United States Patent [19]

Kijima

[11] 3,772,798

[45] Nov. 20, 1973

[54] **SUSPENSION TYPE LEVELLING DEVICE**

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[22] Filed: **Sept. 15, 1971**

[21] Appl. No.: **180,718**

[30] **Foreign Application Priority Data**

Sept. 22, 1970 Japan 45/83078
Nov. 9, 1970 Japan 45/98556

[52] **U.S. Cl.** **33/348,** 33/391, 33/291, 73/515, 248/363, 308/1

[51] **Int. Cl.** **G01c 9/12,** G01c 9/14

[58] **Field of Search** ..... 33/391, 346, 397–400, 33/291, DIG. 1, 348; 248/1, 363; 308/1, 10

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Primary Examiner—Robert B. Hull
Attorney—Silverman & Cass

[57] **ABSTRACT**

A suspension type levelling device comprising a fixed member provided with a convex or concave bottom surface and a suspended member provided with a concave or convex top surface complementary to the bottom surface of the fixed member having substantially the same curvature. A thin liquid film is interposed therebetween so as to produce an attractive force between the both members. The suspended member maintains a position representing the true level or, in other words, the line connecting the center or axis of curvature of the top surface of the suspended member and its center of gravity remains in a vertical position independent of an inclined position of the fixed member. The vertical position can be obtained by suitably the surface tension of the liquid, viscosity of the liquid, weight of the suspended member, the contacting surface, the thickness of the liquid film and the radius of curvature.

5 Claims, 14 Drawing Figures

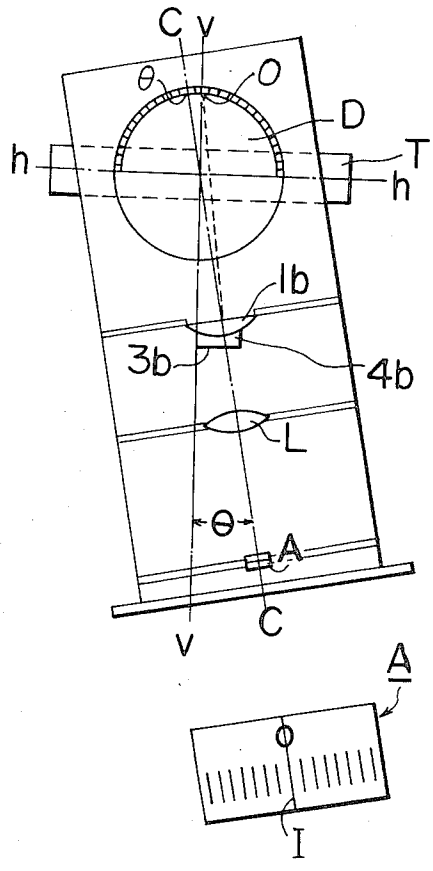


FIG. 1

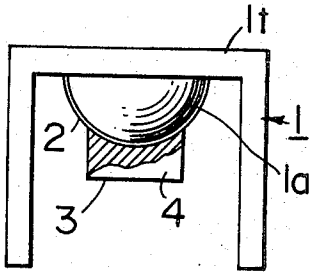


FIG. 2

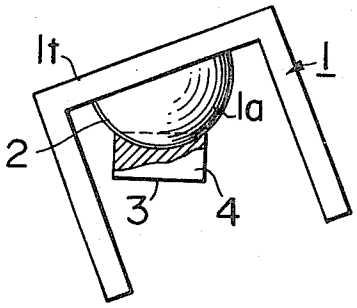
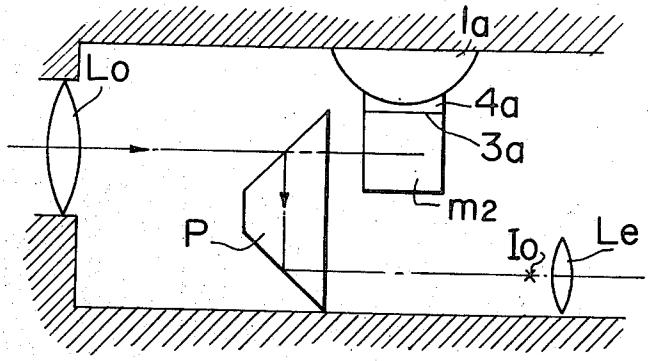


