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COMPLETE SPECIFICATION

Measuring Instrument for the Determination of Variations of the Gravitational Acceleration

I, STEPHAN BARON VON THYSSEN-BORNEMISZA, of Stadhouderslaan 126, Haag, Holland, formerly of Bodekerstrasse 36, Hannover, Germany, an Hungarian Citizen, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The invention relates to a measuring instrument for the determination of variations of the gravitational acceleration.

The accurate determination of variation of the gravitational acceleration is of great importance for the exploration of the earth, particularly for determining the position of deposits. Hitherto for this purpose mostly the Sterneck pendulum has been utilized. Measurements effected with this instrument have, however, the defect that they are lengthy, complicated and comparatively inaccurate.

This invention has for its object an instrument for the determination of the variations of gravitational acceleration which has the advantage over the known devices that it delivers very accurate results, it operates quickly and is simple to handle and construct. Moreover, the instrument is shock proof and easy to transport and for this reason it is particularly suitable for the use of what may be termed measuring gangs in open country.

The instrument comprises a mass connected to a lever system, the variations in the position of which due to variations in the gravitational acceleration produces variations in a lever arm, the variation of the lever arm being such that the displacement of the mass is amplified. To the lever system in which the mass is located a spring is attached which tends to oppose change of position. If for example the gravitational acceleration is increased and thereby the lever system is displaced, then the lever arm with which the mass acts around the lever fulcrum is prolonged, or the lever arm with which the spring acts is shortened. Consequently, the mass has to move further in the direction of the original displacement. Obviously the reverse would occur if the gravitational acceleration decreased. The arrangement may be such that, with the variation of the gravitational acceleration and the variation in the position of the mass caused thereby that lever arm varies with which the mass itself acts around the lever fulcrum. An auxiliary mass may also be employed and this may be so disposed that its lever arm varies when the mass moves.

If the measurements are correctly selected it is possible to provide an instrument according to the invention which has a maximum sensitiveness and therefore becomes particularly suitable for the exploration of deposits.

The invention may be carried into effect in a variety of ways. For example, a mass may be secured to or suspended from one end of a rod, the other end of which terminates in a blade spring in such manner that this holds the rod in inclined position. If now the gravitational acceleration is increased, the inclination of the rod and consequently the lever arm of the mass is increased. The system comes to a rest only when the blade spring is able to balance out the effect of gravitational acceleration and the increase of the lever arm as a result of the accentuation of its curvature.

A rod oscillating on a knife edge may also be employed and on one end of this rod a mass may be disposed, its other end being held by a coil spring adapted to balance the mass. If at a suitable point of the rod an auxiliary weight extends steeply or vertically upward or if at such a place a horizontal pendulum

[Price 1/-]

is arranged, then if the gravitational acceleration increases the weight descends and the auxiliary weight takes up an inclined position, or the horizontal pendulum oscillates, respectively. Thus, such variations cause an increase in the leverage of the auxiliary weight. In this case again the system will come to rest only when the expansion of the coil spring is able to balance the combined action of the gravitational acceleration and the increase of the leverage. Obviously, the opposite occurs when the gravitational acceleration decreases.

In order to further enhance the measuring accuracy it is of advantage to take into account those variations which the length of the spring used in the device suffers under the influence of variations of temperature. Even springs made of the best material (refined or alloyed steel, quartz, tungsten) generally have a temperature coefficient of tension from -5 to $-15 \cdot 10^{-6}$. These coefficients are no doubt considerably lower than those considered unavoidable until recently, from 100 to $-200 \cdot 10^{-6}$ (compare Kohlrausch, table 20). In spite of the progress made by employing particular materials, it has not been possible to neglect the influence of the temperature with the necessary measuring accuracy ($1 \cdot 10^{-6}$) of the gravitation.

This source of error can be eliminated only by making the frame bearing the spring or the reading device for measuring the longitudinal variations, out of a material, whose coefficient of expansion is $\left(\frac{dL}{dt}\right)$ equally high, but with an opposite sign of coefficient of tension $\left(\frac{dE}{dt}\right)$ of the spring. Generally it is not possible to compensate a temperature coefficient of the tension by a temperature coefficient of expansion. It is only possible by using a coil spring, as the coefficient of tension of the spring, with a change of temperature, causes a difference in the length of the spring.

With a blade or a flat spiral-spring, such a compensation would not be possible, as, with these springs, a variation of tension—caused by temperature—produces angular, but not longitudinal variations.

The following examples show where compensation with coil-springs is possible, the temperature-coefficient of which is as high as can be obtained with good springs.

