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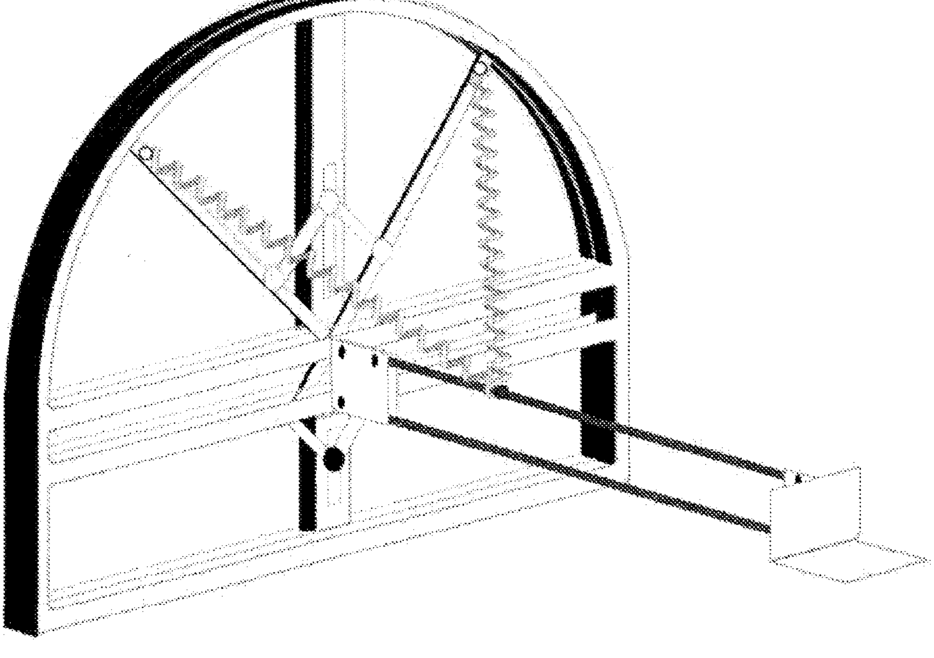
(56) Documents Cited:
WO 2009/082207 A1 **WO 2007/035096 A2**
US 4883249 A

(58) Field of Search:
INT CL **F16F**
Other: **WPI; EPODOC**

(54) Title of the Invention: **Device to accomplish energy-neutral adjustment of a zero-stiffness mechanism (read gravity equalised structure) using an improved virtual-spring method**
Abstract Title: **A balance support device incorporating a virtual adjusting zero-free length spring within a gravity-equalised structure**

(57) A balance support device incorporating a virtual adjusting zero-free length spring within a gravity-equalised structure is provided. The device comprises a semi-circular outer support frame 4 which includes a semi-circular guide-rail. Within the semi-circular guide-rail run the long ends of a pantograph 6 which has a central pivot point 12 located on a vertical guide-rail 5. The adjustment of the pantograph 6 is maintained by a combination of movable guide blocks 13 and fixing means 9 for screwing the guide blocks into the vertical guide-rail 5. Two springs 3 have each of their ends attached to a long end of the pantograph 6 and to a horizontally extending parallelogram arrangement 7. The two springs serve to balance any load applied to a distal end of the parallelogram arrangement 7. The springs can thus be adjusted via a conical-path within the Y-Z-axes to create a resultant centre-line virtual spring force whose spring-length can be altered as is its effective attachment point on the Y axis.

FIG 16.



