Sept. 27, 1955 K. O. HEINTZ ET AL 2,718,707

INCLINOMETER

Filed Dec. 31, 1953 2 Sheets-Sheet 1

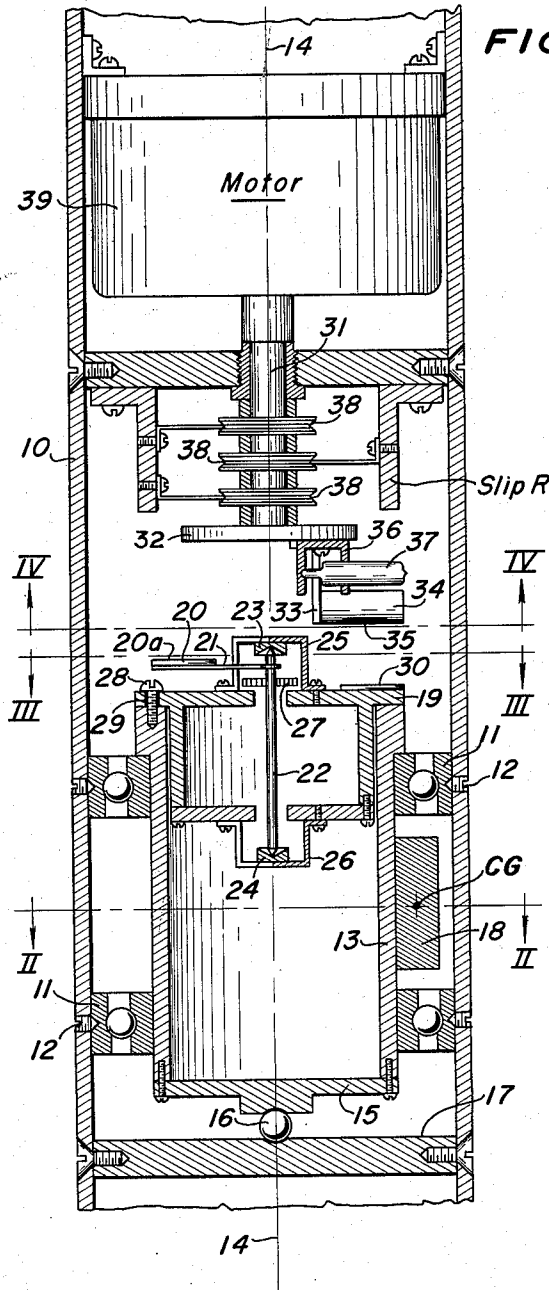


FIG. 1.

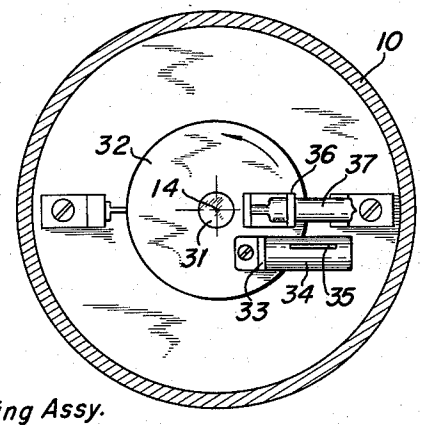


FIG. 4.

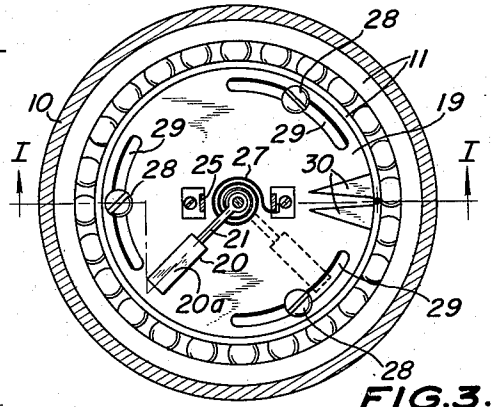


FIG. 3.

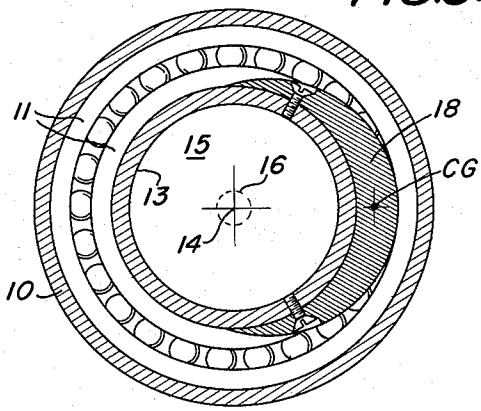


FIG. 2.

