time be used for more exact adjustment of the inherent period and of the zero position of the pendulum by inclining the bed-plate. These 3 screws cross the borings, and their purpose is to create a firm con-

nection with the bed-plate on which the pendulum is mounted by means of bolts fixed into the pillar with cement, for which purpose this latter is provided with a special spirit-level for proper orientation. Thereby the dangerous pressure of the former adjusting screws, which might easily be changed by the effect of the wind, thus modifying the microseismic motions of the 2nd order, is avoided.

For the more exact adjustment of the zero point of the pendulum another couple of screws, $N_2 N_2$, may be used, which allows the lower end of EE to be displaced vertically to the plane of the picture.

In order to effect this more exact adjustment of the zero point even then when the pendulum is entirely covered, a special contrivance with toothed wheels is provided, the construction of which is only roughly indicated in the diagram.

To the lower part of the bed-plate a rod OO is fastened, which may be rotated at its outer end V by means of a key which can be applied there. This rod at its lower end terminates in a conical wheel W_1 . This toothed end by means of W_2 , which is constructed identically, transfers the rotation of the rod to the vertical screw PP, which with its thread engages the toothed wheel Q. Q is fixed to a horizontal axis which carries a toothed wheel on each side at equal distances from Q. (As the axis is placed vertically to the plane of the drawing, this is not visible in the figure.) Both these external toothed wheels transfer the rotation to the toothed screwheads, $N_2 N_2$.

In a similar manner the horizontal displacement is effected in the lower part by means of 2 screws.

The whole apparatus may be hermetically isolated from the external air by a plate-glass cover SS. This cover consists of a glass-box of thick plate-glass, so constructed that the panes are joined together, by means of red-lead putty between the brass angles TT. The exclusion of the air below is effected by means of an india-rubber membrane, the lower part of the cover being screwed on to the plate by numerous screws.

In case it should appear that red-lead putty alone is not sufficient, the margin along the brass-edge may be covered over with a lute such as Rudol.

In the drawing many details have been omitted, e. g. the little electro-magnet attached to the apparatus for transmitting

a shock in the determination of the galvanometric transmission factor. Further there are fixed to the bed-plate conducting wires, which pass through hermetically closed borings, for connecting the pendulum-coils with the galvanometer and for supplying the current to the electro-magnet which produces the shock in the determination of the constants. A little mirror