FIG. 3



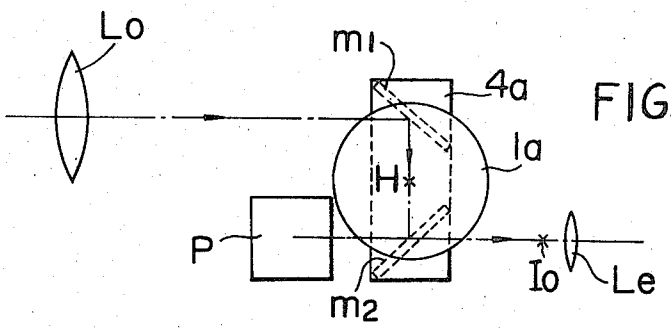


FIG. 4

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FIG. 5

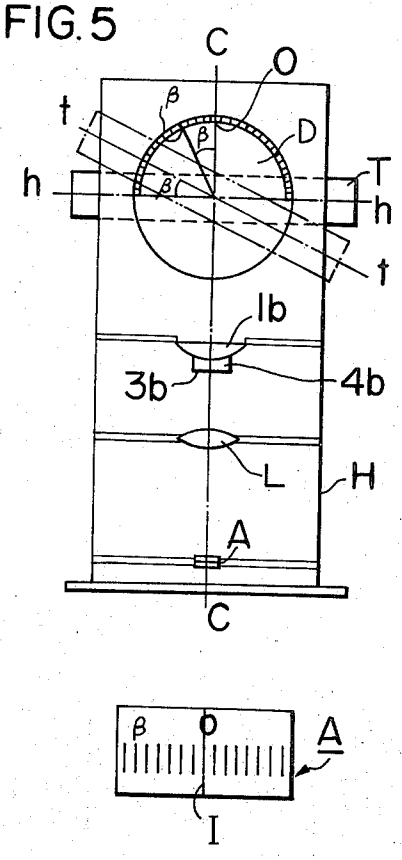


FIG. 6

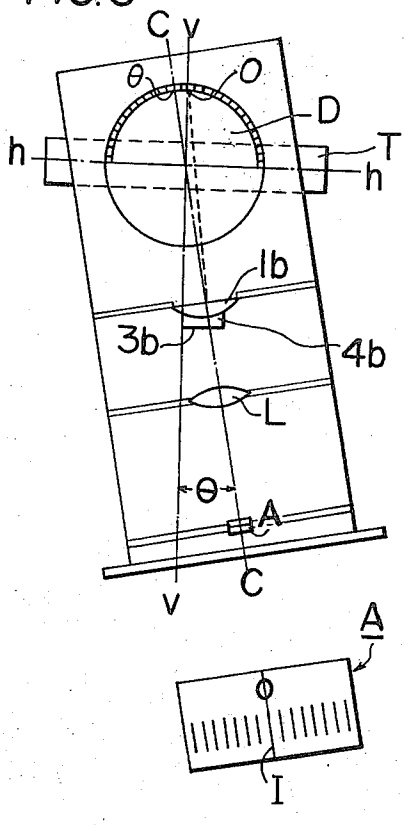


FIG. 7

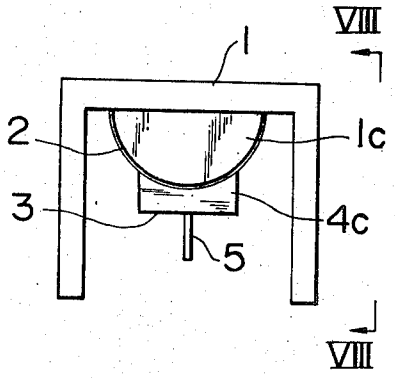
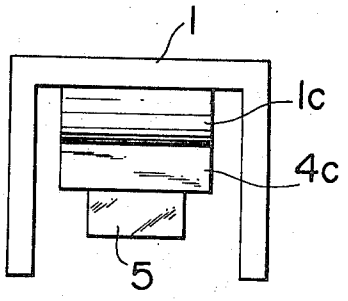