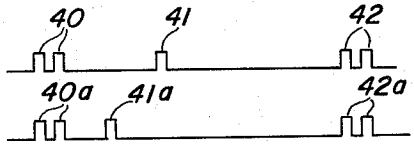


FIG. 5A.

FIG. 5B.

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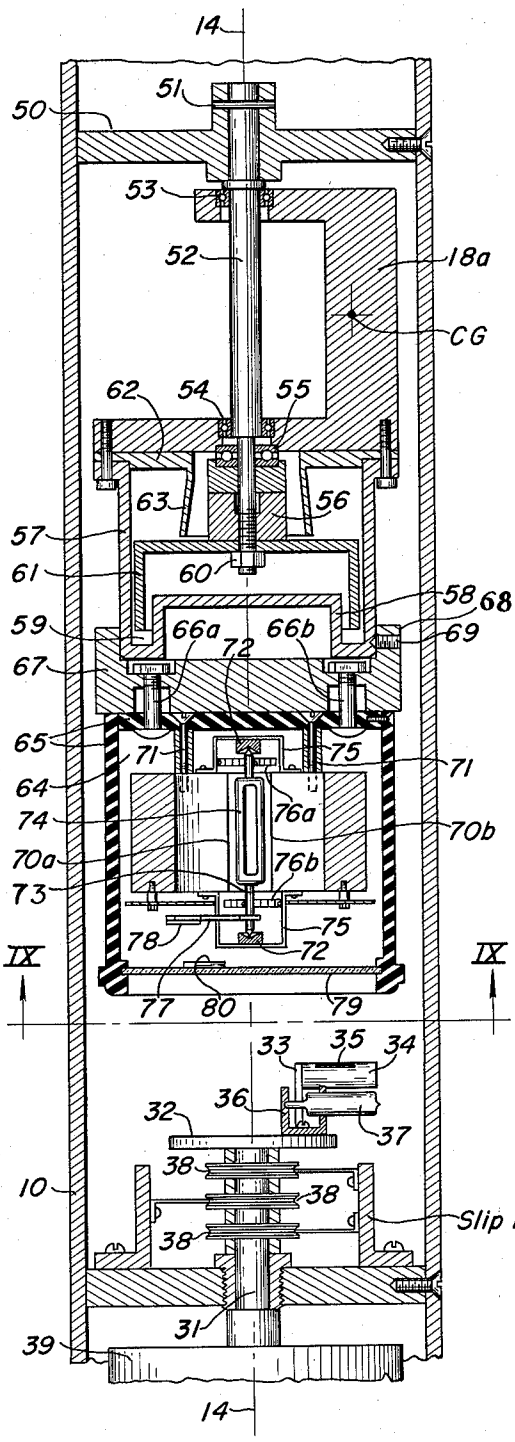
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INCLINOMETER

Filed Dec. 31, 1953 2 Sheets-Sheet 2

FIG. 8.



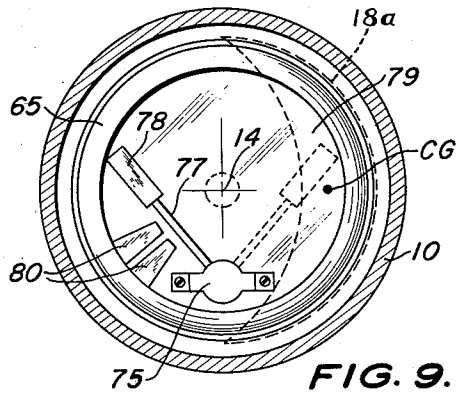


FIG. 9.

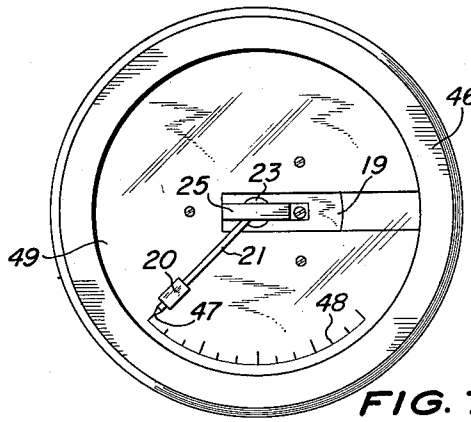


FIG. 7.

