PATENT SPECIFICATION

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(54) AN ELECTRO-MECHANICAL MEANS FOR DRIVING A TIMEPIECE

(71) We, CENTRE ELECTRONIQUE HORLOGER S.A., of 2, rue A.-L. Bréguet, Neuchâtel, Switzerland, a corporation organized under the laws of the Confederation of Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to an electro-mechanical means for driving a timepiece.

According to the present invention there is provided an electro-mechanical means for driving a timepiece, the means of drive comprising a resonance member producing an oscillatory motion about an axis, and a transformer means used to convert the oscillatory motion into a unidirectional motion, the resonance member comprising a rigid mounting having a resilient arm connected thereto and positioned perpendicular to the axis of oscillation and at least two masses mounted thereon and spaced apart from one another, the transformer means comprising a pawl secured to the resonance member and co-operating with a ratchet wheel, wherein the pawl is mounted on the resonance member in such a way that a shock applied in a direction perpendicular to the axis of oscillation of the resonance member has a negligible effect on the motion of the pawl.

The drawing illustrates, by way of examples, several embodiments of the electro-mechanical means of drive according to the invention.

Figure 1 is a view in elevation, partially in cross-section, of a first embodiment.

Figure 2 is a plan view, with a part torn away, of this embodiment.

Figure 3 is a view corresponding to that of figure 1, of a second embodiment.

Figure 4 is a view corresponding to that of figure 1 of a third embodiment.

Figure 5 is a view in elevation, partially in cross-section, of a fourth embodiment.

Figure 6 is a plan view, partly in cross-section, of this fourth embodiment.

Figure 7 is a view in elevation of a fifth embodiment, in which the electro-mechanical means of drive is of a piezoelectric nature.

Figure 8 is a plan view of this fifth embodiment.

Figure 9 to 13 are schematic views of the explanation of the theory of the electro-mechanical means of drive.

Figures 1 and 2 illustrate a electro-mechanical means of drive using a motor in particular for a wrist watch. It comprises a resonator and a transformer, destined to convert the oscillating motion of the resonator into a step-by-step rotary motion, mounted on a platen 1.

The resonator comprises two masses 2 and 3 connected by a rigid arm 4. The mass 2 is active in the sense that it constitutes a magnet in the shape of a parallelepiped, magnetized perpendicularly to the platen, moving in a direction parallel to the latter in the air gap 5 of an electromagnet 6 excited by two coils 7 and 8. The coils 7 and 8 are energized either by alternating current or by direct current pulses, according to any known manner. The frequency of the alternating current or of the direct current pulses can be controlled e.g. by the use of a quartz crystal in conjunction with a frequency divider. The mass 3 acts as a counter-weight. The arm 4 also comprises two lateral arms 9 and 10 having parts of reduced thickness 11 and 12 which are resilient. The two ends of the arms remote from the arm 4 are held in a part 13 secured to the platen 1 of the watch. On the arm 4 is secured in addition a pin 14 from which extends a very thin spring strip 15 supporting a pawl jewel 16. This pawl jewel 16 drives a ratchet wheel 17 having a large number of teeth. A retaining pawl 18 held by a fixed pin 19 prevents the wheel 17 from turning backwards.

The motor operates as follows:

The energising of coils 7 and 8 sets up an oscillatory motion of the mass 2 and

[*Price 25p*]

arm 4, and this motion transmitted through the arm 4 causes a deformation of the parts 11 and 12, causing the parts 11 and 12 to be bent to a shape which takes the form of an arc of a circle. The construction of the device is such that the centre of gravity of the masses 2 and 3 and of the arm 4 is situated in the neighbourhood of the axis 20 in order to achieve equilibrium. The result of this equilibrium is that the normal oscillating motion is effected around the axis 20. On the other hand the deformation of the resilient parts 11 and 12 resulting from an acceleration of the type which may be caused by a shock is different from the deformation due to the normal motion of the motor. A shock if applied perpendicular to a plane parallel to the parts 11 and 12 and to the axis 20 will cause deformation in the shape of an "S" of the arms 9 and 10 bearing these parts, and the two masses situated at the ends of the arm 4 will move to positions parallel to one another, relative to the longitudinal axis of the arm 4. The more rigid and shorter in length the parts of reduced thickness 11 and 12 are, which opposes such a deformation, will mean the watch will have a better resistance against shocks. In addition, as shown in figure 2, the strip 15 of the driving pawl 16 is parallel to the parts of reduced thickness 11 and 12, and is secured by pin 14 that is perpendicular to the arm 4 and secured in a less rigid part of the arm 4. Consequently, a shock applied perpendicular to this less rigid part of the arm 4 will not alter the distance between the retaining pawl 18 and the driving pawl 16. A shock or an acceleration parallel to the strip 15 of the pawl, that is in the direction capable of producing any error in the movement of the drive, produces a practically negligible deformation of the resilient mounting, owing to the fact that the parts 11 and 12 are more rigid in this direction (this type of shock produces a compression stress in the arms).