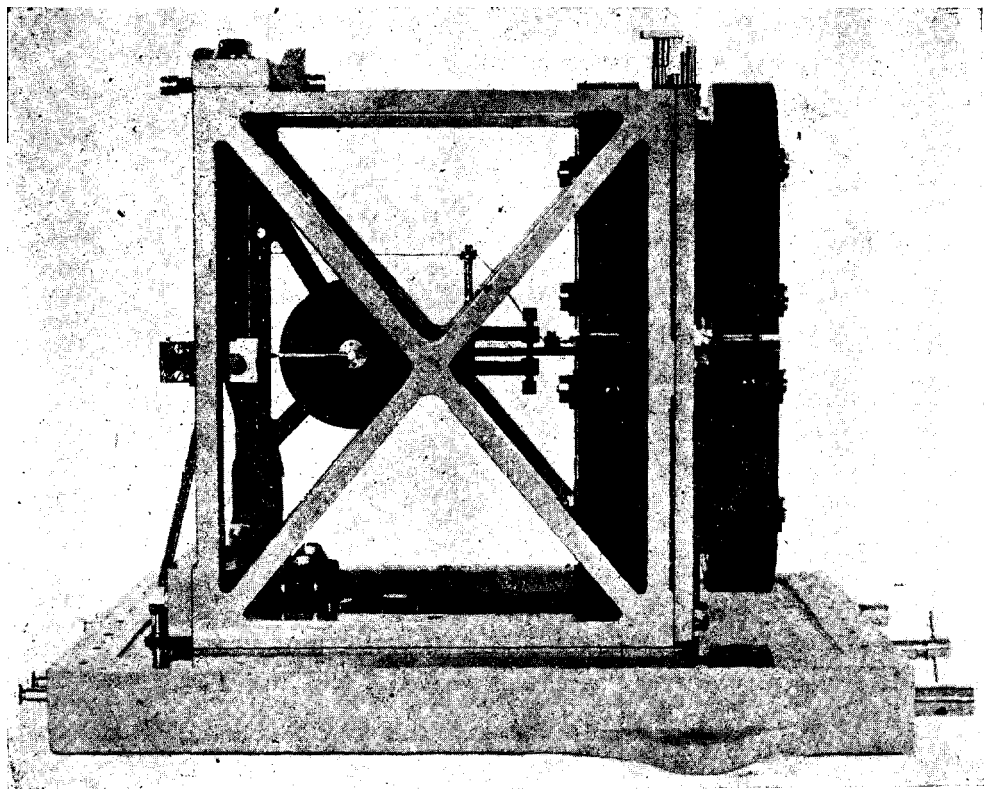


Fig. 2.

also forms part of the apparatus, which is fastened to the oscillating system near the axis of rotation and which is used for the determination of the constants. It may also be used for obtaining the pendulum-length after the method of varying the inclination of the pendulum-axis.

There is also missing in the drawing a small pedestal which can be screwed on to the pendulum-structure, and which

may be used for obtaining the pendulum-length directly from the duration of the oscillation of the system by tilting the bed-plate after removing the case and turning the bed plate through an angle of 90° so that the rotation-axis of the horizontal pendulum falls into a horizontal plane.

Fig. 2 contains a photograph of this horizontal pendulum in about $1/4$ actual size, in which a few details are more easily recognisable.

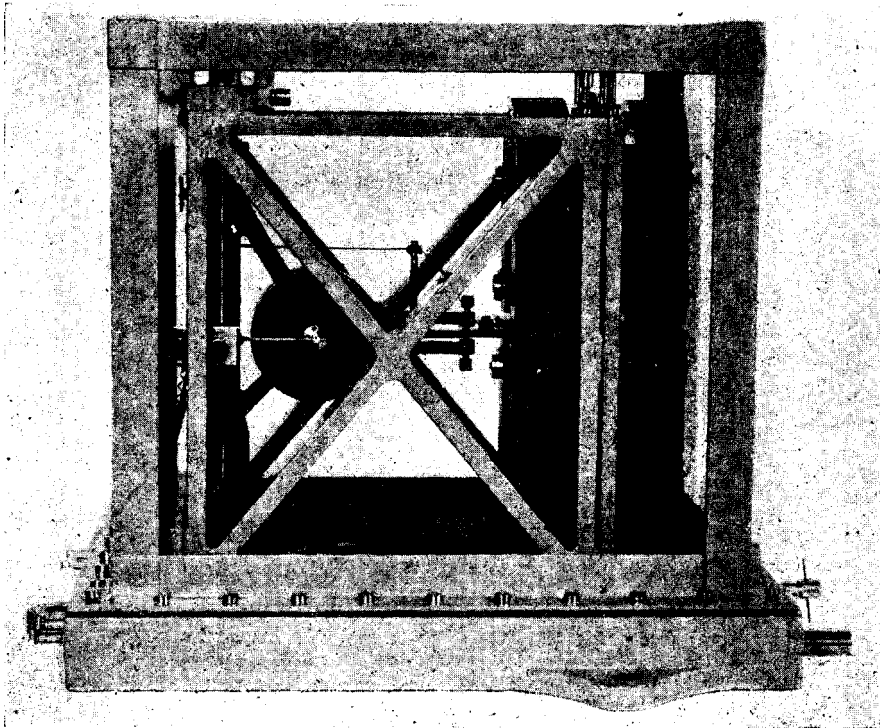


Fig. 3.

Fig. 3 shows the apparatus with the cover of plate-glass. In both cases the drawing fails to show the bolts with their threads and nuts, by means of which the basis must be firmly attached to the low level column.

On the Inherent-Period of the New Pendulum.

Before being finally mounted in the Seismic Station, every horizontal pendulum must have been subjected to a preliminary

investigation either in a laboratory or in the station itself. As this type of pendulum is constructed without adjusting screws which allow the basis to rest on three points, it is possible for the purpose of preliminary experiments to make use of three special adjusting screws with broad screw-nuts by passing these screws through the bolt-holes and screwing them into the nut-plates placed underneath. In this way it is possible freely to vary the rotation-axis of the pendulum which passes through the plate-springs.