FIG. 8



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FIG.9

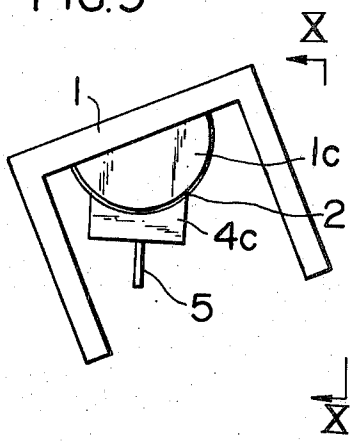


FIG.10

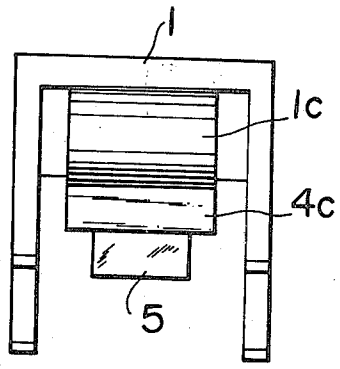


FIG.11A

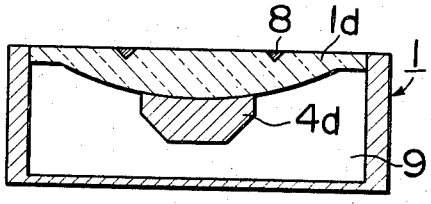


FIG.12A

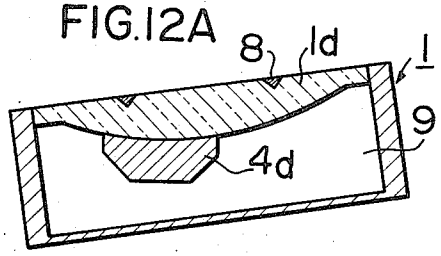


FIG.11B

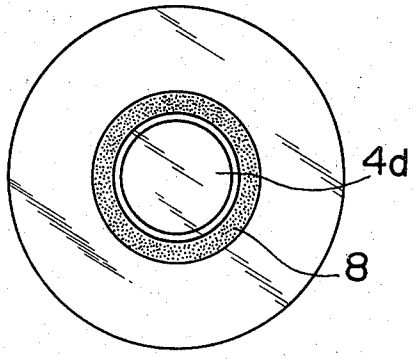
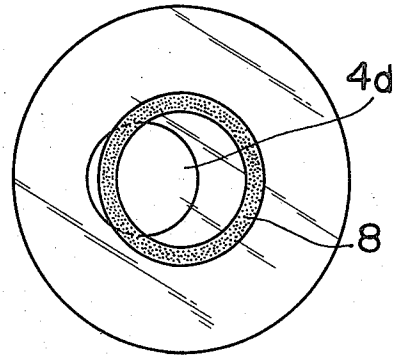


FIG.12B



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SUSPENSION TYPE LEVELLING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a suspension type levelling device conveniently used in optical devices such as automatic leveling devices.

2. Description of Prior Art

Heretofore it was known to provide a level indicator using the bubble in liquid principle. It is also known to provide a vertical line indicator using the principle of a pendulum.

The known devices using the above principles are not practical for use with a portable type optical device such as an automatic leveling device. This is because of the fact that the known devices are influenced by vibration when they are set on such an optical device. In order to stabilize the vibration, some kind of vibration dampers are required, but such devices are usually costly and complicated.

SUMMARY OF THE INVENTION

The present invention has for its object to mitigate such disadvantages of the known levelling means or vertical indicating means, while using an entirely novel idea to suspend an indicating means provided with a convex top surface down from a complementary concave supporting member with the interposition of a thin liquid film, such as silicone oil film, therebetween.

In a particular form of the invention the curved surface may be a spherical surface. In another form of the present invention the curved surface may be a cylindrical surface.