In the following table, the temperature-coefficients of the tension of springs are compared with those of the expansion of materials which may be used for the frame and the scale.

$\frac{dE}{dt}$ of the spring	employed material of the frame	$\frac{dL}{dt}$ of the frame
$-24.0 \cdot 10^{-6}$	aluminium	$+23.8 \cdot 10^{-6}$
$-16.5 \cdot 10^{-6}$	copper	$+16.5 \cdot 10^{-6}$
$-12.0 \cdot 10^{-6}$	iron	$+12.0 \cdot 10^{-6}$
$-4.5 \cdot 10^{-6}$	tungsten	$+4.5 \cdot 10^{-6}$
$-3.0 \cdot 10^{-6}$	porcelain	$+3.0 \cdot 10^{-6}$

It shows how, with quite different temperature-coefficients of the springs, the material of the frame can be adapted.

The compensation is particularly important in cases where the temperature-coefficients of the spring are extremely low, even under present conditions. For instance springs have become known, whose temperature-coefficient of tension is about $-2.0 \cdot 10^{-6}$ and less (Guillaume's watch-steel). To render possible accurate measuring with such springs in accordance with the present invention metal frames are used, whose temperature-coefficients of the length are equally high.

Such metals are the so-called invariable nickel-iron alloys (e.g. of the type known under the Registered Trade Mark Invar, containing about 36% of nickel). With springs having a coefficient of $-0.6 \cdot 10^{-6}$, quartz-glass has proved to be a particularly suitable material.

To increase the accuracy of compensation to the utmost, care must be taken that there shall be no difference between the temperatures of the spring and the frame. To avoid the appearance of such differences, the location of the spring and the rod in the same insulated part is of advantage. This can be done e.g. by making the frame in the shape of a tube in which the spring is disposed. The temperature of the spring adapts itself

largely to that of the tube.

Furthermore, as the measuring instruments must be very carefully levelled with the various subsequent measurings taking place at different spots, it may be important to cut out the levelling error altogether.

Thus it may occur that, with a levelling error of one second (angular measure), considering the great sensitivity of inclination the measuring error may reach 10 "Millidynes" (scientific unit) or more, whereas the necessary accuracy of measuring only amounts to one "Millidynes". Such an accurate levelling cannot be obtained safely and quickly enough with a spirit-level or such like. Moreover, these levelling devices are extremely sensitive as regards temperature.

There is a possibility of considerably reducing the necessary accuracy when levelling, by using simultaneously two meters of gravity of equal sensitivity, and locating them in such a position, that variations of inclination are acting thereupon in an opposite sense. The medium figure resulting from the measuring of both systems therefore will contain no error of inclination.

The attached drawings show various embodiments of the invention by way of example.

Figs. 1 to 5 show schematical views of five different embodiments of the invention;

Figs. 6 to 9 show in side elevation and plan a further embodiment of the invention;

Fig. 6 being a side elevation;

Fig. 6*a* is a perspective view of a constructional detail,

Fig. 7 a plan view of the instrument in the position of rest;

Fig. 8 a side elevation, and

Fig. 9 a plan view of the instrument in the position after transposition to a new station;

Fig. 10 a modification of the invention according to Fig. 5;

Fig. 11 a modification of the invention according to Fig. 1;

Fig. 12 a further modification of the invention according to Fig. 5.

Fig. 1 shows the lever L from one end of which is suspended a weight M and the other end of which is connected to a blade spring E secured to the base U. If the gravitational acceleration is increased the equilibrium of the lever system is upset with the result that the lever L takes up a more inclined position. The lever arm L_1 is thereby increased. The increase of the lever arm causes further inclination of the system. The latter will come to rest only when the increased elastic opposing force brought about by the stronger curvature of the blade spring is able to balance the combined action of the gravitational acceleration and the increase of the lever arm to L_2.

Fig. 2 shows a lever arm L to one end of which is attached a weight M^1 carried by the spring E and the other end of which is supported by means of a knife edge on the base U. An auxiliary mass M is rigidly attached to the lever L on the top of same. If the lever L is inclined as shown in Fig. 1, then the auxiliary mass M will have a lever arm L_2. This process is conducive to a further inclination of the system.

In Fig. 3 a substantially horizontal lever L is employed to one end of which is attached a weight M and the other end of which is connected to a blade spring E secured to the base U. Mounted on the lever there is a spirit level J. If the gravitational acceleration is increased the equilibrium of the lever system is upset with the result that lever L assumes a more inclined position. Due to this the bubble of the spirit level moves to the left as shown in Fig. 3 and the centre of gravity S of the spirit level moves to the right. The lever arm L_1 of the spirit level is thereby prolonged and its value will be L_2. The operation is the same as in the other embodiments.