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DRAWINGS

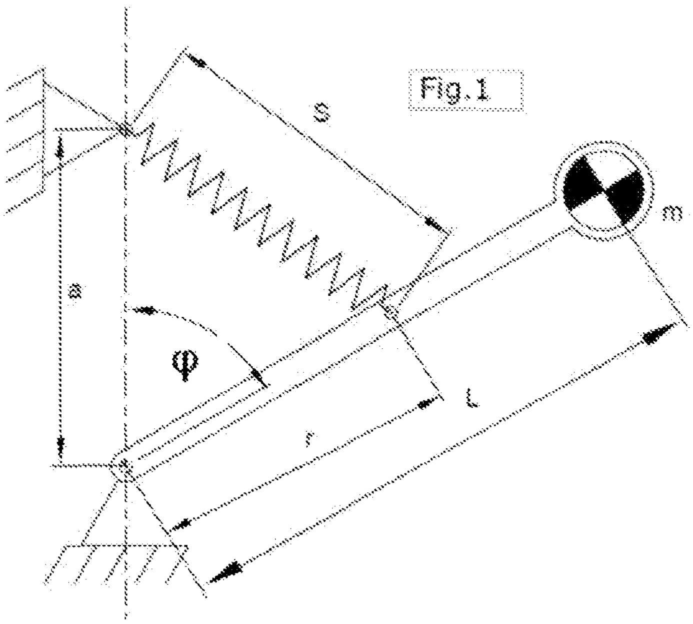


Fig.1

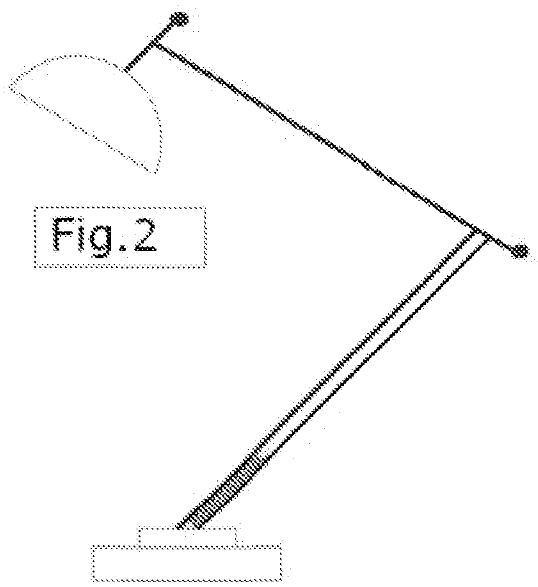


Fig.2

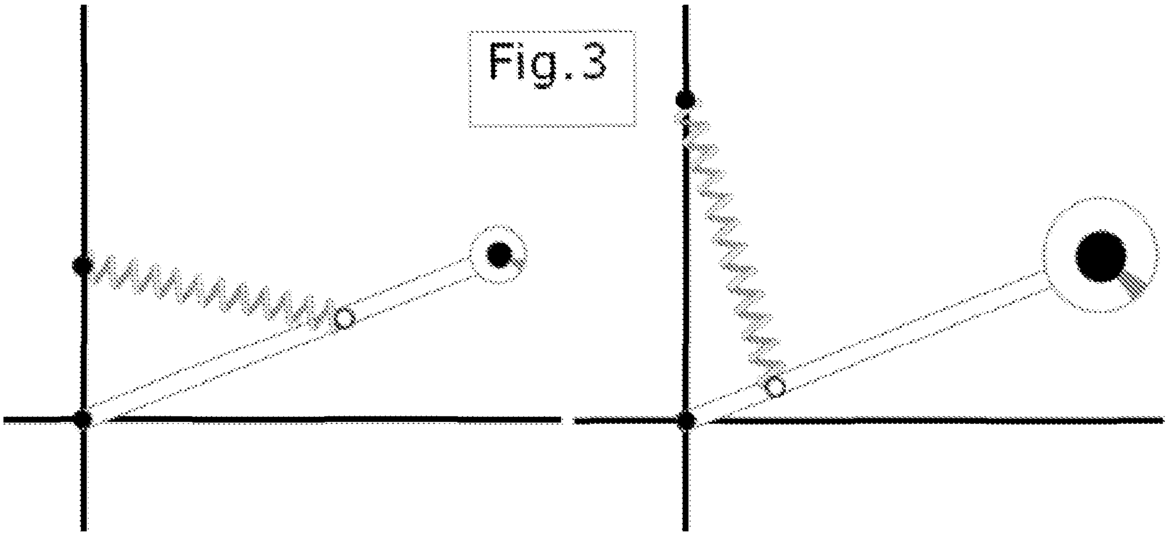


Fig.3