The center of curvature and the axis of curvature are both intended to be enbraced by the term "datum of curvature" used hereinafter.

In accordance with the present invention, by suitably selecting the size and curvature of the curved surfaces of the convex and concave elements, weight of the suspended element, and viscosity of the interposed liquid, an optical device having an ideal damping characteristic may be realized.

BRIEF DESCRIPTION OF THE DRAWING

For a better understanding of the invention, reference is made at the accompanying drawings, in which:

FIGS. **1** and **2** are schematic illustrations, showing an embodiment of the present invention;

FIG. **3** is a schematic side view of the optical system for an automatic levelling device, embodying the present invention;

FIG. **4** is a schematic plan view of the optical system of the system shown in FIG. **3**;

FIG. **5** is a schematic view of the optical system of a theodolite incorporating the levelling device according to the present invention, shown with its optical axis aligned with the vertical direction;

FIG. **6** is a schematic view of the optical system of FIG. **5**, shown with its optical axis deviated from the vertical direction;

FIG. **7** is an end view of another embodiment of the levelling device according to the present invention;

FIG. **8** is a side view, taken from the direction of the arrows VIII—VIII, of the embodiment of FIG. **7**;

FIG. **9** is an end view of the embodiment of FIG. **7**, shown at a position slightly deviated from its horizontal position;

FIG. **10** is a side view, taken from the direction of the arrows X—X of the embodiment in the position of FIG. **9**;

FIGS. **11A** and **11B** are respectively, a sectional view and a plan view of a simple level embodying the present invention; and

FIGS. **12A** and **12B** are, respectively a sectional view and a plan view of the simple level, shown in a different posture.

Like parts are designated by like numerals and symbols throughout the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. **1** and **2**, an embodiment of the levelling device according to the present invention comprises a legged body **1**, of which top board **1***t* can be held either at a horizontal posture or at an inclined posture by means of the legs thereof. With the embodiment of FIGS. **1** and **2**, if the legs of the body **1** are placed on a horizontal surface, the top board **1***t* is held horizontal, while if the legs are placed on an inclined surface, the top board **1***t* is similarly inclined. The top board **1***t* of the body **1** carries a downwardly convex spherical suspending member **1***a* integrally formed therewith. The surface of the spherical member **1***a* is coated with a thin liquid film **2**, and a weight member **4** is suspended from the suspending member **1***a* in such a manner that an upwardly concave spherical top surface of the weight member **4** is slidably carried by the downwardly convex spherical surface of the suspending member **1***a* with interposition of the thin liquid film **2**. An example of the material for the thin liquid film **2** is, for instance, silicone oil, but the invention is not restricted to the use of silicone oil. The radius of curvature of the concave spherical top surface of the weight member **4** is made substantially identical with that of the convex spherical surface of the suspending member **1***a* or more preferably, is made slightly smaller than that of the latter to compensate for the thickness of the thin oil film.

The weight member **4** has a central axis, which passes through both the center of curvature of its concave top surface and the center of gravity of the weight member **4**, and the weight member **4** is suspended in such a manner that the central axis always passes through the center of curvature of the convex spherical surface of the suspending member **1***a*. A planar bottom surface **3** of the weight member **4** intersects the aforesaid central axis of the weight member **4**, and the planar surface **3** is preferably perpendicular with respect to the central axis.

The sliding relation between the aforesaid concave surface of the weight member **4** and the convex surface of the suspending member **1***a* is such that the gravity acting on the weight member **4** causes the weight member **4** to assume the lowermost possible position along the convex spherical surface of the suspending member **1***a* of the body **1**, regardless of the posture of the body **1**, provided that the weight member **4** does not touch any other parts of the body, such as the legs of the body. Since the plane tangential to the convex spherical surface of the suspending member **1***a* at the lowermost point thereof is always horizontal, the aforesaid central axis of the suspended weight member **4** is always kept vertical, so as to hold its planar bottom surface **3** horizontal, regardless of the posture of the body

1. The movement of the weight member 4 along the convex spherical surface of the suspending member 1*a* is similar to the movement of a drop of water hanging on a tree leaf at the lowermost position thereof.