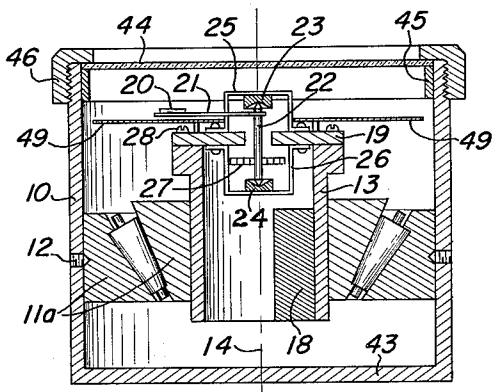


FIG. 6.

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2,718,707

INCLINOMETER

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Application December 31, 1953, Serial No. 401,510

8 Claims. (Cl. 33—215)

The present invention relates to new and improved apparatus for determining the extent of inclination of an object from a vertical position. More particularly, the invention relates to improved apparatus for determining at the surface of the earth the inclination of a well logging instrument or similar device while it is in a well bore in the earth at any desired depth.

In the drilling of oil wells, particularly when employing present day conventional rotary drilling methods, it is often difficult if not impossible to cause the drill always to progress vertically downward at great depths into the earth. Also in conventional drilling practice, it sometimes becomes desirable to divert the drill purposefully away from a vertical direction. In either case it becomes desirable frequently to measure the direction and amount of inclination of the well bore from the vertical throughout its length so that the position of the bottom of the well, or of any intermediate portion of the well bore, relative to the mouth of the well may be calculated with reasonable accuracy. To this end, many forms of apparatus and combinations of apparatus elements have been devised to yield the desired information.

It is one object of the present invention to provide an improved apparatus for determining inclination from the vertical. It is another object of the present invention to provide an improved apparatus which may be used in combination with orientation devices to determine both the direction and amount by which a well bore or a device in the well bore deviates from the vertical. It is a further object of the invention to provide an apparatus which will record this information as the well bore is traversed by the apparatus.

Stated briefly, the apparatus of the present invention comprises a free pendulum, and a smaller, yieldably restrained pendulum which is carried upon the free pendulum. When the apparatus is supported with its central axis in a vertical position, the free pendulum is free to rotate around this central axis carrying the entire restrained pendulum with it. In the aforementioned vertical position, the pendulum arm of the restrained pendulum is also movable around a vertical axis but the restraining element associated with this smaller pendulum causes the small pendulum arm to take up a predetermined position arcuately spaced around the central axis from the center of gravity of the free pendulum. When the central axis of the apparatus is tilted from the vertical position, the center of gravity of the free pendulum moves into a position below the tilted central axis and the restrained pendulum arm moves arcuately, relative to the center of gravity of the free pendulum, from the aforementioned predetermined position toward the direction of tilt of the central axis.

A preferred embodiment of the apparatus of the present invention also comprises at least two mirrored surfaces associated, respectively, with the free pendulum and with the restrained pendulum, a light source adapted to revolve around the central axis of the apparatus,

a photosensitive cell adapted to revolve in fixed relation to the light source and so positioned as to receive reflected light from each of the mirrored surfaces during some portion of each revolution around the central axis, and means for revolving the light source and photosensitive cell around the central axis at a uniform rate.

The nature and objects of the invention can be more fully understood from the ensuing description when considered in conjunction with the accompanying drawings in which:

Figure 1 is an elevation view, partly in section, of one embodiment of apparatus employing the present invention;

Figure 2 is a sectional view along the line II—II of Figure 1;

Figure 3 is a sectional view along the line III—III of Figure 1;

Figure 4 is a sectional view along the line IV—IV of Figure 1;

Figures 5A and 5B represent the type of records produced by recording elements employed with the apparatus of the present invention;

Figure 6 is an elevation view, partly in section of another embodiment of apparatus employing the present invention;

Figure 7 is a plan view of the apparatus of Figure 6;

Figure 8 is an elevation view, partly in section, of a preferred embodiment of apparatus employing the present invention; and

Figure 9 is a sectional view along the line IX—IX of Figure 8.

In the following description of the several figures of the drawing, it is assumed, for purposes of simplification of description and definition, that the apparatus, as described, is held or supported with its principal central axis in a vertical position. It will be appreciated, however, that in normal operation this principal central axis may be tilted away from vertical whereupon certain elements of the apparatus will move relative to this central axis.