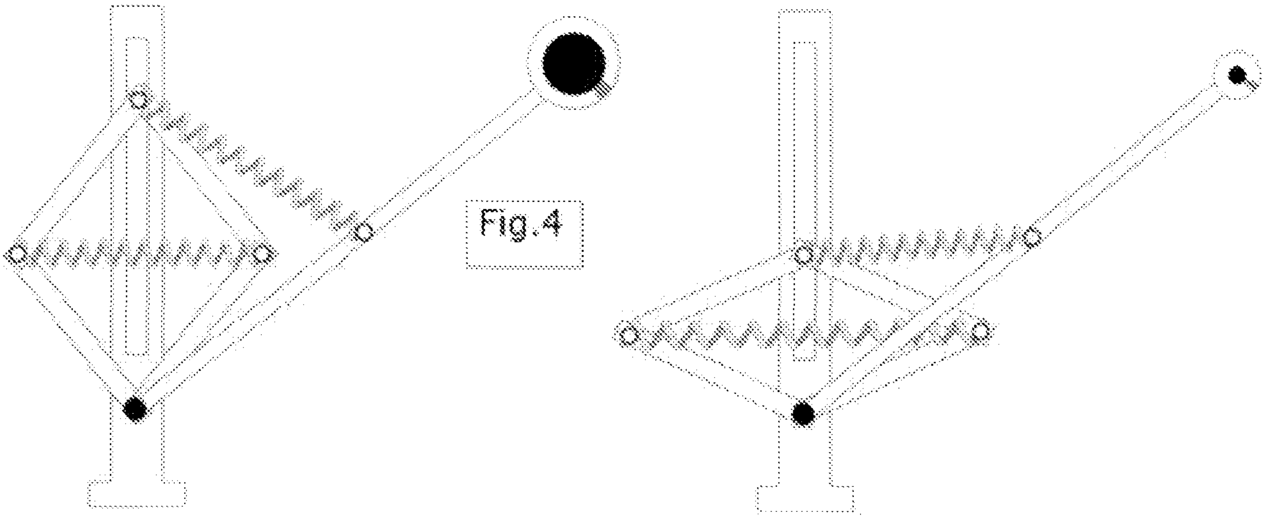


Fig.4

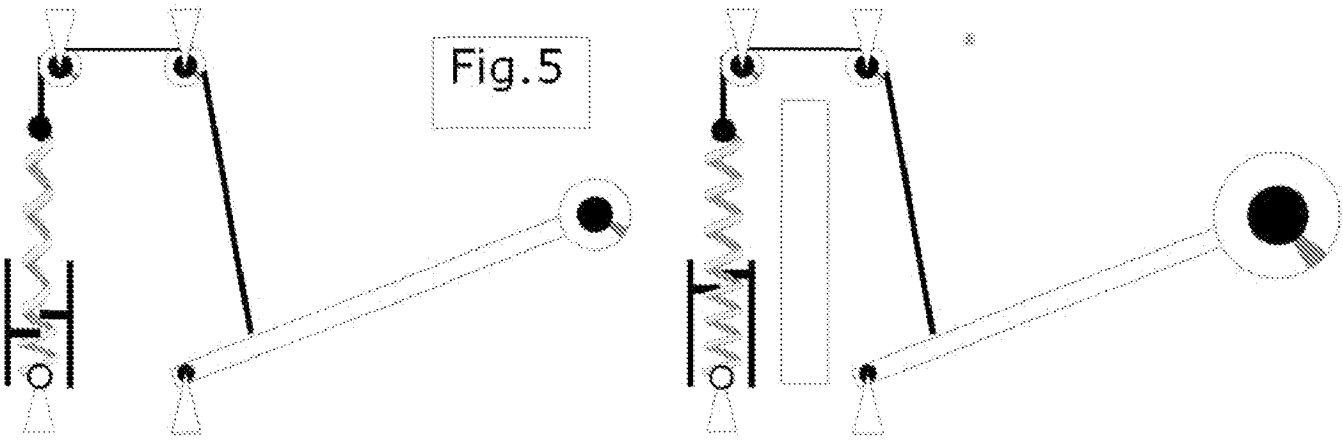


Fig.5

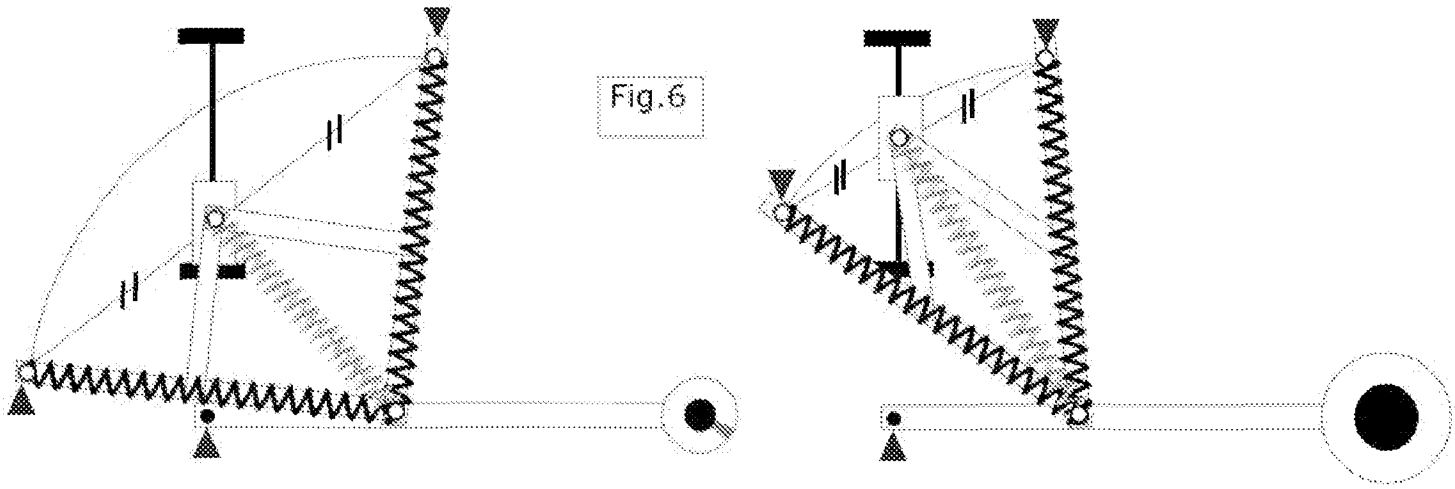


Fig.6

Fig.7

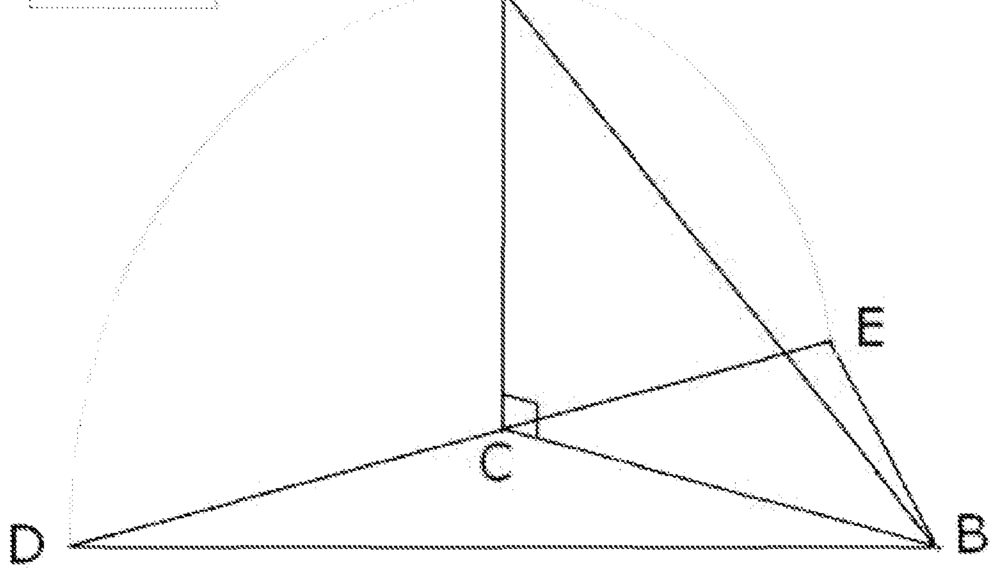


Fig.8