The adjustment of the natural frequency is effected by a rotation of the counterweight 3 around its securing axis 21 after loosening the screw 22. The effect of the flat 23 is to position the centre of gravity of the mass eccentrically in relation to the securing axis 21.

The adjustment modifies the moment of inertia of the moving parts whilst having only a negligible effect on its equilibrium.

Figure 3 is a view, corresponding to that of figure 1, of a second embodiment. This embodiment differs from the first embodiment solely by the fact that the rigid arm has been replaced by two rigid arms and the two resilient arms have been replaced by a single arm.

The motor illustrated in figure 3 comprises a platen 25, a resonator comprising two masses 26 and 27 connected by a strip 28 forming two rigid arms 29 and 30. The active mass 26 moves in the air gap 31 of an electromagnet 32 excited by two coils of which only one 33 is shown. The strip also has a median arm 35 the part of reduced thickness 36 of which is resilient. The end of this arm remote from its junction with the arms 29 and 30 is held in a part 34 secured to the platen 25. A spring strip 38 extending from a pin 37 secured to the strip 28 carries a pawl jewel 39. This pawl 39 drives a ratchet wheel 40 cooperating with a retaining pawl 41 carried by a fixed pin 42. The operation of the motor is identical with that of the figures 1 and 2.

Figure 4 is a view, corresponding to that of figure 3, of a third embodiment. It differs from the second embodiment solely by the fact that the mounting strip has only one connecting arm between the masses instead of two. The motor illustrated in figure 4 comprises a platen 45, a resonator comprising two masses 46 and 47 connected by a strip 48 having a rigid arm 49. The active mass 46 moves in the air gap 50 of an electromagnet 51 excited by two coils only one of which 52 is shown. The mounting strip 48 also has a median arm 53 the part of reduced thickness 54 of which is resilient. The end of this arm remote from its junction with the arm 49 is held in a part 55 secured to the platen 45. A spring strip 57 extending from a pin 56 secured to the strip 48 carries a pawl jewel 58. This pawl jewel 58 drives a ratchet wheel 59 cooperating with a retaining pawl 60 held by a fixed pin 61. The operation of this motor is identical with that of the figures 1 and 2.

Figures 5 and 6 respectively show a vertical cross-section and a plan view, partly in cross-section of a fourth embodiment, constituting an electrodynamic motor. It comprises a platen 65 on which are mounted two magnets 66, 67 generating two magnetic fields perpendicular to the platen 65 and of opposite directions. The magnet 66 comprises two magnetized pole pieces 70, 71 made of a material of high magnetic energy, mounted on the ends of a "U" shaped part 72 made of soft iron. In the same way, the magnet 67 comprises two magnetized pole pieces, of which only one 73 is shown, mounted on the ends of a "U" shaped part 74. A flat coil 75 is disposed in the two air gaps formed between the two pairs of pole pieces and is mounted at 68 and 69 by means of rivets or screws on an insulating support 78, clamped between two mounting parts 79, 80, which also serve to bring the current to the coil 75 and act as counterweights. The support 78 is clamped between the two mounting parts 79, 80 by means of screws 81, 82. The insulation between the two mounting parts 79, 80 is achieved by means of insulating members of which only one 82′ is visible, these members being lodged in corresponding cavities, of which only one 82″ is shown, of the lower mounting part 80. The mounting parts 79, 80 are each provided with a resilient arm 83, 84 ending in a securing lug 85, 86. These two lugs 85, 86 are secured in an insulated fashion, to the platen 65 by means of two screws 87, 88. The upper mounting piece 79 carries a strip 89 to which is secured a pawl jewel 90 cooperating with a ratchet wheel 91. A retaining pawl jewel 92 is mounted on one end of a strip 93 the other end of which is secured to a pin 94. The operation of this embodiment is the same as that of the preceding embodiments, the difference residing in the electrodynamic drive by means of the coil 75.