In addition to this, as was mentioned above, the two upper screws on the pendulum-structure give another possibility of changing the inclination of the axis of rotation and also the inherent period.

As a rule all the horizontal pendulums possess the peculiarity of increasing their inherent period with growing amplitudes in a much higher degree than this might have been expected from the theory of the ordinary pendulum.

As in aperiodical Seismographs one has chiefly to do with very small deviations, this would not have any great influence on the ultimate result, if one would always choose as the standard a medium-sized period for small amplitudes.

This rule applies still more to the various groups of longitudinal waves which probably present the greatest interest in modern Seismometry.

It was now a question of studying this property more closely also in the case of the new pendulum-type.

Suppose the range of application of these pendulums were for an inherent period between 11—13^s.5; therefore such a pendulum was adjusted in the case of great amplitudes to the period $T = \text{ca. } 14^{\text{s}}$. It appeared that with a normal orientation of the suspension-device of the pendulum the damping is very slight. It is not in the least inferior to that of the delicate Zöllner suspension-method.

There resulted from a long series of oscillation observations as an average for the logarithmic decrement:

$$\Delta = 0,0189.$$

For the dependence of the inherent period on the amplitude there could be observed with this weak damping any desired number of individual periods after a strong single deflexion, from

which by means of graphic adjustment the following table has been computed:

2a	T
0,0270	13 ^s 67
200	13.60
150	13.56
100	13.50
50	13.44
40	13.42
30	13.41
20	13.40
10	13.38
0	13.37.

In these experiments the scale of the telescope was at a distance of 5 m from the pendulum-reflector.

The figures given under 2a denote the sum of the deflexion-angles of the pendulum to the right and to the left, for which the period T is correct.

The chief range of application of the pendulum in the galvanometric registration-method extends only between $2a = 0.0000$ and 0.0010 , where the table indicates the inherent period $T = 13^s.37$ and $13^s.38$ which show an almost identical result.

A striking peculiarity of this new pendulum-type appears from these experiments. But also in the case of very great amplitudes, which are of little interest to precision-seismometry, the increase of the period with the amplitude is insignificant.

In this place we may observe that the above-mentioned phenomenon appears only in those cases when the pendulum has been properly adjusted.

The chief condition of this is that the upper and lower plate-spring must fall exactly into one plane and that this plane should be placed in a vertical direction.

The result is entirely different if these conditions are not fulfilled.

By screwing under one of the ends of a plate-spring a brass-plate of ca. 1 m/m thickness containing a hole bored through it, the normal condition was destroyed on purpose, so that the planes of the plate-spring were displaced a little in relation to each other. In order to obtain the zero-position, the basis of the

pendulum had now to be inclined. In this way a mechanical error of construction was purposely introduced.

A strong damping resulted and consequently during the observation of the dependence of the period on the amplitude it was often necessary to displace the pendulum anew, in order to observe a greater number of values. The plate-springs looked a little bent after all these observations and had to be exchanged for new ones, which were smooth.

Similarly as in the above case the following table has been constructed :

2a	T
0.0230	13 ^s 83
200	13.73
150	13.45
100	13.00
50	12.24
40	12.05
30	11.84
20	11.62
10	11.37
0	11.08.

Even in these experiments there are recognizable considerable variations of the inherent period at different amplitudes.

Whereas this dependence assumes an almost linear form in the first case, it may here be represented by a curve. The range of application between 0.0000 and 0.0010 shows here already a difference which in the first case is obtained for an interval of 0.0000 to 0.0270.

In all cases, therefore, where the suspension is wrongly adjusted, the pendulum could be used for finer measurements only when using an auxiliary table, by means of which the dependence of the period on the amplitude may be corrected.

Definition of the Constants of the Seismograph.

Before mounting the pendulum at the seismic station the reduced length of the pendulum I must be ascertained from observations once for all.

With this type of pendulum this task is quite simple, as it is possible to adjust its axis of rotation in a horizontal line,

for which purpose a third foot is used which may be screwed on to the pendulum-structure. This causes the weight of the pendulum to be supported partly by one of the plate-springs.

As experiments have proved, this plate-spring is not damaged in the process.