Referring first to Figures 1 and 2, the apparatus of this invention may be suitably enclosed within a housing **10** which will generally be cylindrical although it may, of course, be of any other desired shape. Within the housing **10** are a pair of conventional ball or roller bearings **11** whose outer race members may be secured against movement with respect to housing **10** by any appropriate means, such as the set screws **12**. Fitted concentrically within the inner race members of bearings **11** is an elongated, usually cylindrical, support member **13** whose central longitudinal axis **14** is preferably coaxial with respect to the central axis of housing **10**. For purposes of the present description, it will be assumed that both of the aforementioned axes are coaxial and may be referred to indiscriminately by the reference numeral **14**. The lower end of support member **13** may be provided with a plate, or equivalent element, **15** adapted to bear against a suitable thrust bearing, such as the ball thrust bearing **16**, carried on plate **17** within housing **10**.

Affixed to one side of support member **13** is a major mass **18**. The size, shape, and placement of mass **18** upon support member **13** will depend to a large extent upon the "mass symmetry" of support member **13** and upon the distribution of other masses which may be mounted upon member **13**. Since the primary purpose of mass **18**, when combined with support member **13**, is to form a free pendulum adapted to rotate freely around axis **14**, it will be appreciated that the size, shape, and placement thereof should be chosen so that the effective center of gravity of these elements is adjacent the point CG in Figures 1 and 2. Hereinafter and in the appended claims, this effective center of gravity will be referred to generally as the

center of gravity of the major mass **18**. From the foregoing, it will be appreciated that although the mass **18** has been shown exterior of the support member **13**, the mass may, if desired, be mounted on the interior of the support member so long as the effective center of gravity thereof is eccentric (i. e. spaced radially) with respect to central axis **14**.

It will be apparent to workers in the art that, when the central axis **14** is vertical, the support member **13** carrying mass **18** is free to rotate around axis **14**. However, when the apparatus is tilted so that, for example, the upper end of axis **14** is tilted to the left within the plane represented by the surface of the paper on which Figure 1 is drawn, mass **18** will rotate around axis **14** until its center of gravity is in the same plane as axis **14** and in the direction of tilt of said axis. In other words, with the assumed direction of tilt mentioned above, mass **18** would move arcuately through 180 degrees from the position shown in the drawing. Movement of mass **18** would, of course, cause support member **13** to turn about its central axis.

Carried upon the upper end of support member **13** by a plate, or equivalent supporting structure, **19** is a restrained pendulum or weighted arm assembly comprising a minor mass **20** affixed to the outer extremity of a lever arm **21**. The weight of minor mass **20** is but a small fraction of the weight of mass **18** and need be only large enough to impart a turning moment to lever arm **21**. As may be seen from Figure 1, the inner extremity of lever arm **21** is secured to a vertical shaft **22** so that arm **21** is held in a horizontal position when axis **14** and shaft **22** are vertical. In other words, the lever arm **21** is arranged in a plane which is substantially perpendicular to the axis of the shaft **22**. Shaft **22** is mounted for substantially frictionless rotation on jeweled pivot bearings **23** and **24**, or the equivalent. Pivot bearings **23** and **24** are, in turn, held in place relative to plate **19** by brackets **25** and **26** respectively. Resilient spring means, such as a flat spiral hair spring **27** encircling shaft **22**, is anchored at its outer end to bracket **25** and thence through plate **19** to support member **13**. The inner end of spiral spring **27** is operatively connected to lever arm **21** by direct attachment to shaft **22** on which lever arm **21** is secured.

It will be appreciated that spring **27** may be so adjusted that, when shaft **22** is vertical, arm **21** and mass **20** will always come to the resting or reference position represented by the solid-line outline of these elements in Figure 3. On the other hand, when the upper end of shaft **22** is tilted to the right in the plane of the paper on which Figure 1 is drawn, mass **20** will produce a turning moment on arm **21**, against the yieldable restraining action of spring **27**, and cause the mass **20** and arm **21** to seek the position represented by the broken-line outline of these elements shown in Figure 3. The movement of mass **20** from the resting, or reference, position around the axis of shaft **22** will be proportional to the amount of tilt of shaft **22**.

It is important to the operability of the apparatus of the present invention that, when the central axis **14** is in a vertical position, the center of gravity of mass **20** should be spaced arcuately around axis **14** with respect to the center of gravity CG of the mass **18**. Accordingly, plate **19** is preferably secured to support member **13** by a plurality of means, such as screws **28** threaded into support member **13** and passing through arcuate slots **29** provided in plate **19**. By suitable initial placement of plate **19** upon support member **13** and slight rotary adjustment of plate **19** around axis **14** before tightening screws **28**, the normal resting position of mass **20** may be spaced arcuately around axis **14** from center of gravity CG in the relative position represented in Figures 1, 2, and 3. In general, the normal resting position of the center of gravity of minor mass **20** should be spaced arcuately around axis **14** from the center of gravity CG of major mass **18** by an amount less than 180 degrees and preferably not less than about 90 degrees.