In Fig. 4 the spirit level J of Fig. 3 is replaced by a ball K rolling in a cup S. If the lever L is inclined the ball rolls to the right as shown in Fig. 4 and the lever arm L_1 of the ball will become L_2.

It will be seen in Fig. 5 that lever L of the mass remains the same when the inclination varies, while the lever arm L_1 of the spring E varies accordingly. If the gravitation increases the lever L_1 is reduced to L_2 thereby causing further inclination of the system.

In the construction according to Figs. 6 to 9 the beam W oscillating around a knife edge L carries on one side a small mass M and is connected on the other side to a coil spring F. Above the knife edge L is pivoted the horizontal pendulum P, mounted for example as illustrated in Fig. 6a the axis on which said pendulum P pivots being slightly inclined to the vertical when the beam W is horizontal. The spring may comprise two parts of opposed twist to compensate the twisting forces due to temperature variations.

The operation of this instrument is as follows:

In the constructions according to Figs. 1 to 5 the lever arm is shown in two positions, the first one at the starting of the

measurement, the second one after transposition to a new station.

When working with the horizontal pendulum according to Figs. 6 to 9 at the starting point of the measurement the balance beam W is released and the horizontal pendulum P is also released, while the spring remains fixed. The position of the horizontal pendulum P is determined on a graduation mounted in a suitable position. Thereupon all parts are again fixed. After the instrument has been transported to the new station the balance beam and the horizontal pendulum are again released. If the gravitation is different the horizontal pendulum will take up a new position, and from this the variation of gravitation may be calculated. After a reading has been taken the device is again fixed and the fixing of the spring is temporarily released to compensate spring tensions. After the spring has again been fixed release is again effected and reading taken, in order to obtain a basic reading prior to going over to a new position, the reading at this third position being referred to the said basic reading.

In Fig. 10 the spring is mounted in a frame consisting of a material whose coefficient of expansion is equal to the coefficient of tension of the spring, however with reverse sign.

Figs. 11 and 12 show devices which are composed of two measuring instruments of the kind described. In both cases the two parts are symmetrically arranged. They are rigidly connected together, thus forming a single measuring instrument. The levelling is carried out with less than 1/10 of the hitherto obtained accuracy. The errors of inclination remaining in consequence thereof are, however, more than compensated by the used arrangement, inasmuch as they have equal height at both parts of the combined instrument, but in the opposite sense. Thus it becomes possible to increase considerably the accuracy and especially to diminish the time taken in measuring.

In order to compensate the torsional forces produced by variations of temperature the spring can be composed of two parts of opposed twist.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. Measuring instrument for the determination of variations of the gravitational acceleration comprising a mass connected to a lever system the variations in the positions of which due to variations in the gravitational acceleration produces variations in a lever arm the variation of said lever arm being such that the displacement of the mass is amplified.

2. Device according to claim 1, characterised by the fact that the mass and a spring are so arranged in the lever system, that a variation of the gravitational acceleration changes the lever arm of the mass or of the spring.

3. Device according to claim 2, characterised in that one end of the lever system is connected to a spring holding the system in an inclined position.

4. Device according to claim 3, characterised by the fact that a mass is suspended from the end of the lever system.

5. Device according to claim 2 or 3, characterised by the fact that the spring holds the lever system in a substantially horizontal position and that an auxiliary system comprising movable parts is arranged upon the lever system.

6. Device according to claim 5, characterised by the fact that the auxiliary system consists of a spirit level.

7. Device according to claim 5, characterised by the fact that the auxiliary system consists of a cup in which a ball is moved.

8. Device according to claim 2, characterised by the fact that the lever system comprises a substantially horizontal part connected to a mass, that it is supported upon a knife edge and that it bears a horizontal pendulum, the movement of which amplifies the oscillation of the mass.

9. Device according to claim 2, characterised by a lever system supported upon a knife edge comprising several parts arranged angularly to each other, said parts comprising a substantially horizontal element to which a mass is connected.

10. Device according to claim 9, characterised by the fact that an auxiliary mass is connected to a support projecting from the lever.

11. Device according to claim 2, characterised by the fact that the spring is connected to a frame consisting of a material the temperature coefficient of expansion of which is substantially equal to the temperature coefficient of tension of the spring, but acts in a contrary sense thereto.