By measuring in this position the duration of oscillation of the system, counting 100 periods every time, one may calculate l from the usual pendulum formula, viz.

$$l = \frac{T_0^2}{4\pi^2} \cdot g.$$

In this way was the result found for a model ordered for Copenhagen:

$$l = 137,6 \text{ m/m.}$$

If the experimenter has patience there is nothing to prevent him from using the method of varying of the inclination of the rotation-axis of the pendulum¹⁾ and finding the length of the pendulum from a series of equations after the method of the smallest squares.

The axis of rotation may be varied by means of two screws at the top of the structure. But inclining the basis together with the whole system would be preferable in a similar manner as this is done with the Hengler-Zöllner frame.

Whereas in the Galitzin-pendulums varying the inclination is admissible only within small limits on account of the flexibility of the suspension-wires, it is possible in this type of pendulum to produce any desired inclinations in order to ascertain the length of the pendulum.

In this place I want to draw attention to the advisability of measuring the periods at the various inclinations in small amplitudes, which is the most practicable method, if one is observing the oscillation of the pendulum by means of the galvanometer belonging to the set.

For the above-mentioned pendulum a series of 7 equations, which were constructed from observations in a disturbed place for periods between 12^s and 5^s, gave the following result:

$$l = 138.2 \pm 1.0 \text{ m/m,}$$

a quantity which corresponds with the calculated one directly.

¹⁾ Note: Prince B. Galitzin. Lectures on Seismometry. Freely translated into German by O. Hecker p. 315.

After ascertaining the reduced pendulum-length the seismograph may be permanently mounted in its place. In doing this it is recommendable to perform the mounting in such a way that no free adjustable screws should be used as this was the case with the former Galitzin-pendulums.

For this purpose in the new type 3 bolts are provided which may be luted into the column which must be as broad and low as possible.

By screwing on to the screw-thread of the projecting part corresponding screw-nuts, the basis of the structure with its borings is lifted above the screws so that the basis will now be supported by the screw-nuts. For the purpose of approximate orientation the spirit-level is used which is attached to the bed-plate.

In order to adjust the right zero-position as well as the desired inherent period use should be made chiefly of these three screw-nuts below the basis, and the adjusting top-screws should be employed as rarely as possibly for the inclination of the axis of rotation.

The usually observed gradual decrease of the inherent period of the pendulum will appear more sharply at the beginning of the fitting up than when inclining the whole system. Finally the bed-plate is firmly screwed on by the three top screw-nuts. Still it is advisable to wait about 2 weeks after the mounting and the adjustment of the inherent period before carrying out a more precise controlment and the determination of the final constants, making use in the adjusting of the zero-position of the toothed wheel mechanism only in case of a more precise regulation.

As is well known, the inherent period is adjusted when the damping-magnets are removed i. e. when the front part of the pendulum is less loaded. Therefore it might be expected that after screwing on the damping magnets a little addition to the inclination of the rotation-axis and consequently a shortening of the period would take place.

With the old pendulums however, the observations constantly showed just the reverse; instead of the adjusted period $13^{\text{s}}.5$ a longer period of about $16^{\text{s}}.0$ resulted near the limit of aperiodicity, which every time after the mounting of the magnets necessitated a repetition of the inclination of the pendulum-frame.

This question O. Somville¹⁾ has investigated more closely and has ascribed the variability of the period to the diamagnetic qualities of the copper-plate used for damping.

By choosing a suitable alloy of copper and aluminium it has been managed to remove this defect in the new pendulums.

When adjusting the permanent inherent period the same phenomenon may be observed (a fact which was mentioned when describing the method of ascertaining the reduced pendulum-length after the variation-method of inclining the rotation-axis), viz. that it can be determined more easily by means of the galvanometer in the case of oscillations which when observed with telescope and scale at a distance of 5 m from the pendulum-reflector do not exceed 10 m/m. Here it is advisable to place the detached damping-magnets in such a way that they load the pendulum-frame with their weight similarly as when they are screwed on.

The determination of the constants μ^2 and k by means of these pendulums is very simple. The cover consisting of plate-glass all parts are visible, and by means of a total-reflection prism the telescope and scale may be orientated in any direction within a semicircle.