In the drawing of Figures 1 and 3 the longitudinal axis of shaft **22** has been represented as coaxial or coincident with the axis **14** of support member **13**. It is to be noted, however, as will become apparent from subsequent description of the embodiment shown in Figures 8 and 9, that the axis of shaft **22** need not be coincident with axis **14** so long as the two axes are substantially parallel to each other. Stated broadly, the lever arm **21** should move in a plane which is substantially perpendicular to the axis **14**, and the axis of shaft **22** should be substantially perpendicular to the plane in which lever arm **21** moves.

The apparatus of the present invention is readily adaptable to yield inclination indications at a remote distance from the apparatus thus far described. To this end there may be combined with the inclination responsive elements described above photoelectric means, similar to the means disclosed by A. B. Hildebrandt in United States Patent 2,614,334 issued October 21, 1952. Thus, the mass **20** may be provided with a plane mirrored surface **20***a* and there may be affixed to the upper surface of plate **19** one or more plane mirrored surfaces **30**. In the form of apparatus shown in Figures 1 and 3, the respective planes of mirrored surfaces **20***a* and **30** should be substantially horizontal when axis **14** is vertical.

Mounted within housing **10** upon a rotatable shaft **31** is a table member **32**. A bracket **33** carrying an electric lamp within a lamp shield **34** is secured upon table member **32** in a position such that light from the lamp may pass through a slit **35** in shield **34** and shine upon the mirrored surfaces **20***a* and **30** when shaft **31** is rotated. Also secured to table member **32** is a bracket **36** carrying a photosensitive cell **37** in a fixed relation to the light source **35**. Photosensitive cell **37** is positioned relative to light source **35** and mirrored surfaces **20***a* and **30** so that during some portion of each revolution of shaft **31** and table member **32** said cell will receive light reflected from each of the mirrored surfaces. As may be seen from Figure 1, the shaft **31** is preferably mounted coaxial with respect to the central axis **14**. A plurality of slip rings **38** carried upon shaft **31** provide suitable sliding contacts for electrical connections leading to and from the photosensitive cell **37** and the source of light within light shield **34**. Shaft **31** may be driven at a uniform rate by a motor **39** mounted within housing **10**. As will be apparent to workers in the art, motor **39** may be a clock-work motor or a small electric motor and may include a gear reduction box (not shown) between motor **39** and shaft **31**.

Referring now to Figures 5A and 5B there are shown, respectively, two graphs such as would be produced by the apparatus of the present invention when employed with the elements shown and described in conjunction with Figure 5 of the aforementioned Hildebrandt Patent 2,614,334. In the drawing of Figures 5A and 5B of the present disclosure, it is assumed that a single, relatively narrow, mirrored surface **20***a* is arranged upon minor mass **20** and that two closely spaced mirrored surfaces **30** have been mounted upon plate **19** in the relation shown in plan view in Figure 3. It is further assumed that the light source **35** and photosensitive cell **37** scan these mirror surfaces in a clockwise direction. When the axis **14** of the apparatus is held in a vertical position, passage of the light source and photosensitive cell over mirrored surfaces **30** produces the two "kicks" or responses **40** shown in Figure 5A. Passage of the light source and photosensitive cell over mirrored surface **20***a* in the course of revolution of table member **32** produces the single kick **41**. Since the rate of movement of the recording chart and the rate of scanning of the mirrored surfaces are both held constant, the distance between kicks **40** and **41** are proportional to the arcuate spacing of mirrored surfaces **30** from mirrored surface **20***a*. Continued revolution of table member **32** causes the light source and photosensitive cell to pass once again over the mirrored surfaces **30** and produces the kicks **42**.

When the axis **14** of the apparatus is tilted away from

vertical, the mass **18** moves to a position such that its center of gravity is below the tilted axis, and this motion causes mirrored surfaces or indicants **30** likewise to move. Under these conditions of tilt, the mass **20** carrying mirrored surface or indicant **20***a* moves arcuately toward mirrored surfaces **30** by an amount proportional to the inclination of axis **14**. As shown in Figure 5B, this action causes the kick **41***a*, produced by reflection of light from mirrored surface **20***a*, to move closer to the kicks **40***a*, produced by reflection of light from mirrored surfaces **30**; and the distance between kicks **40***a* and kick **41***a* is proportional to the amount of tilt applied to axis **14**. As will be apparent to workers in the art, the actual relation between the angle of tilt and the amount of separation between the recorded kicks **40***a* and **41***a* may readily be determined from a calibration chart provided for each inclinometer and recorder assembly.