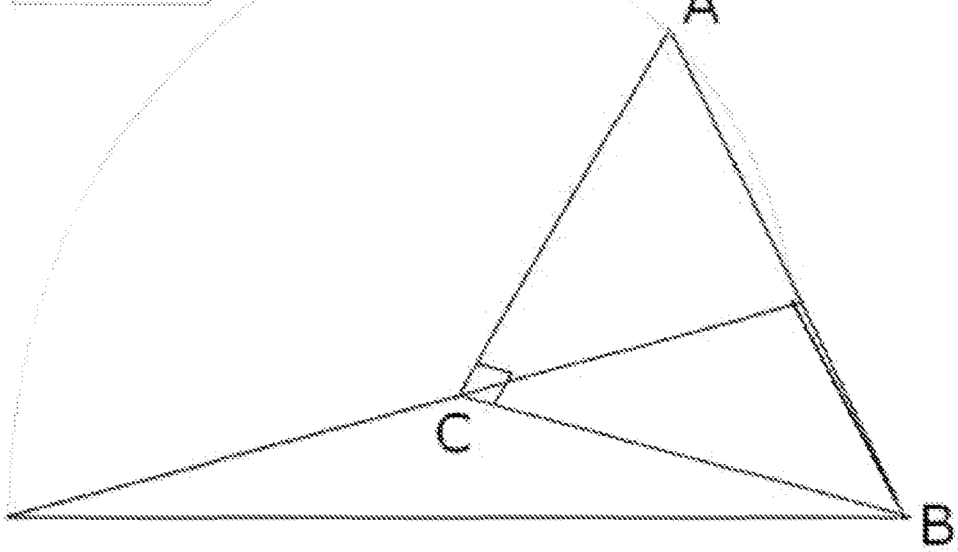


Fig.9

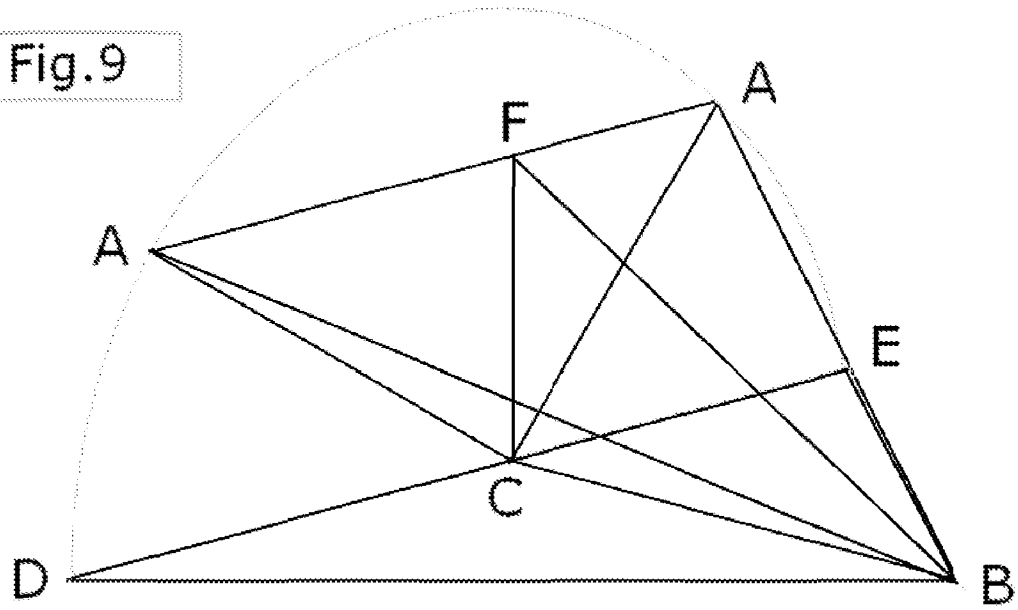


Fig.10

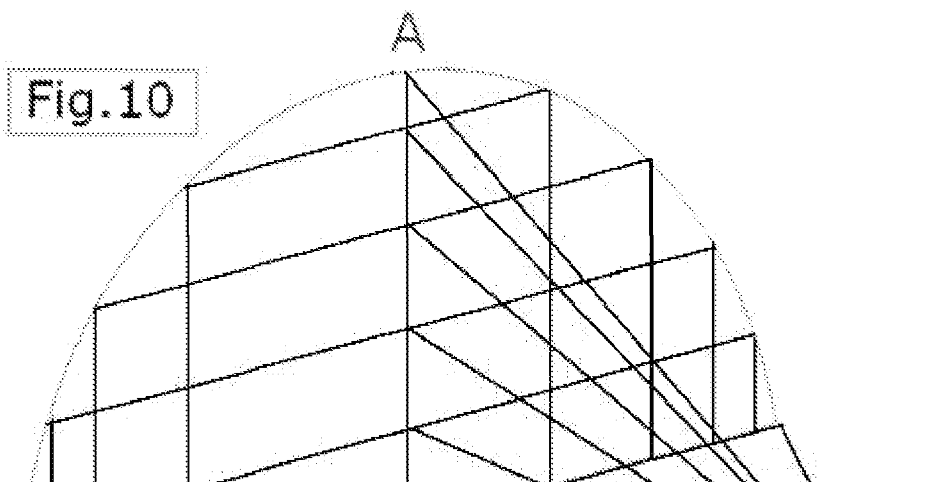


Fig.11

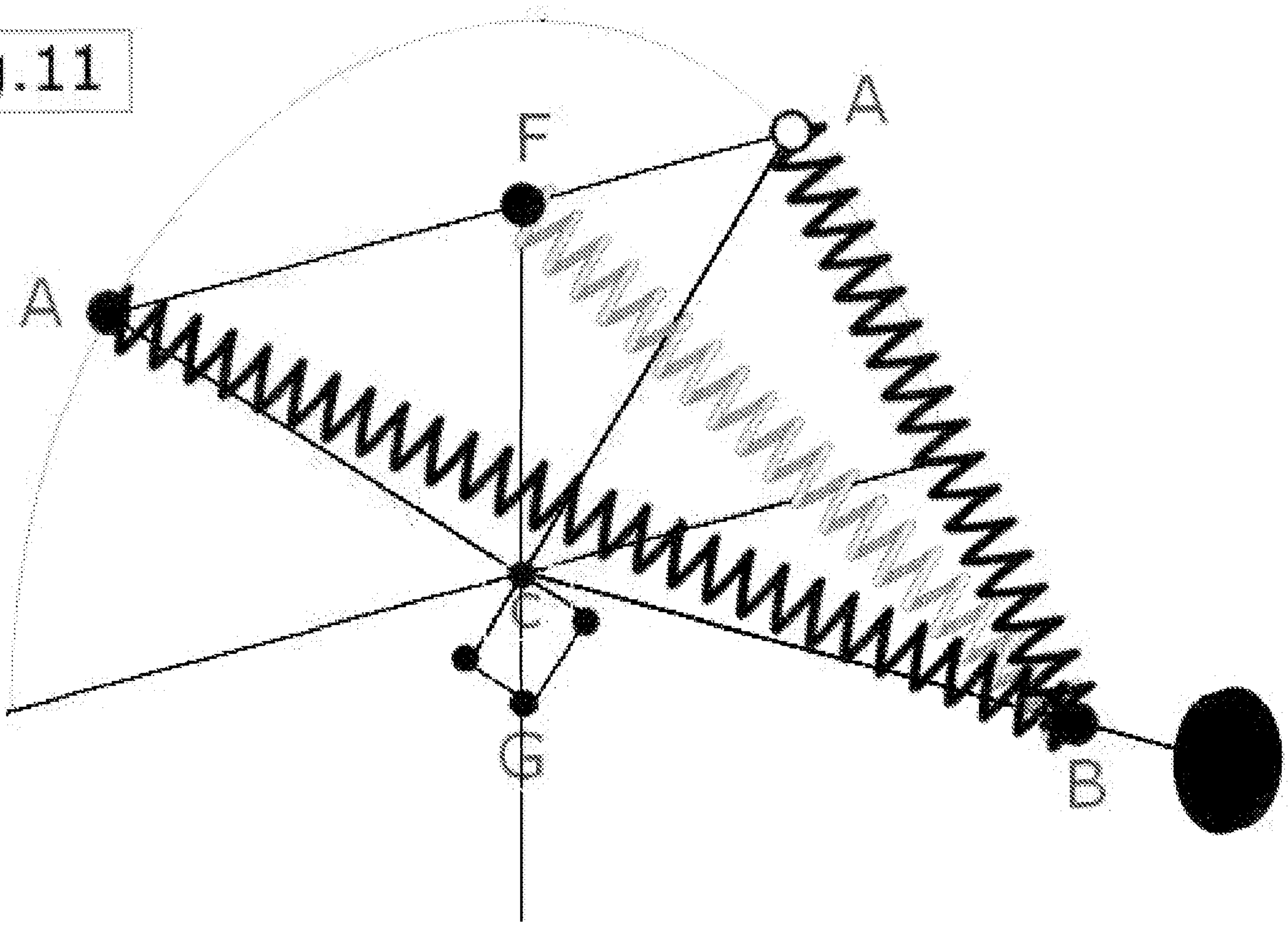
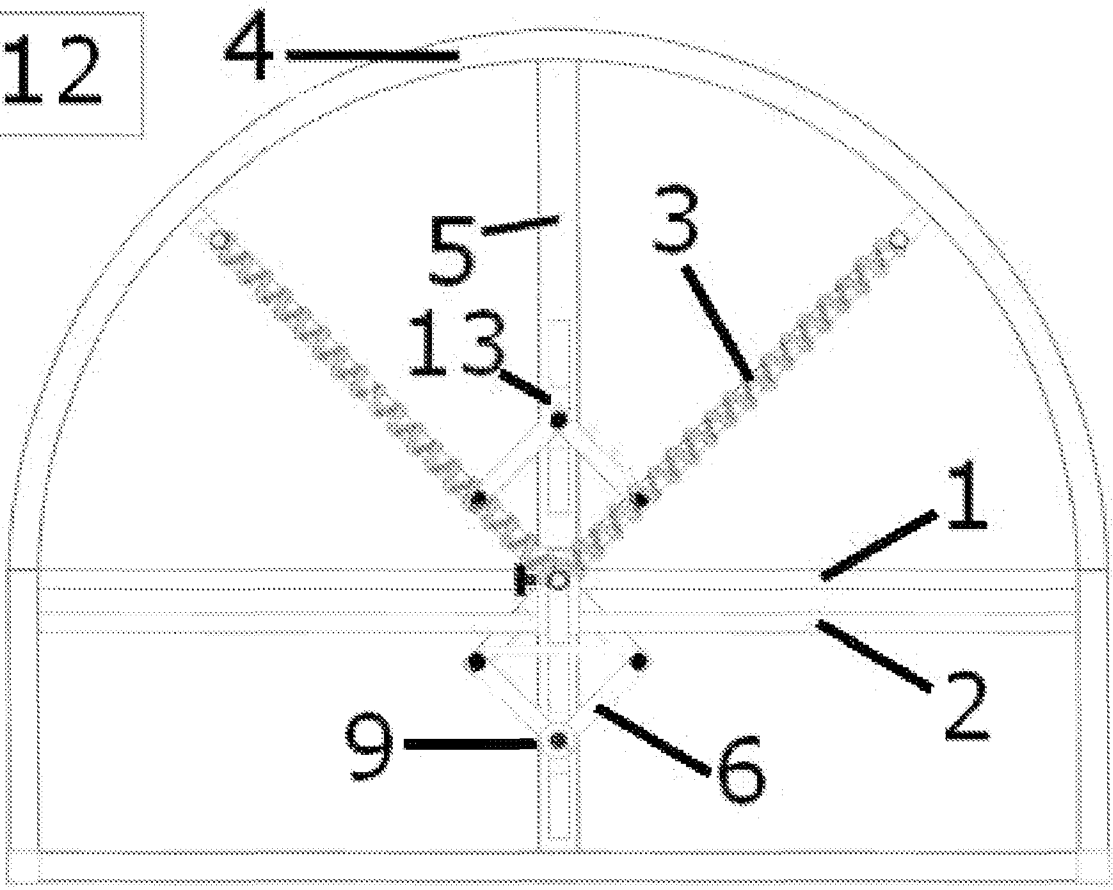