If the inherent period shows no alteration after mounting the damping-magnets, the quantity $\xi = 0$, and the working up of the observations is considerably simplified. It is even easy to obtain by practical means that μ^2 becomes infinitesimal, which renders possible a rapid and easy calculation of the important constants.

In case the knocker of the impelling electromagnet should be placed too close to the weight, the cover should be lifted after the completion of the observations, and the impelling electromagnet screwed back. Thereupon the pendulum should be covered again and the lower margin of the cover is fastened down firmly by means of screws.

On the Behaviour of the Pendulum in Air-Draughts.

One of the most important questions for every seismograph is probably its behaviour in various currents of air which in

¹⁾ Compare: Annales de l'Observatoire royal de Belgique, 3 série. A. I, 1922.

windy weather or in consequence of sudden changes of temperature may appear in the pendulum-room. Where the enlargement of the seismograph does not exceed 200, these influences are less striking. But in the galvanometric registration-method we have to deal with enlargements varying between 1000 and 2000 for certain wave-periods.

This circumstance therefore deserves very serious attention for the purpose of being able to measure real dislocations of the ground and not incidentally wrong inclinations which are due to the pressure of the moving air.

We are dealing here chiefly with the question of how to find the proper explanation of the so-called microseismic movements which appear on windy days and sometimes completely disfigure and mark a great percentage of the most beautiful earthquake-diagrams.

It is a well-known fact that in closed rooms a sensitive pressure-variometer shows constant disturbances on windy days. These disturbances are chiefly due to the variable sucking effect of the wind. If the direction and the strength of the wind remained absolutely constant, such a variometer would denote an air-pressure as little lower than the actual height of the barometer outside, as the wind in passing near openings and gaps of the room causes the air inside to become a little rarefied. Thereby a pull would be exercised in a special direction on the inner walls and all objects contained in the room, as air would constantly be streaming into the more rarefied room through pores and parts sheltered from the sucking of the wind. All objects that could be bent or tilted would incline a little. As the strength and the direction of the wind is never constant and usually varies intermittently, the rarefication of the air will also vary constantly, and consequently the objects placed in the room will execute corresponding oscillations.

Therefore a well-sheltered horizontal pendulum in a closed room may indicate irregular movements under the sucking effect of the wind, when the system is not firmly enough connected with the basis of the station.

As I have shown by an experiment¹⁾, the sucking effect

1) Compare: L. c. J. Wilip. On the Influence of Air-Currents on Highly Sensitive Horizontal Pendulums. 1911.

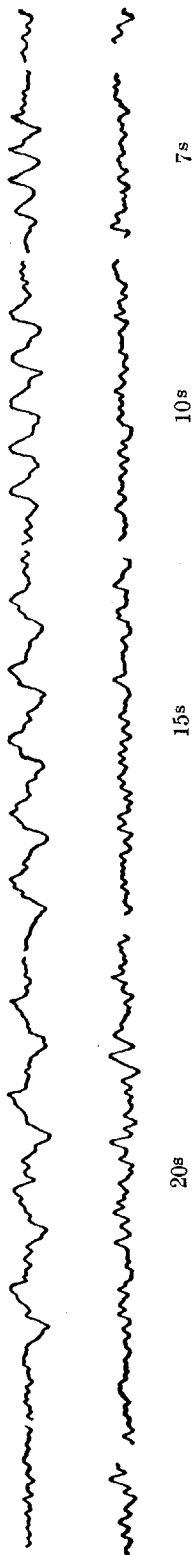


Fig. 4.

of the wind carried out at Pulkovo may very well be imitated by means of an electric ventilator. It is only necessary to place the ventilator before an opening of the closed pendulum-room and by means of it to rarefy and condense the air in the interior by alternately commuting the direction of the current.

In this way the pendulum-frames and boxes set up periodical oscillations as indicated by the registering galvanometer.

This method is a simple device for testing the seismographs on any station as to their stability.

As usually there are no suitable openings in the walls, it will be found convenient to create such an opening by nailing over the opened door a card-board screen into which a suitable opening is cut for the ventilator.

After this method one of these new seismographs was tested, the conditions required for the mounting of the pendulum being completely absent. The pendulum was simply set up in a stone window-bay on the second story of the University building, it being impossible to screw on the basis of the frame.