Turning now to Figures 6 and 7 there is shown a modified embodiment of the apparatus of the present invention adapted for direct reading. In this embodiment, the housing **10** is provided with a flat base plate **43** whose outer plane surface is perpendicular to the central axis **14**. The upper end of housing **10** may be closed by a transparent window **44** which may be held in place by appropriate internal and external rings **45** and **46**, respectively.

Secured within housing **10**, by means such as set screws **12**, is a conventional tapered roller bearing assembly **11***a* which may serve not only as a swivel bearing but also as a thrust bearing. Secured centrally within the inner race element of the bearing assembly **11***a* is a light weight support member **13** having a major pendulum mass **18** secured therein with the center of gravity of said mass eccentric with respect to the axis **14**. A restrained pendulum or weighted arm assembly comprising the plate **19**, minor pendulum mass **20**, lever arm **21**, pivot shaft **22**, pivot bearings **23** and **24**, pivot support brackets **25** and **26**, and spiral hair spring **27** is mounted upon the upper end of support member **13**. As in the embodiment illustrated and described in conjunction with Figure 1, the plate member **19** is preferably affixed to support member **13** by means of screws **28** which threadably engage support member **13**. Arcuate slots, similar to the slots **29** shown in Figure 3, may be provided in plate **19** although these slots are not visible in Figures 6 and 7. When the apparatus of Figures 6 and 7 is assembled, plate **19** may be mounted upon support member **13** and its position adjusted so that, when central axis **14** is vertical, the center of gravity of mass **20** is spaced arcuately around said axis a suitable amount relative to the center of gravity of mass **18**.

In the embodiment of apparatus shown in Figures 6 and 7, the outer extremity of lever arm **21** may be provided with a pointer **47**, or other suitable indicant, which may cooperate with a calibrated indicant scale **48** carried upon a dial plate **49** which may be suitably affixed to plate **19** or support member **13**. It will be apparent that lever arm **21** must be spaced slightly above dial plate **49** and also that the perimeter of dial plate **49** must not drag against the walls of housing **10**. Indicant scale **48** may be calibrated to indicate directly the degrees of inclination of central axis **14**.

Referring now to Figures 8 and 9 there is shown a preferred embodiment of apparatus in accordance with our invention, this embodiment of apparatus being particularly adaptable to use as a well bore inclinometer. Besides the elements shown in the drawing, the housing **10** may include suitable apparatus, such as a recording magnetic compass or a gyroscope for azimuthal orientation of the apparatus. Orientation apparatus of the above indicated type is well known in the prior art and does not form a direct part of the present invention. Accordingly, such orientation apparatus will not be described herein.

Suitably affixed within housing **10**, substantially perpendicularly with respect to the central longitudinal axis **14** thereof, is a mounting plate **50**. Arranged coaxially with respect to axis **14** and anchored centrally in plate **50** as by means of transverse pin **51**, is a vertical shaft **52** depending below plate **50**. Journaled upon shaft **52**, as by upper and lower precision ball bearings **53** and **54**, respectively, is a major pendulum mass **18***a*. Mass **18***a* is so shaped that its effective center of gravity CG is eccentric with respect to shaft **52** and central axis **14**, and it is supported for rotation on shaft **52** by ball thrust bearing **55** and a nut, or other retaining element, **56** fixedly engaging shaft **52**.

Depending from and suitably affixed to the lower end of mass **18***a* is a cylindrical cup-like member **57** which functions, in part, as a support member analogous to the support member **13** shown in Figures 1 and 6. The lower end of cup or support member **57** is closed by an inwardly depressed bottom portion **58** which thereby forms in the lower end of cup member **57** an annular cavity **59**. Rigidly affixed to the lower end of shaft **52** as by means of nut **60** is an inverted cup **61** having the rim thereof concentric in the annular cavity **59**. The cup-like support member **57** is partially filled with a viscous liquid, such as a high viscosity-index lubricating oil or other similar viscous liquid whose viscosity is not appreciably changed by changes in temperature. It will be appreciated that the inverted cup **61** and the cup-like support member **57** cooperate, through the medium of the viscous liquid contained therein, to provide a viscous drag capable of damping oscillatory movement of mass **18***a* around shaft **52** and relative to housing **10**.