Fig.12



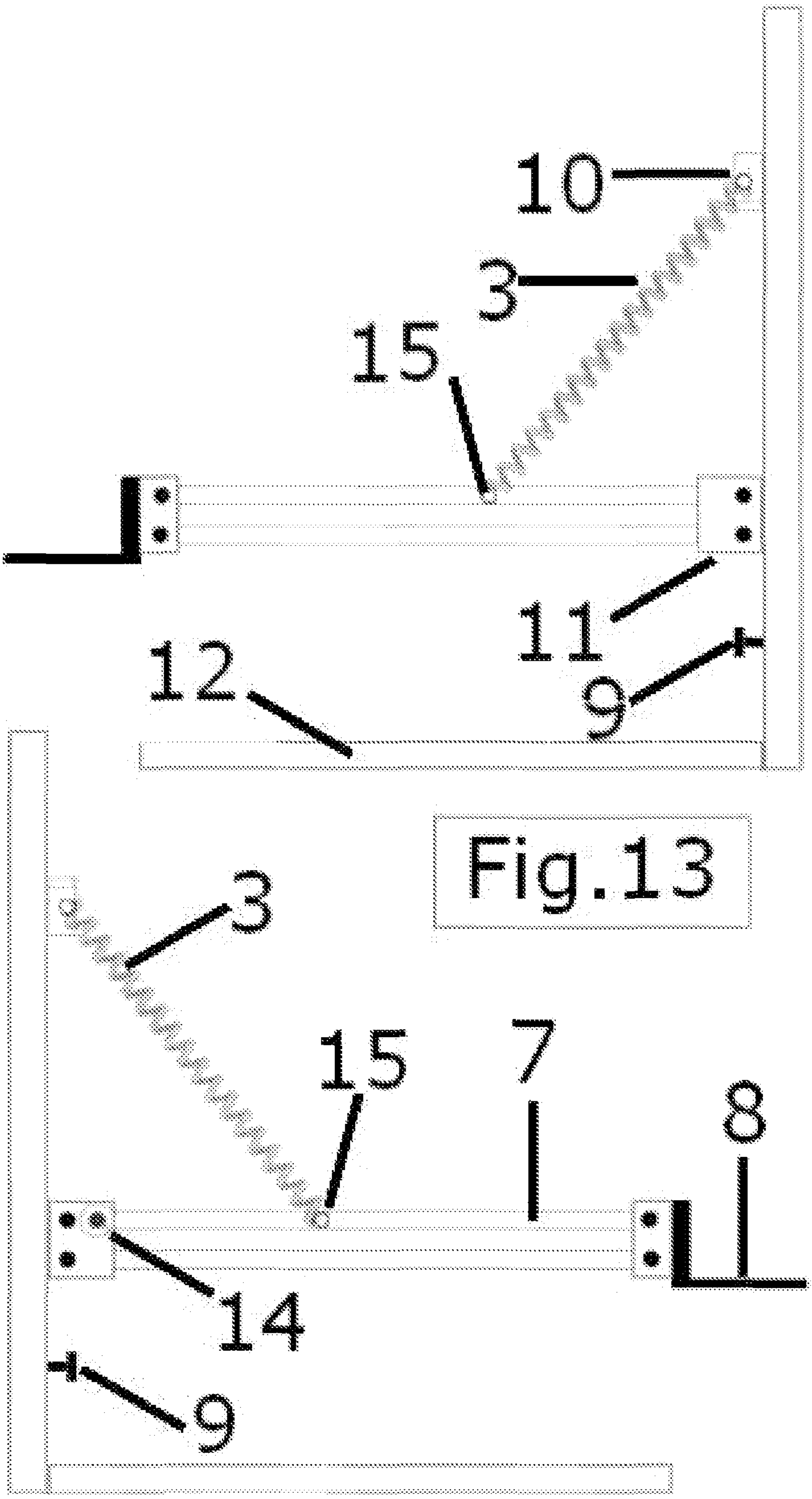


Fig.13

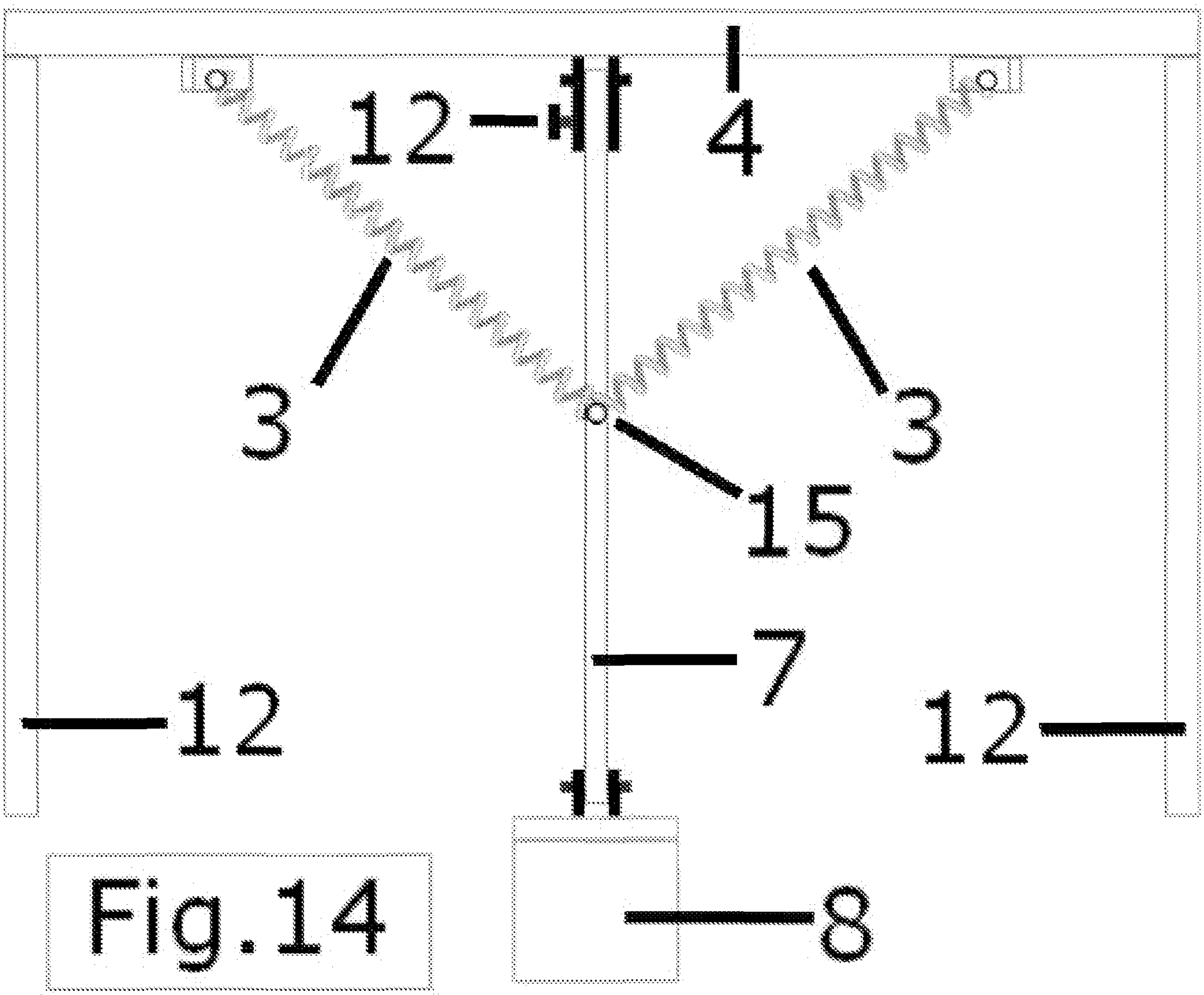