Figures 7 and 8 illustrate, in elevation, respectively in a plan view, a fifth embodiment constituted by a piezoelectric motor. In such a motor, the transformation of electric energy into mechanical energy is effected by means of a compound strip of piezoelectric material. In order to obtain a motion of sufficient amplitude, it is necessary to use a long compound strip.

The illustrated motor comprises a platen 95 on which is mounted a compound strip 96 of piezoelectric material which is polarized. To this end one of the ends of the compound strip 96 is held in a support 97 provided with a flange 98, secured to the platen 95 by means of two screws 99 and 100. The compound strip 96 is fed at this end by two conducting leads 101 and 102. To the other end is secured a mass 103 connected by an arm 104 to a counterweight 105. This counterweight 105 carries a strip 106 to the free end of which is secured a pawl jewel 107 cooperating with a ratchet wheel 108.

A jewel 109, forming a retaining pawl, is secured to the end of a strip 110 the other end of which is secured to a pin 111, mounted on the flange 98 of the support 97, by means of an adjusting member which is not shown. The mass 103 is mounted on the compound strip 96 by means of a screw 112, the inner end of which is applied against a clamping piece 113 acting on one face of the compound strip 96. The other end of the compound strip is mounted in the same fashion in the support 97, that is by means of a screw 114, the inner end of which is applied against a clamping piece 115 acting on the same face of the compound strip 96. The motor is provided in addition with a shock limiting device constituted by a part 116, secured to the arm 104 and provided with an elongated hole 117, in which is engaged a pin 118 driven into the platen 95.

The operation of this embodiment is as follows: the normal oscillating motion takes place around an axis 119 coinciding with the axis of the pin 118. The width of the hole 117 of the part 116 is very slightly larger than the diameter of the pin 118 in order to avoid all contacts. The pawl 107, placed at a certain distance from the axis 119, has an amplitude which is sufficient to drive the ratchet wheel 108. If an acceleration or a shock perpendicular to a plane parallel to the compound strip and to the axis 119 occurs, the assembly of the two masses 103, 105 rotates around an axis which passes very near to the driving pawl 107. This pawl is therefore only subjected by the shock in a very small displacement. The deformation of the compound strip under the influence of a shock is limited by the part 116 coming into contact with the pin 118, which prevents any error in the movement of the drive or an excessive stress in the compound strip.

In the embodiments described with reference to the figures 1 to 6, the insensibility to shocks was obtained by combining the following properties: a) equilibrium of the masses about an axis of a member on which they are mounted b) short length of the resilient arms of the resonance member or strip c) the driving pawl being parallel to the resonance strip.

In the embodiment described with reference to the figures 7 and 8, the condition of equilibrium is not satisfied, but the point of contact between the pawl and the ratchet wheel is very near to a part of the assembly which is insensitive to shocks.

Figures 9 to 13 illustrate the theory of the motor.

a) Simple vibrating strip.

Consider to begin with a simple vibrating strip with a fixed mass m_1 (figure 9) and a short resilient part having a return force constant k (torque per unit of angular displacement). The mass develops a sinusoidal motion around a point situated in the middle of the resilient part, at a distance l_1 from the mass.

$$\text{Then } \omega_1^2 = k/J = k/m_1 l_1^2 \qquad (1)$$

where ω_1 is equal to 2π times the vibration frequency, and where J is the moment of inertia of the mass in relation to the centre of rotation.

If the support is subjected to an acceleration a in the downward direction, the mean position of the mass in relation to the support is deviated in the upward direction by a length h_a

$$h_a = m_1 l_1^2 \ a/k \qquad (2)$$

Introducing ω_1 into this equation one finds:

$$h_a = a/\omega_1^2 \qquad (3)$$

This relation shows that there exists a relationship between the frequency developed in a resilient system and the deformation to which it is subjected under the influence of a shock. This relationship is independent of the type of mounting of the resilient system.