The galvanometric transmitting factor in the experiment amounted to $k = 77$, with $\mu^2 = 0$, and the registration was carried out for 2 conditions. The galvanometer reflector was situated at a distance of 1 m from the registration drum.

The first curve in Fig. 4 refers to the case in which the system was supported by 3 adjusting screws as in the old pendulums; the second, which was taken on another day, shows the result for the same pendulum, with this difference that the basis was simply made to touch the wall with as many points as possible without the adjusting screws.

The ventilator was set up in such a way that the wind-current did not strike the pendulum-box, and in both cases it automatically commuted the direction of the current for 4 different intervals of time, namely 7, 10, 15 and 20^s. These groups are marked on the registration by interruptions. The velocity of the drum had been adjusted to 15 m/m per minute.

It is to be seen quite distinctly how in the first case the seismograph imitates the period of commuting. There have resulted pretty regular microseismic movements of the 2nd order. In the second curve, where the seismograph was supported by the window in a more stable manner, nothing is to be recognized of the regularity of the previous record. The short indentations resulted from sea-waves and the long irregular deviations most probably denote chiefly movements of the University building

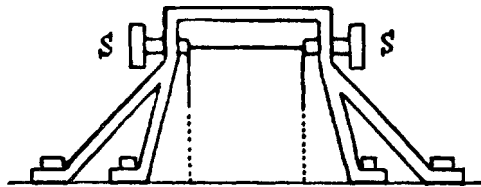


Fig. 5.

in consequence of variable wind-pressure. The total pressure-variation amplitude which under these conditions could be called forth by this ventilator, amounted to 0.14 m/m Hg-column, as could be ascertained by means of a simple closed petroleum-manometer.

This experiment proves very distinctly the great advantages of the new construction and allows the conclusion to be drawn that the old method which consisted in mounting the seismographs unprotected on 3 adjusting screws supported by points on plates placed below, is not admissible.

Even if one should be of opinion that in the registration of earthquakes the accompanying vibrations of the pendulum-stand, as is the case with all pendulum-apparatus, should not have a serious influence on the ultimate result, one ought never to underrate this influence of air-draughts.

Here one might even raise the question, if this construction always affords sufficient immunity against the sucking effect.

It is imaginable that seismic stations might be set up in places where the winds often possess a hurricane-like character, and that in consequence quite considerable pressure-variations might result in closed rooms.

For such cases I could recommend a still more stable method of mounting which is outlined in Fig. 5.

Above the cover of the pendulum a stout cross-beam of iron is erected (as is shown in the figure), which is strongly attached by means of bolts sunk into the column. The upper margin of the glass-box may then be damped between two screws with absolutely flat points (SS). That the pressure is developing on both sides with uniform strength, one can easily see from the zero-position of the pendulum. This method of fastening ought to render the system inflexible in a specially efficient manner.

The Registration-apparatus of H. Masing.

It is a great merit for a master mechanician to have brought the registration-apparatus to such a high degree as that posses-

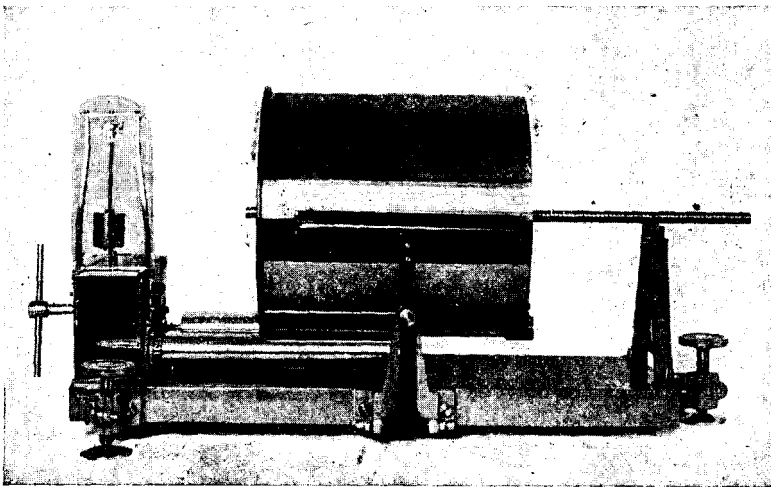


Fig. 6.

sed by the present models which is now being constructed by H. Masing for two velocities, namely 15 m/m and 30 m/m per minute.