Fig.14

Fig.15

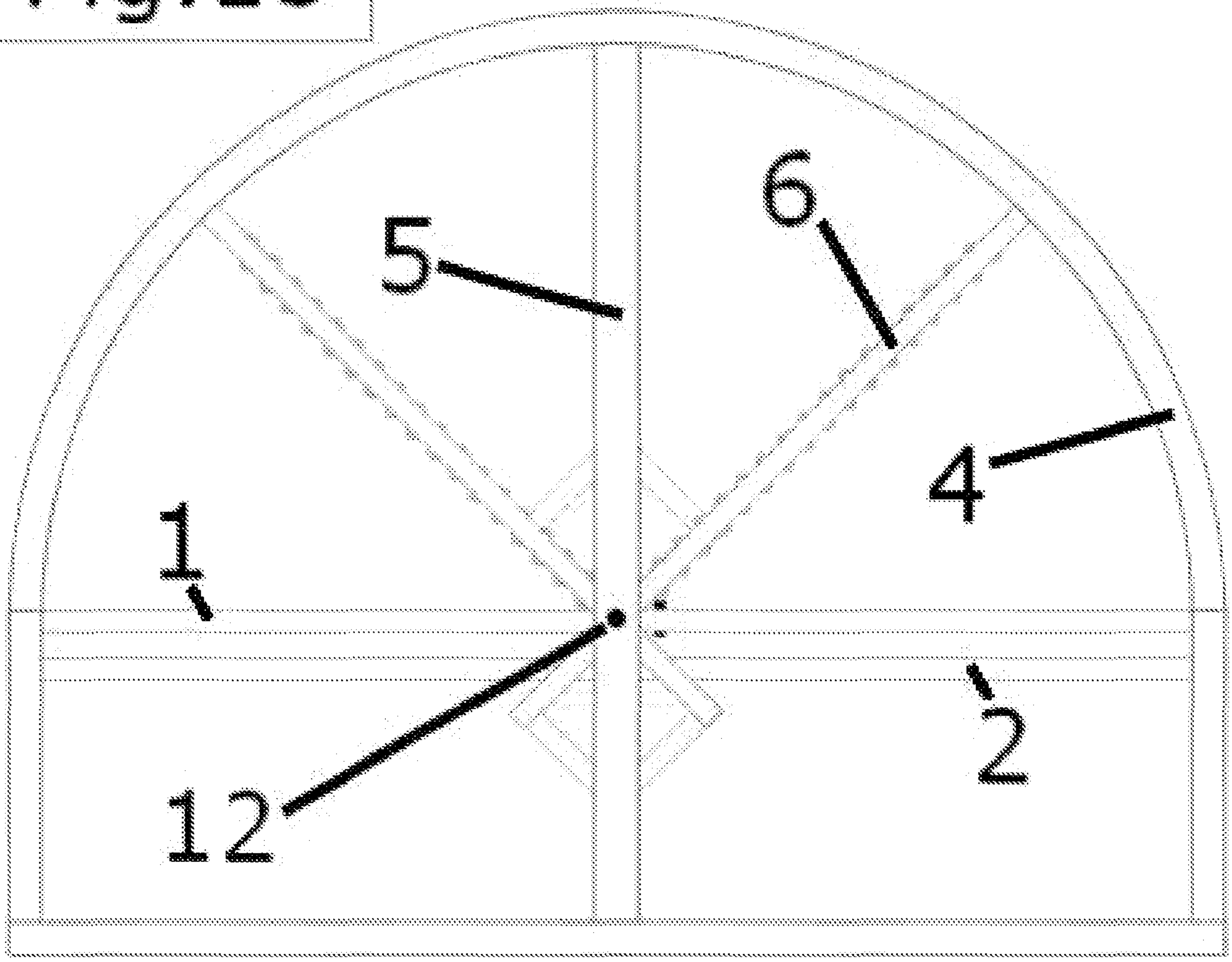
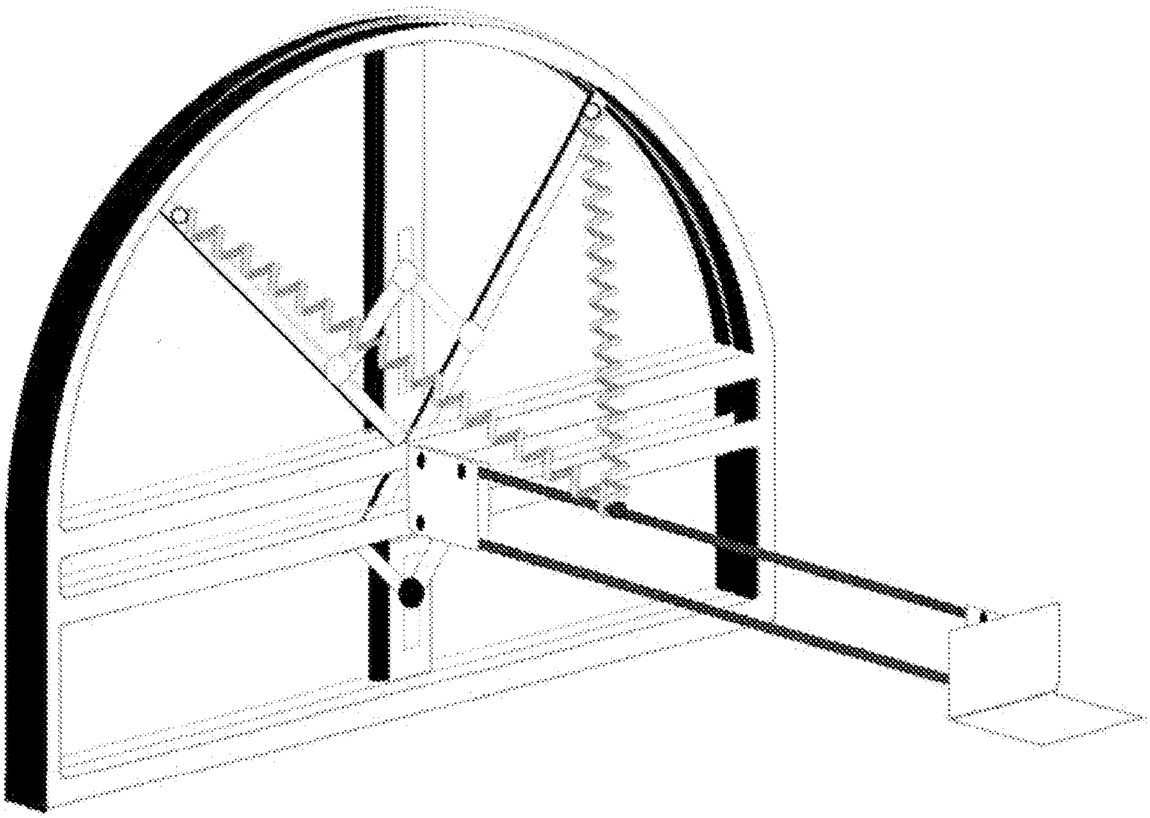


FIG 16.