Now let A be the amplitude of the motion of the mass m_1, P the energy dissipated in the course of the motion and Q the quality factor of the system (including the pawl and ratchet). It is known that the following relation exists (see for instance: Max Hetzel "The application of electricity and electronics to wrist watches" Horological Journal, March-July 1963, p. 81—233)

$$A=\sqrt{\frac{2PQ}{m_1\omega_1^3}} \qquad (4)$$

On the other hand, it is known that when the pawl and ratchet system is perfectly adjusted, the amplitude of the motion of the pawl is equal to the length of one of the teeth of the ratchet wheel, and the tolerable displacement of the mean position of the pawl is limited to half the length of one of the teeth. The condition which must be respected is therefore

$$h_a<\frac{A}{2} \qquad (5)$$

Taking into account the equations (3) and (4), this condition becomes:

$$A<\sqrt{\frac{PQ\omega_1}{2m_1}} \qquad (6)$$

The acceleration which can be tolerated, in the case of a tuning fork watch, may be deduced from the following data: $P=4{,}5\mu W$, $Q=1640$, $\omega=2\pi\,.\,360$ Hz, $m_1=0.565$ gr. Therefore: $a<121$ msec$^2=12{,}4\,.\,g$
where g is the acceleration due to gravitational force of the earth.

Several types of motors had the following values $P=4uW$, $Q=200$, $\omega=2\pi\,.\,300$ Hz, $m_1=0{,}04$ gr. Therefore: $a<134$ m/sec$^2=13{,}7\,.\,g$.

The shocks which can be tolerated found here are generally higher than those resulting from the movements of the wrist. But certain activities produce peak shocks the value of which is considerably higher. Formula (6) shows that the accuracy of the drive motion can be improved either by increasing the rate of drive, the quality factor or the frequency of the oscillatory movement, or by reducing the vibrating mass. But other considerations prevent these values from being greatly modified, and owing to the fact that they appear under a root, the improvement in security which is possible is small.

Let us now consider the system shown in figure 10 and corresponding to the first four embodiments. Here the mass m_1 is balanced by a mass m_2 connected to m_1 and situated on the opposite side of the strip. Equilibrium is established when the following conditions are satisfied:

1) The centre C is on the straight line joining the centres of gravity of the masses m_1 and m_2.
2) The distances l_1 between the mass m_1 and the centre C of the strip and l_2 between the mass m_2 and C are such that

$$m_1l_1=m_2l_2 \qquad (7)$$

In other words equilibrium is established when the centre of gravity of the masses is situated on the axis of rotation defined by the resilient mounting.

In a perfect state of equilibrium, the strip or member is bent in the shape of an arc of a circle when the masses are in a oscillatory state, ω_1 of this motion is given by

$$\omega_1^2=k/J=k/(m_1l_1^2+m_2l_2^2) \qquad (8)$$

$$\omega_1^2=\frac{k}{m_1l_1\,(l_1+l_2)} \qquad (9)$$

The effect of shock perpendicular to the plane of the strip is to cause the latter to be deformed in a different manner. If equilibrium is perfect, the strip bearing the masses takes the shape of an S (figure 12) the masses situated at the ends of the strip moving to positions parallel to one another, relative to the longitudinal axis of the strip. The masses are displaced, remaining parallel by a quantity

$$h_a=(m_1+m_2)\ l_3^2\ a/12k \qquad (10)$$

It is advantageous to express this displacement as a function of ω_d associated with the direction in which the shock occurs

$$h_a=a/\omega_d^2 \qquad (11)$$

The direction perpendicular to the plane of the strip is associated with ω_2 the value of which is

$$\omega_2/\omega_1=3{,}464\ r_g/l_3 \qquad (12)$$

where r_g is the radius of gyration defined by

$$r_g^2=J/m=J/(m_1+m_2) \qquad (13)$$

where m is the total mass of the masses.

If the strip of the driving pawl is situated parallel to the strip with its securing pin perpendicular to the strip, it moves in the same direction whether the system oscillates or is subjected to an acceleration perpendicular to the strip. But in this second case the more rigid the strip the greater the tolerance to shock for the balanced system.