When the top board 1*t* of the legged body 1 is inclined from its horizontal position, as shown in FIG. 1, to a non-horizontal position, as shown in FIG. 2, the suspended weight member 4 slides along the convex spherical surface of the suspending member 1*a* until the suspended weight member 4 assumes its lowermost possible position, as pointed out in the foregoing. The actual motion of the weight member 4 depends on the surface tension and viscosity of the liquid constituting the thin liquid film 2, the weight of the suspended weight member 4, the contact area between the suspending member 1*a* and the suspended weight member 4, the thickness of the liquid film 2, and the radii of curvature of the convex spherical surface of the suspending member 1*a* and the concave spherical top surface of the suspended weight member 4.

From the description of the basic elements of the invention set forth above, it will be seen that several important objects have been achieved.

It is an important object of the present invention to provide an improved levelling device capable of presenting a reference horizontal plane, which consists of a body 1 having a suspending member 1*a*, a suspended weight member 4, slidably carried by the suspending member 1*a* of a body 1 through a liquid film, and a planar reference surface 3 formed at the bottom of the suspended weight member 4, whereby the planar reference bottom surface 3 is kept horizontal regardless of the posture of the body 1 by properly selecting the values of the aforelisted constants.

In order to suspend a weight member such as 4 from a body such as 1 in a pivotal fashion, it has been known to use a string or a strap, in combination with a suitable damper for preventing the weight member from vibrating. Such known suspending means, however, has a shortcoming in that its anti-impact properties are rather poor and the correction of the shape and elasticity of the string or strap is difficult to accomplish. Accordingly, with such known suspending means, the allowable inclination of the body 1 for ensuring proper levelling has been restricted to at most 20 minutes, namely one third of one degree. To obviate such difficulty, it has been proposed to use a free surface of liquid for allowing a sizeable inclination of the body 1. The use of the free surface of a liquid, however, causes difficulty in that such free liquid surface is susceptible to rippling, especially when a wide area of the free surface is used, and it is extremely difficult to completely eliminate adverse effects due to such ripples.

Therefore, the present invention does not use either the string type suspension or the free liquid surface type suspension. For instance, the present invention uses a suitable surface tension of a liquid film 2 for suspending the weight member 1*a*, so as to ensure the free sliding of the suspended weight member 4 along the spherical surface of the suspending member 1*a*, in response to the inclination of the body 1.

The inventor has succeeded in providing stable movement of such suspended weight member 4, without using any damper, simply by selecting a proper combination of the surface tension and the viscosity of the liquid film 2, the weight of the suspended weight member 4, the contact area between the suspended weight member 4 and the suspending member 1*a*, the thickness of the liquid film 2, and the radii of curvature of the coacting convex and concave surfaces of the suspending and suspended members 1*a* and 4.

It is another feature of the invention that the area of the reference horizontal planar surface 3 can be made wider, as compared with the corresponding area of conventional levelling devices.

Furthermore, the elimination of dampers for stabilizing the motion of the movable suspended member according to the present invention simplifies the structure of the levelling device, so that the manufacturing cost of the levelling device can also be reduced.

FIGS. 3 and 4 illustrate an automatic levelling device, which embodies the principles of the present invention as described hereinbefore by referring to FIGS. 1 and 2. In FIGS. 3 and 4, a suspending member 1*a* having a downwardly convex surface, which is similar to the suspending member 1*a* of FIG. 1, is integrally secured to the body of the device carrying an objective lens L_o, a rectangular prism P, and an eye lens L_e. Thus, the suspending member 1*a*, the objective lens L_o, the rectangular prism P, and the eye lens L_e can tilt together, if the body tilts. A weight member 4*a* having a concave spherical top surface and a planar bottom surface 3*a* is suspended so as to slidably contact the convex spherical surface of the suspending member 1*a*, in a manner similar to that in the embodiment of FIGS. 1 and 2, so that the bottom planar surface 3*a* of the suspended weight member 4*a* can be kept horizontal regardless of the posture of the spherical surface of the suspending member 1*a*. A pair of planar reflective mirrors m_1 and m_2 are secured to the bottom planar surface 3*a* in such a manner that the reflecting surfaces of the two mirrors are always kept vertical and intersect with each other at right angles. In the optical system of the embodiment of FIGS. 3 and 4, the incident light beams from the objective lens L_o are projected to and reflected by the mirrors m_1 and m_2, and are delivered to the rectangular prism P from where the light beams are directed to the eye lens L_e by double deflections at the prism P. The eye lens L_e produces the image of an object (not shown) from which the incident light beams emanate.