Title:

Device to Accomplish Energy-Neutral Adjustment of a Zero-Stiffness Mechanism (Read Gravity-Equalised Structure) Using an Improved Virtual Spring Method.

Description:

Background-

In general terms, when a system is said to be perfectly neutrally-statically-balanced, a supported mass is said to have a *constant potential energy (PE)* throughout its range of movement. That range of movement is determined by the pivoted nature of the mass's support arm and other countenance factors.

This countenance to the supported mass's weight is often achieved through the use of *springs* and/or *counterweights*. Invariably, the springs used are said to be zero-free length springs, meaning they are pre-tensioned to such a degree that their tension *k* is proportional to their *length*, in lieu of their elongation.

Because the supported mass, or P*ayload*, can be said to have *constant PE*, no energy is required to move or elevate the mass. The mass, in the context of a statically balanced system, is said to be weightless. This type of system is said to be *Gravity Equalised*.

Moreover, when the support arm and attached mass is released after elevation or repositioning, the mechanism, as a whole, will not move as there is *no preferred rest-position* within the arc of movement of the device's balance arm.

A basic spring to mass gravity equalised arrangement can be seen in Fig.1 (Herder), whereby a single zero-free length spring is perfectly balancing a mass m with lengths a,r,L for any angle ϕ .

A classic example of a Gravity Equalised Device in use today is the *Anglepoise Lamp* (See fig.2)

Other applications that currently use Neutral-Stability principles are assembly-line robotic-arms and personal assistive devices. The common principle behind all these examples of industrial use remains the same, that being any fixed payload is perfectly counter-balanced by any opposing equal-force, so that the operating energy requirement is minimal.

Problem 1:

As a rule of thumb, most gravity equalised structures support a constant load. The downside to this is that if the supported and perfectly countered load is changed, the equitable state of the system is lost, so requiring adjustment.

Problem 2:

That *Change of Payload* adjustment often takes large amounts of input energy effort, resulting in larger actuators for robotic arm manipulators, and with an increase in running costs also. In the case of orthopaedic arm supports, the wearers will simply not have the muscle strength to carry-out this adjustment.

Therefore, there is a need to reduce that adjustment energy requirement down to a minimum -read *energy free adjustment*.

Published Solutions / Methods:

Within this field, there are several publically known methods of achieving this energy-free or energy neutral-adjustment of an equalised structure, to compensate for a change in payload. They are as follows (*The description and original-drawings of each method below originate from the Authors as indicated*):

A. Simultaneous Displacement

The *Simultaneous Displacement* method (Fig. 3) changes the distances *a* and *r* simultaneously, in such a way that the spring length does not change (and hence no work is required). The product of *a* and *r*, however, does change, and hence so does the balancing setting.

The Authors of Method A above are:

van Dorsser, W.D., Barents, R., Wisse, B.M., Herder, J.L. (2007) "*Gravity-Balanced Arm Support With Energy-Free Adjustment.*" ASME Journal of Medical Devices, Vol. 1, No. 2, pp. 151-158.

B. Storage Spring

The second method, the *Storage Spring* method (Fig. 4), makes use of a spring that provides the energy needed to adjust the balancing spring. As a result, the system contains two balancers, one for the payload and another one to balance the adjustment motion.

The Authors of Method B above are:

Barents R, Schenk M, Dorsser WD van, Wisse BM, Herder JL (2011) *'Energy-free adjustment by spring-to-spring balancing in gravity equilibrators'*. ASME J. of Mech. Design, 133(6)061010.

C. Stiffness Adjustment

A third type of energy-free adjustment is called the *Stiffness-Adjustment (Fig.5)* method and works by adjusting the spring stiffness of the balancer spring by changing the number of engaged coils when it is at its rest length.

The Authors of Method C above are:

van Dorsser, W.D., Barents, R., Wisse, B.M., Schenk, M., Herder, J.L.(2007) "Energy-Free Adjustment of Gravity Equilibrators Using the Possibility of Adjusting the Spring Stiffness", submitted to Proceedings of the IMechE Part C, J. of Mechanical Eng. Science.

D. Virtual Spring

The *Virtual Spring* method (Fig. 6) works by replacing the single zero free length spring of the basic static balancer by two substitute zero free length springs. These springs generate a virtual spring with the same spring properties as the initial spring, but with a unique difference: the virtual spring length can be adjusted without external energy, by rotating the substitute springs in a coordinated fashion using a pantograph. Effectively, this virtual spring and pantograph construction changes the value of a, without elongation of the substitute springs.

The Authors of Method D above are:

Wisse, B.M., van Dorsser, W.D., Barents, R., Herder, J.L. (2007) *"Energy-Free Adjustment of Gravity Equilibrators Using the Virtual Spring Concept,"* ICORR2007, Noordwijk, The Netherlands.

As can be seen with the above methods distances *a* and / or *r* (Fig.1) are altered to achieve payload adjustment.

Problem 3:

In regards to Method D, I suggest that it will not create a virtual spring as envisaged, nor will it produce an energy free actuation as indicated.

Looking at Fig. 6, the mechanism operates within the X & Y axis only.

The pantograph, it is said, is just there to symmetrically move the two '*real*' zero free lengths springs about their shared centre-line. It serves no other purpose other than this function, so for analysis of this published method / device, it can be ignored.

We now have just the two springs which share a common attachment point on the pivoted balance-arm with supported mass.

It is said that the springs converge or diverge about an arc, and are supported off that arc in their rest positions after adjustment. It is proposed by the Authors that the centre line resultant force is equivalent to a virtual spring whose effective length changes by the virtual lifting of its attachment point along the Y-axis, thus altering *a* (Fig.1). It is in this manner, it is proposed, that an energy-free adjustment is achieved.

This is not correct. The resultant centre-line spring force will effectively maintain the same length as the two real springs throughout their arcing motion, so no energy free adjustment or change in the virtual spring length, nor resetting of a zero-stiffness mechanism for a change in payload has occurred. It will, for all intents and purposes, 'stay' fixed and unaltered on the resultant centre-line.

Therefore, this published method, in my opinion, is open for adaptation and improvement, resulting in a new and original device. Even if Method D, in its present published form proves to work, although unlikely, my adaption below is an innovative and distinctive step beyond what is published already.

Statement of Invention:

The methodology and mechanical arrangement I submit is a correction / adaptation of a previously proposed and published method of Energy Neutral Adjustment using a virtual spring (method D). In that published arrangement it can be seen that all components operate within the X & Y axis only.

My design / invention utilises a new virtual spring method of energy-neutral adjustment of a zero-*stiffness mechanism operating uniquely* ***within the X,Y & Z axis*** (Spatial-*Vectoring*). *This way, the* resultant centre line spring-force will be equal to 2*k*, and achieve an altered virtual length.