12. Device according to claim 11, characterised by the fact that with springs of a temperature coefficient of about $-2.0 \cdot 10^{-6}$ invariable nickel iron alloys are utilised for the frame.

13. Device according to claim 11, characterised by the fact that with

measurement, the second one after transposition to a new station.

When working with the horizontal pendulum according to Figs. 6 to 9 at the starting point of the measurement the balance beam W is released and the horizontal pendulum P is also released, while the spring remains fixed. The position of the horizontal pendulum P is determined on a graduation mounted in a suitable position. Thereupon all parts are again fixed. After the instrument has been transported to the new station the balance beam and the horizontal pendulum are again released. If the gravitation is different the horizontal pendulum will take up a new position, and from this the variation of gravitation may be calculated. After a reading has been taken the device is again fixed and the fixing of the spring is temporarily released to compensate spring tensions. After the spring has again been fixed release is again effected and reading taken, in order to obtain a basic reading prior to going over to a new position, the reading at this third position being referred to the said basic reading.

In Fig. 10 the spring is mounted in a frame consisting of a material, whose coefficient of expansion is equal to the coefficient of tension of the spring, however with reverse sign.

Figs. 11 and 12 show devices which are composed of two measuring instruments of the kind described. In both cases the two parts are symmetrically arranged. They are rigidly connected together, thus forming a single measuring instrument. The levelling is carried out with less than 1/10 of the hitherto obtained accuracy. The errors of inclination remaining in consequence thereof are, however, more than compensated by the used arrangement, inasmuch as they have equal height at both parts of the combined instrument, but in the opposite sense. Thus it becomes possible to increase considerably the accuracy and especially to diminish the time taken in measuring.

In order to compensate the torsional forces produced by variations of temperature the spring can be composed of two parts of opposed twist.

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1. Measuring instrument for the determination of variations of the gravitational acceleration comprising a mass connected to a lever system the variations in the positions of which due to variations in the gravitational acceleration produces variations in a lever arm the variation of said lever arm being such that the displacement of the mass is amplified.

2. Device according to claim 1, characterised by the fact that the mass and a spring are so arranged in the lever system, that a variation of the gravitational acceleration changes the lever arm of the mass or of the spring.

3. Device according to claim 2, characterised in that one end of the lever system is connected to a spring holding the system in an inclined position.

4. Device according to claim 3, characterised by the fact that a mass is suspended from the end of the lever system.

5. Device according to claim 2 or 3, characterised by the fact that the spring holds the lever system in a substantially horizontal position and that an auxiliary system comprising movable parts is arranged upon the lever system.

6. Device according to claim 5, characterised by the fact that the auxiliary system consists of a spirit level.

7. Device according to claim 5, characterised by the fact that the auxiliary system consists of a cup in which a ball is moved.

8. Device according to claim 2, characterised by the fact that the lever system comprises a substantially horizontal part connected to a mass, that it is supported upon a knife edge and that it bears a horizontal pendulum, the movement of which amplifies the oscillation of the mass.

9. Device according to claim 2, characterised by a lever system supported upon a knife edge comprising several parts arranged angularly to each other, said parts comprising a substantially horizontal element to which a mass is connected.

10. Device according to claim 9, characterised by the fact that an auxiliary mass is connected to a support projecting from the lever.

11. Device according to claim 2, characterised by the fact that the spring is connected to a frame consisting of a material the temperature coefficient of expansion of which is substantially equal to the temperature coefficient of tension of the spring, but acts in a contrary sense thereto.

12. Device according to claim 11, characterised by the fact that with springs of a temperature coefficient of about $-2.0 \cdot 10^{-6}$ invariable nickel iron alloys are utilised for the frame.

13. Device according to claim 11, characterised by the fact that with

springs of a temperature coefficient of about $-0.6 \cdot 10^{-6}$ quartz glass is utilised for the frame.

14. Device according to claim 11, characterised by the fact that the spring is positioned within the frame.

15. Device according to claim 11, characterised by the fact that the frame is of tubular shape and contains the spring in it.

16. Device according to claim 2, characterised by the fact that several instruments of the same sensitiveness to inclination are combined with each other in such a manner, that the variations of inclination are effective upon the several parts of the combined instrument in a contrary sense.

17. Device according to claim 1, characterised by the fact that the spring consists of two parts of opposed twist.

18. The measuring instrument for the determination of variations of the gravitational acceleration substantially as described with reference to the accompanying drawings.

Dated this 14th day of January, 1935.

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