In the embodiment of FIGS. 3 and 4, the tilting of the body is limited to be a few degrees at most. As described in the foregoing, the planar bottom surface 3*a* of the weight member 4*a* is kept horizontal, regardless of the posture of the spherical body 1*a*. As a result, the two mirrors m_1 and m_2 are always kept vertical. Furthermore, the nearly constant distance between the objective lens L_o and the middle point H between the two mirrors m_1 and m_2, taken along the optical axis of the optical system, is selected to be equivalent to one half of the focal length of the objective lens L_o. Thus, the following three conditions are established in the embodiment of FIGS. 3 and 4.

1. The two mirrors m_1 and m_2 are always kept vertical.
2. The tilting angle of the optical system, consisting of the objective lens L_o, the mirrors m_1, m_2, the rectangular prism P, and the eye lens L_e, is comparatively small, for instance, less than a few degrees.
3. The distance between the objective lens L_o and the middle point H of the two mirrors m_1 and m_2 is equivalent to one half of the focal length of the objective lens L_o.

Under the aforesaid three conditions, a viewer looking into the optical system from the right of the eye lens L_e, as seen in FIGS. 3 and 4, can see an object which is located on the same level as the optical system. For instance, if a fine visible reference cross line (not shown) is provided in the optical system, e.g., at a point I_o where the image of an object is formed, the viewer can see through the optical system an object located on the same horizontal level as the reference line. If the device, as illustrated in FIGS. 3 and 4, is used in land surveying, a surveyor can see a surveying pole (not shown) and can accurately determine the height of the device relative to the ground level at the pole, even when the device tilts by an angle within a predetermined range.

In the embodiments of FIGS. 1 and 2 and FIGS. 3 and 4, the surfaces of the suspending and suspended members 1*a* and 4 or 4*a* are assumed to be spherical. The present invention is not restricted to such spherical contact surface between a slidably suspended weight member and a coacting suspending member. The body of the levelling device in any one of the preceding embodiments is allowed to tilt about the center of the spherical surface of the suspending member 1*a* in any direction, but for certain applications, a body is allowed to tilt only about one axis. FIGS. 7 to 10 illustrate another embodiment of the present invention, which is suitable for a machine whose body tilts only about one axis. In FIG. 7, a legged body 1 can be identical with the similarly numbered legged body of the embodiment of FIG. 1, except that the legged body 1 of this embodiment carries a cylindrical suspending member 1*c* integrally secured thereto. The suspending member 1*c* has a downwardly convex cylindrical surface. The central axis of the cylindrical suspending member 1*c* is held substantially horizontal, at right angles to the plane of FIG. 7, which minimizes endwise restraint requirements. A thin liquid film 2 is provided on the cylindrical surface of the suspending member 1*c*. The cylindrical concave top surface of a suspended weight member 4*c* is kept in slidable contact with the liquid film 2 on the cylindrical surface of the suspending member 1*c*, when the weight member 4*c* is suspended by the suspending member 1*c* in the same manner as the embodiment of FIG. 1. The radius of curvature of the cylindrical surface of the suspending member 1*c* is selected to be substantially identical with the corresponding radius of curvature of the concave top surface of the suspended weight member 4*c*. The weight member 4*c* is suspended by properly selecting the surface tension of the liquid film 2, while also considering the values of the viscosity of the liquid film, the weight of the suspended member 4*c*, the contact area between the suspended member 4*c* and the cylindrical suspending member 1*c*, the thickness of the liquid film 2, and the radii of curvature of the cylindrical convex surface of the suspending member 1*c* and the cylindrical concave top surface of the suspended weight member 4*c*. In FIG. 7, the suspended weight member 4*c* is homogeneous, and the mid-plane containing the axis of curvature of the concave cylindrical top surface of the suspended member 4*c* and the lengthwise surface center line on the concave cylindrical top surface passes through the center of gravity of the weight member 4*c*. The suspended weight member 4*c* has a planar bottom surface 3, which intersects perpendicularly the aforesaid mid-plane. A planar mirror 5 is secured to the planar bottom surface 3 of weight member 4*c*, so as to cause the mirror 5 to lie on the aforesaid mid-plane. With the aforesaid relation between the suspending member 1*c* and the suspended member 4*c*, the latter member 4*c* is always kept at the lowermost position along the downwardly convex cylindrical surface of the suspending member 1*c*, so that the planar bottom surface 3 is kept horizontal and the mirror 5 is kept vertical, regardless of the posture of the suspending member 1*c* of the body 1.