So that the fluid contained within cup **57** will not be readily spilled therefrom, the upper end of cup **57** may be closed by a plate **62** having a central opening adapted to pass shaft **52** as shown in the drawing. A skirt **63** depending from plate **62** around the periphery of the aforesaid opening may also be provided to prevent spillage of the fluid out of cup **52**.

Depending from the lower end of cup-like support member **57** is a restrained pendulum assembly, designated generally by the numeral **64**. In a preferred embodiment of our invention, the restrained pendulum assembly **64** is provided by suitable, and minor, modification of a commercially available direct current 100 microampere panel-type electric meter whose outer case is designated by the numeral **65**. The electrical terminals **66***a* and **66***b* of the microammeter are secured to, and electrically short-circuited by, a circular metallic plate **67** having an upwardly projecting rim **68** adapted to embrace the lower end of cup-like support member **57**. A plurality of set screws **69** penetrating transversely through the rim **68** provide means for securing the plate **67** to support member **57** and also provide means whereby the orientation of the restrained pendulum assembly **64** may be adjusted relative to the free, or major, pendulum mass **18***a*.

Contained within the microammeter case **65** is a permanent horseshoe magnet having the pole pieces **70***a* and **70***b* providing a suitable air-gap therebetween. The aforesaid magnet is conventionally spaced from the walls of case **65** and affixed relative thereto by means, such as screws and spacers **71**. Pivotally supported within the air gap of the magnet by upper and lower jewelled bearings **72** is a vertical shaft **73** carrying a small coil of copper wire **74**, the terminals of which are electrically connected in conventional manner (by means not shown) to terminal screws **66***a* and **66***b*. The jewelled pivot bearings **72** are rigidly held in place relative to the horseshoe magnet and other supporting structure by suitable brackets **75**. As may be seen from Figure 9, the pivot bearings **72** need not be placed so that the shaft **73** is coaxial with respect to the central axis **14**. The axis of shaft **73** may, if desired, be eccentric with respect to central longitudinal axis **14** but it is essential that, when the axis of shaft **73** is eccentric to axis **14**, then the axis of shaft **73** must be substantially parallel to axis **14**.

Encircling the upper and lower ends of shaft **73** are,

respectively, spiral hair springs **76***a* and **76***b*. The inner ends of spiral springs **76***a* and **76***b* may be secured to shaft **73** while the outer ends thereof are secured to support brackets **75**. In a preferred form of the invention the springs **76***a* and **76***b* encircle the shaft **73** in opposite directions, i. e. in a manner such that, when shaft **73** turns in a given direction, it will tend to tighten the spiral **76***a* and simultaneously loosen the spiral **76***b*.

Affixed to the lower portion of vertical shaft **73** is a horizontal lever arm **77** which may be the conventional indicator needle of the microammeter mentioned hereinbefore. Adjacent the outer extremity of the lever arm **77** there is secured thereon a minor mass **78**. In the preferred embodiment wherein restrained pendulum **64** comprises a direct current microammeter, the mass **78** may consist of a small strip of mirror-backed glass which is cemented to the needle or arm **77**. The purpose of the mirrored surface will be explained hereinafter.

It will be understood from consideration if the foregoing description that the tension of the two counterwound spiral springs **76***a* and **76***b* may be adjusted relative to each other such that, when shaft **73** and central axis **14** are vertical, the arm **77** and minor mass **78** may be caused to take a normal resting position such as is represented by the full-line outline of these elements shown in Figure 9. The position of this normal resting position relative to the center of gravity of the mass **18***a* may then be adjusted by loosening screws **69** and turning the entire restrained pendulum assembly **64** relative to major mass **18***a* until minor mass **78** is positioned arcuately around axis **14** relative to mass **18***a* as represented in Figure 9. It will be appreciated that, when the axis **14** is tilted so that its upper end is above the center of gravity CG of the major mass **18***a*, the arm **77** and the minor mass **78** will then move (against the restraining action of at least one of the spiral springs **76***a* or **76***b*) toward the position represented in Figure 9 by the broken line outline of these arm and minor mass elements.

Attention is directed to the fact that the electrically short-circuited coil **74**, positioned in the magnetic field existing between the permanent magnet poles **70***a* and **70***b*, exerts a damping action (as distinguished from a constant restraining action) which minimizes oscillatory swing of the minor mass **78** around the axis of the shaft **73**. It will be apparent that the coil **74** may, if desired, be replaced by an equivalent small sheet of non-magnetic metal similarly mounted upon the shaft **73**. Accordingly, the coil (or sheet of non-magnetic metal) **74** and the permanent magnet having poles **70***a* and **70***b* may be described as magnetic means operatively associated with the lever arm **77** and the supporting member for damping oscillation of the minor mass **78**.