The consequences of the war are still perceptible everywhere and an increase in the cost of the photographic registration-method has resulted. Therefore one may ask if it would not be appropriate to reduce the working expenses of this very expensive method without suffering any loss?

The question is to be decided whether half the velocity of 30 m/m per minute recommended by Prince B. Galitzin before the war, would be sufficient to obtain a precise and incontestable analysis of the registrations of earthquakes.

In fact the registrations of distant earthquakes with which precision-seismometry is chiefly concerned, become still more graphic with a velocity of 15 m/m, as is to be seen in the beautiful registrations of E. Gherzi¹⁾ at Zi-ka-wei. For the resolution of periods which amount to less than 1^s these apparatuses are not designed, as their sensitivity is considerably diminished at this stage.

For similar periods which chiefly appear in local earthquakes, cheaper seismographs recording on smoked paper are to be preferred. The most that may be apprehended is that in the determination of the time the precision would suffer a little, which could easily be compensated for by appropriate measuring methods, for instance by obtaining a magnification of the horizontal direction of the lines by means of cylindrical lenses.

Thus the shortening of the minute to one half would be justified in our times, when all things are so expensive.

But if this should be desired, the lesser velocity could be exchanged for the greater at any time.

In Fig. 6 a reproduction of a photographic view of this apparatus is given.

It differs from the registration-apparatus mentioned in the „Lectures on Seismometry“²⁾ and has been developed from an apparatus constructed by H. Masing for second-class stations. A single clock-mechanism provided with a strong spring causes the rotation-movement of the heavy drum as well as a shifting of it in the direction of the rotation-axis. Instead of the former Foucault-regulator a conical pendulum-regulator is used.

1) Cf: Observatoire de Zi-ka-wei. Notes de seismologie. Nr. 4. Janvier-Juin 1923. Par le R. P. E. Gherzi S. J.

2) Cf: L. c. p. 227.

By applying revolving balls in the axle bearings and introducing various other improvements, Mr. H. Masing has succeeded in reducing the friction to a minimum, so that the move-

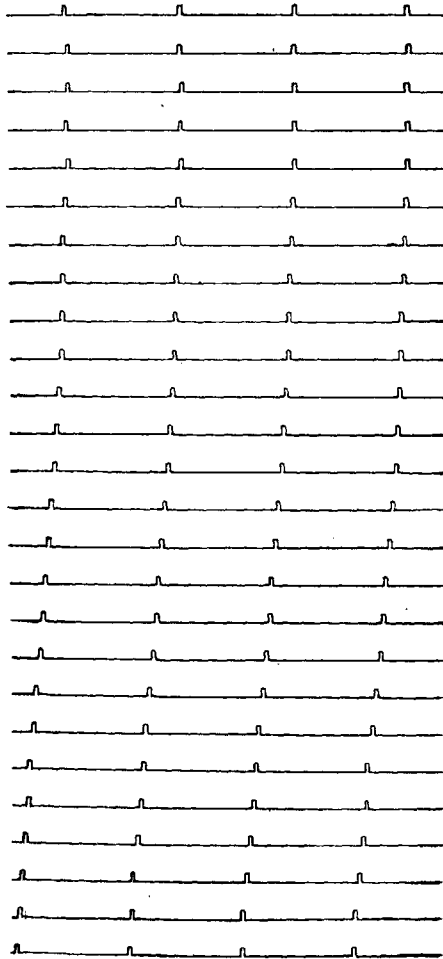


Fig. 7.

ment is hardly inferior to that of the above mentioned type, as is to be seen from Fig. 7.

The distance of the lines from each other amounts on the registration-paper to 5 m/m. The mechanism with one winding up works ca. 26 h. continuously, so that the spring must be

wound up once a day. If one uses registration-paper of the size of the drum-surface, viz. $30 \times 92 \text{ cm}^2$, it is not necessary, with 15 m/m velocity, to change the paper until after 48 hours. The intermediate winding up must not be forgotten. At a velocity of 30 m/m the change of paper must, of course, be effected daily.