More particularly, if the body 1 of the levelling device of FIG. 7 is tilted about the central axis of the cylindrical surface of the suspending member 1*c*, as shown in FIG. 9, the suspended weight member 4*c* slides around the cylindrical surface of the suspending member 1*c*, in such a manner that the bottom planar surface 3 of the suspended member 4*c* is kept horizontal, regardless of the tilting angle of the body 1, provided that no part of the weight member 4*c* and the mirror 5 hits the body 1. As a result, the plane of the mirror 5 is always kept vertical, as shown in FIGs. 9 and 10. Furthermore, the sliding motion of the weight member 4*c* is damped by the viscosity of the liquid film 2, and there is no need for using a separate damper for preventing the vibration of the suspended weight member 4*c*.

FIGS. 5 and 6 illustrate a theodolite, in which the levelling device according to the present invention is incorporated for providing automatic correction for any tilting of the optical system thereof. In FIG. 5, the symbol D represents a graduated dial, which is rotatable together with a telescope T of the theodolite. A housing H rotatably carries the telescope T, and when a longitudinal central axis C—C of the housing H through the center of the dial D is held vertical, while holding the telescope T horizontal, the 0 degree line of the dial D lies on the axis C-C thus held vertical. In this embodiment, a plano-convex spherical lens 1*b* is fixed to the housing H, in alignment with the central axis C—C, with its convex surface facing downward. The plano-convex lens 1*b* acts as a suspending member, and a liquid film (not shown) is applied on its convex surface, so as to suspend a plano-concave lens 4*b* in a freely slidable fashion. The optical axis of the plano-concave lens 4*b* is in alignment with the aforesaid axis C—C, and a planar bottom surface 3*b* of the plano-concave lens 4*b* is cut at right angles to its optical axis, so that the surface 3*b* is always kept horizontal, like the aforesaid reference planar bottom surface 3 of FIG. 1. An image-forming lens L is secured to the housing H in alignment with central axis C—C, as shown in FIG. 5, so that the image of the 0 degree line of the dial D is formed at a point on the optical axis C—C. A viewing glass A having a reference indicating line I is mounted on the housing H at said image-forming point on the central axis C—C at right angles thereto, so as to produce the image of a part of the dial D in the proximity of its intersection with the axis C—C on the glass A, as shown at the lower end portion of FIG. 5.

When the telescope T of the theodolite is oriented to an object with an angular altitude β, as shown by dash-dot lines in FIG. 5, the image of the graduation β on the dial D will be brought in alignment with the reference line I in the viewing glass A.