The face of the microammeter which constitutes a major portion of the structure of restrained pendulum **64** is preferably covered by a sheet of transparent material **79**, such as glass or plastic. One or more narrower strips of mirror surfaced glass **80** may be cemented to the transparent material **79** at a predetermined position thereon to provide a reference position indicant similar to the indicant **30** referred to in connection with Figures 1 and 3.

Positioned within housing **10** below the transparent face of restrained pendulum assembly **64** is a source of light **35** and a photosensitive cell **37** which may be mounted for rotation in fixed relation around the central axis **14**. Since the structure, function, and operation of these elements may be identical with that already described in conjunction with Figures 1 and 4, a repetition of that description here is not necessary.

It is to be understood that the specific forms of apparatus illustrated in the drawings are by way of example and that the invention is not restricted thereto, but that obvious variations thereof may be made by persons skilled in this particular art without departing from the scope of the invention which is to be limited only by the following claims.

What we claim is:

1. An inclinometer comprising, in combination: a support member; means mounting said support member for free rotation around the central longitudinal axis of said member; a major mass affixed to said support member with the center of gravity of said mass eccentric to said central longitudinal axis; a weighted arm assembly, said assembly comprising a lever arm movable in a plane substantially perpendicular to said central longitudinal axis, pivot means mounting said lever arm upon said support member for rotation of the lever arm around a second axis which is substantially perpendicular to said lever arm plane, a minor mass mounted upon said lever arm with the center of gravity of said minor mass eccentric to said second axis, and resilient spring means anchored at one end thereof to said support member and operatively connected at the other end thereof to said lever arm to restrain rotary motion of the lever arm around said second axis; and means on said support member for adjusting the position of said weighted arm assembly so that the center of gravity of said minor mass is spaced arcuately around said central longitudinal axis relative to the center of gravity of said major mass.

2. Apparatus in accordance with claim 1 in which said second axis is coextensive with respect to said central longitudinal axis.

3. Apparatus in accordance with claim 1 in which said pivot means includes a shaft carrying said lever arm, and said resilient spring means consists of a pair of spiral springs encircling said shaft in opposite directions, with the inner end of each spring affixed to said shaft and the outer end of each spring anchored to said support member.

4. An inclinometer comprising, in combination: a housing; an elongated support member; means mounting said support member within said housing for free rotation around the central longitudinal axis of said support member; a major mass affixed to said support member with the center of gravity of said mass eccentric to said longitudinal axis; a weighted arm assembly, said assembly comprising a lever arm movable in a plane substantially perpendicular to said longitudinal axis, pivot means mounting said lever arm upon said support member for rotation of the lever arm around a second axis which is substantially perpendicular to said lever arm plane, a minor mass mounted upon said lever arm with the center of gravity of said minor mass eccentric to said second axis, and resilient spring means anchored at one end thereof to said support member and operatively connected at the other end thereof to said lever arm to yieldingly restrain rotary motion of said lever arm around said second axis; and means on said support member for initially adjusting the position of said weighted arm assembly so that the center of gravity of said minor mass is spaced arcuately around said central axis a selected amount relative to the center of gravity of said major mass.

5. An inclinometer in accordance with claim 4 having, in combination therewith: means operatively associated with said support member and with said housing for damping oscillation of said major mass around said central longitudinal axis whenever said axis is tilted away from vertical.

6. An inclinometer in accordance with claim 5 in which said means for damping oscillation of said major mass includes a viscous fluid, and in which said weighted arm assembly includes magnetic means operatively associated with said lever arm and said support member for damping oscillation of said minor mass around said second axis whenever the last-mentioned axis is tilted away from vertical.

7. An inclinometer in accordance with claim 4 and including: a first indicant affixed to said lever arm; a second indicant affixed to said support member at a selected reference position; and means carried within said housing and operatively associated with said indicants for pro-

ducing outside said housing indications characteristic of movement of the first indicant relative to the second indicant.

8. An inclinometer in accordance with claim 7 in which both said indicants are plane-mirrored surfaces arranged in planes which are perpendicular to said central longitudinal axis and said means for producing an indication outside said housing includes a light source adapted to revolve around said central longitudinal axis, a photosensitive cell adapted to revolve in fixed relation to said light source and so positioned as to receive reflected light from each of said mirrored surfaces during some portion of each

revolution around said longitudinal axis, and means for revolving said light source and said photosensitive cell around said axis at a uniform rate.

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