Methodology Used:

The following explains the rationale behind my proposal:

Fig.7:

- Firstly, I have a right-angle triangle ABC. If I rotate the triangle about BC, for 180 degrees, we form half a conical shape.
- It can be said that AC is the radius of the semi-circle. AC=CD=CE
- It can also be said that distance AB remains constant upon rotation of triangle ABC about BC.

Fig.8:

- Next I rotate the triangle ABC about BC.

Fig.9:

- I then mirror triangle ABC about the vertical centre-line of the semi-circle.
- If I draw a line between points A to A, and mark the centre point of that chord line, the distance BF < distance AB.

Fig.10:

- By extrapolation, it can be shown that as the mirrored triangles rotate upwards, about BC, as the chord length reduces, the line AB, as it climbs the vertical centre-line AC, increases in length, as does the distance from the point of intersect to C. Distance AB remains constant.

Fig.11

- To convert that method into a device capable of an industrial application, I replace:
- Lines AB for identical zero-free-length springs.
- Line BC becomes an arm with an attached weight. The arm is pivoted vertically about C
- The centre spring represents the resultant centre-line force of the two real springs.
- A guided pantograph ensures the symmetrical arcing operation of points A / A.

Detailed Description:

Example 1:

An example of the invention that utilises this revised / adapted Method D will be shown now, and whilst doing so I shall refer to the following drawings:

Introduction to Drawings:

Fig.12: This shows the front elevation only of the outer housing, pantograph, guide rail, support bars and zero-free length springs (2 off).

Fig.13: This shows both the right-hand and left-hand side views of the device. In more detail can be seen the pivoted and spring-supported weight arm, with the weight-pan affixed to the free end.

Fig.14: This shows the plan-view of the device, highlighting how the two zero-free length springs vector 3-dimensionally (x, y & z axis).

Fig.15: This shows the rear view of the device. In more detail can be seen the pantograph with extended upper legs, and how it is centrally pivoted to the guide rail.

The description of the device is as follows:

I have an outer support frame Fig.12/14/15-(4) with a semi-circular top to it. Within this semi-circular frame I have a guide rail of the same profile.

Within that semi-circular guide rail runs the long-leg ends of a pantograph Fig.12/15-(6).

This pantograph is centrally pivoted off a vertical guide-rail Fig.12/15-(5) as shown Fig.15-(12).

The operational symmetry of the pantograph is maintained by attached guide-blocks running within the vertical slots of the vertical guide-rail Fig.12-(13).

Position of the pantograph, after adjustment, is maintained by screwing in the pantograph-stop into the guide rail, as shown Fig.12/13-(9)

Off the outer housing I have two horizontal support-bars Fig.12/15-(1/2), with the centre-point of the upper one being the radial centre of the semi-circular guide, and the vertical centre-line of the vertical guide.

Off these two support bars is affixed a bracket Fig.13-(11), off which is pivoted a parallelogram Fig.13-(7), off which is affixed a weight-pan Fig.13/14-(8). This parallelogram arrangement ensures that the weight-pan remains level during elevation of the weight-arm.

This parallelogram weight-arm can be held / released from the horizontal position before / after adjustment of the zero-free length springs by screwing in / out the arm-stop Fig.13/14-(14).

Two zero-free length springs share a common fixing point of the weight-arm's upper linkage Fig.13/14-(15). Each connects back onto one of the pantograph upper legs each, as shown Fig.13-(10).

For stability, I have two projecting legs coming off the base of the vertical support frame Fig.13/14-(12).

Description of Operation:

With the weight arm locked in the horizontal position, the pantograph is released. The lower section of that pantograph is either lowered or elevated within the vertical guide-rail (Raised for a reduction in weight / lowered for an increase in supported weight). This action repositions the long pantograph legs symmetrically about the vertical centre-line, with a corresponding repositioning of upper spring arm supports.

As the two springs remained the same length during this adjustment, it can be said that the adjustment was carried out in an energy-free manner. Once adjustment has been completed, the pantograph is locked off once more.

With a new weight seated onto the weight-pan, the weight-bar can be released from the horizontal position. As the device is now in a new, adjusted equitable state, the weight and arm can now be elevated in an energy-free manner also.

At this point, as a result of the repositioning of the two zero-free length springs, it can be said that *the equitable state of the system has been re-established to compensate for the change in payload* because the resultant centre-line force between the two real springs, which is equivalent to a virtual spring-force of tension $2k$, has had its virtual vertical attachment point a raised or lowered. This virtual attachment point elevation allows for a larger mass to be counter-balanced within the context of a gravity-equalised system (vice versa for a smaller weight).

During adjustment of the pantograph, as the two springs did not change length, the adjustment can be said to be energy free, or energy neutral.

The payload can now, once again, be positioned anywhere within the arc of travel in an energy-free manner (energy-free, in reality, means the operating energy is just high enough to over-come any pivot-point friction, but, of course, far less than it would be to elevate a mass by other means). Likewise, the actuation method overcomes the need to use heavy actuation forces to overcome storage spring energy as seen in other methods).

Claims:

Claim 1:

The device will accomplish Energy-Neutral Adjustment of a Zero-Stiffness Mechanism (Read Gravity-Equalised Structure), Using an Improved Virtual Spring Method, to allow for a change in Supported Payload.

Claim 2:

That adjustment in Claim 1 is achieved by the symmetrical conical displacement of two zero-free length springs acting about a common fixed point on a payload support arm.

Claim 3:

The virtual spring in Claim 1 is the resultant centre line force of the two symmetrically re-positioned zero free length springs, whose lengths remain unaltered during a conical-shaped adjustment.

Claim 4:

The virtual spring in Claim 3 has, in effect, an altered length and vertical attachment point, after the adjustment of the real zero-free length springs, thus achieving an energy-neutral adjustment of a gravity equalised structure.

Claim 5:

The energy neutral adjustment in Claim 4 allows for a change in supported payload.

Claim 6:

The adjustment of the zero-free lengths in Claim 3 happens within the Y & Z axis, and the elevation of the virtual spring happens within the X & Y axis.

Claim 7:

The symmetrical adjustment of the zero-free length springs in Claim 4 can be achieved through, but not limited to, the use of a pantograph arrangement.

Claim 8:

The operation of the pantograph-(adjuster) in Claim 7, locks and initial assessment of payload weight can be manually carried out or partially or fully automated.

Application No:	GB1219908.9	**Examiner:**	Mr Kevin Hewitt
Claims searched:	ALL	**Date of search:**	9 February 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 at least	WO 2007/035096 A2 (TECHNISCHE UNIVERSITEIT DELFT) See especially the embodiments schematically illustrated in Figures 4a, 4b & 5.
X	1 at least	WO 2009/082207 A1 (TECHNISCHE UNIVERSITEIT DELFT) See especially the embodiments illustrated in Figures 2 & 3.
A	-	US 4883249 A (GARLAND) See especially Figures 7 & 8.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F16F

The following online and other databases have been used in the preparation of this search report

WPI; EPODOC

International Classification:

Subclass	Subgroup	Valid From
F16F	0003/04	01/01/2006
F16F	0003/02	01/01/2006