Let it be assumed now that the aforesaid central axis C—C of the housing H is deflected by an angle θ relative to the vertical line h—h through the center of the

dial D, as shown in FIG. 6. In this case, if there were not provided the combination of the suspending member 1*b* and the weight member 4*b*, a graduation θ of the dial D would be projected on the viewing glass A. As a result, it would become difficult to accurately measure the angular elevation of an object. With the present invention, the reference bottom surface 3*b* of the plano-concave lens 4*b* is kept horizontal, in response to the sliding movement of the lens 4*b* along the surface of the lens 1*b*. Accordingly, the plano-concave lens 4*b* acts as a prism whose optical axis is deflected by an angle corresponding to the aforesaid deflecting angle θ of the housing H. The deflecting angle of the prism, consisting of the plano-convex lens 1*b* and the plano-concave lens 4*b*, is such that the 0 degree line of the dial D will be projected on the viewing plate A in alignment with the reference line I, as shown at the lower portion of FIG. 6. Consequently, the viewer sees the 0 degree line as aligned with the reference line I on the viewing glass A as long as the telescope T is horizontal, regardless of the deflection of the central axis C—C of the housing H of the theodolite.

FIGS. 11A and 11B show a simple level device according to the present invention. A non-transparent weight member 4*d* is suspended on a transparent plano-convex lens 1*d* acting as a suspending member. An annular ring 8, such as a colored ring, is embedded in the planar top surface of the plano-convex lens 1*d*, in such a manner that, when the top surface of the plano-convex lens 1*d* is held horizontal, the projection of the weight member 4*d* on the top plane of the plano-convex lens becomes concentric with the annular ring 8. On the other hand, if the top surface of the plano-convex lens 1*d* is deflected from the horizontal position, the projection of the weight member 4*d* drifts away from its position concentric with the annular ring 8, as shown in FIGS. 12A and 12B. In a preferred embodiment of the invention, space 9 under the suspending member 1*d* may be sealed while being filled with dry air or a suitable inactive gas, e.g., nitrogen, preferably at a reduced pressure. It is also possible to seal it in vacuo.

What is claimed is:

1. A levelling device comprising a body inclinable at an angle corresponding to the inclination of a support surface, a weight-engaging member integrally secured to said body, said weight-engaging member having a downwardly curved convex surface, said curved surface having a circular cross section extending about a datum of curvature, a liquid film coated on the curved surface of the weight-engaging member, and a weight member having an upwardly curved concave surface, so curved as to match said curved convex surface of said weight-engaging member, said curved concave surface of the weight member having a radius of curvature substantially identical with that of said curved convex surface of said weight-engaging member, said liquid film having a surface tension sufficient to suspendingly support said weight member on said curved surface of said weight-engaging member in a slidable fashion while keeping the concave surface of said weight member in snug contact with said liquid film on said weight-engaging member, whereby a line connecting the center of gravity of said weight member and said datum of curvature of said weight-engaging member remains vertical, regardless of the posture of said body.

2. A levelling device according to claim 1, wherein said curved convex surface of the weight-engaging member of the body is a downwardly convex spherical surface, and said concave surface of the weight member is an upwardly concave spherical surface whose radius of curvature is substantially identical with that of said spherical surface of said weight-engaging member.

3. A levelling device according to claim 1, wherein said curved convex surface of the weight-engaging member of the body is a downwardly convex cylindrical surface, and said concave surface of the weight member is an upwardly concave cylindrical surface whose radius of curvature is substantially identical with that of said cylindrical surface of said suspending member.

4. A levelling device according to claim 2, wherein said weight-engaging member is a plano-convex lens, said weight member is a plano-concave lens being suspended by said plano-convex lens through a liquid film applied on the outer surface of the convex portion of the plano-convex lens, and said plano-convex lens and said plano-concave lens form a prism so as to deflect a light beam incident on the prism by an angle corresponding to the deflection angle of said plano-convex lens relative to a vertical.

5. A levelling device according to claim 2, wherein said weight-engaging member is a transparent plano-convex lens, said weight member is non-transparent, the vertical projection of said weight member on a horizontal plane is a circle whose radius is smaller than the radius of said plano-convex lens, and an annular ring whose radius is substantially identical with said radius of said vertical projection of said weight member is secured to the top surface of said plano-convex lens in a concentric fashion, whereby said body is brought to a horizontal posture when the projection of said weight member on said plano-convex lens is concentric with said annular ring.

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