Here, the amplitude is given by the following expression, which replaces (4)

$$A=\frac{r_c}{r_g}\sqrt{\frac{2PQ}{m\omega_1{}^3}} \qquad (4')$$

where r_c is the distance between the pawl and the centre of rotation. In figure 10 the pawl is supposed to be in the point P. The combination of the relations (4′), (5) and (11) gives

$$a<\frac{r_c\omega_d{}^2}{r_g\omega_1{}^2}\sqrt{\frac{PQ\omega_1}{2m}} \qquad (14)$$

A considerable increase of the tolerable acceleration may be obtained by arranging to have $\omega_d \gg \omega_1$. In the case considered here, $\omega_d=\omega_2$ and ω_2 is defined by (12). Therefore

$$a<\frac{12r_gr_c}{l_3{}^2}\sqrt{\frac{PQ\omega_1}{2m}} \qquad (15)$$

If the strip is short in relation to the radius of gyration, the improvement is considerable. For instance $P=4\mu W$, $Q=200$, $\omega=2\pi \,.\, 300$ Hz, $m=2$ $m_1=0{,}08$ gr, $r_g=4{,}5$ mm, $l_3=1{,}8$ mm, $r_c=1{,}8$ mm

$$a<2910 \text{ m/sec}^2=296 \text{ g}$$

The insensitivity to shock is increased by a factor of 24, compared to the case (1).

In the four first embodiments, the securing pin of the driving pawl is parallel to the mounting strips. Consequently, a shock perpendicular to the plane of the strips does not alter the distance between the driving pawl and the retaining pawl, but merely produces a small variation of the tension of the securing pin. Only a shock in the longitudinal direction of the securing pin would be capable of producing an error in the distance. ω_3 associated with this deformation is given by

$$\omega_3/\omega_1=3{,}464\ r_g/e$$

where e is the thickness of the strip. Taking $\omega_3=\omega_d$, equation (14) indicates that the insensitivity to shock is given by

$$a\frac{12r_gr_c}{e^2}\sqrt{\frac{PQ\omega_1}{2m}} \qquad (16)$$

If, for instance, r=4,5 mm, e=0,1 mm, the factor which multiplies the root has a value of 7800. This factor is so large that a longitudinal shock is practically incapable of causing a counting error.

c) Unbalanced extended mass system.

Figure 13 illustrates, in a very exaggerated fashion, the position of the system comprising an extended mass m and a strip, when an upward shock to the securing point occurs.

Displacement of the end of the strip

$$h=\frac{mal_3{}^2}{EJ_s}(L_3/3-L_g/2) \qquad (17)$$

where E=modulus of elasticity of the strip
J_s=moment of inertia of the cross-section of the strip (constant).

Rotation of the end of the strip.

$$\gamma=\frac{mal_3}{EJ_s}(l_3/2-l_g) \qquad (18)$$

Vertical displacement of any point P on the principal axis of inertia

$$h_p=h-l_p\,.\,\gamma \qquad (19)$$

A point N exists which remains immovable in relation to the support (case of the fifth embodiment). It distance from the end of the strip is given by the condition $h_p=0$. Equation (19) gives

$$l_n=\frac{h}{\gamma} \qquad (20)$$

$$l_n=l_3\frac{2l_3-3l_g}{3l_3-6l_g} \qquad (21)$$

The condition of equilibrium is expressed by $l_g=l_3/2$. It is seen that in that case $l_n=\infty$. In the case of equilibrium, the insensibility of the axis to shock becomes infinite.

The axis N may be made to pass through the point where the oscillating motion has the amplitude which is sufficient for the pawl to produce a driving motion. If, for instance, the axis N must be situated at the point where the strip is secured, then $l_n=l_3$, $l_g=l_3/3$.

WHAT WE CLAIM IS:—

1. An electro-mechanical means for driving a timepiece, the means of drvie comprising a resonance member producing an oscillatory motion about an axis, and a transformer means used to convert the oscillatory motion into a unidirectional motion, the resonance member comprising a rigid mounting having a resilient arm connected thereto and positioned perpendicular to the axis of oscillation and at least two masses mounted thereon, and spaced apart from one another, the transformer means comprising a pawl secured to the resonance member and cooperating with a ratchet wheel, wherein the pawl is mounted on the resonance member in such a way that a shock applied in a direction perpendicular to the axis of oscillation of the resonance member has a negligible effect on the motion of the pawl.

2. An electro-mechanical means as claimed in claim 1, wherein the resonance member comprises a rigid arm, to each end of which a mass is attached, as well as at least one resilient arm, parallel to the rigid arm and secured at one end of the said rigid arm, and at the other end to the rigid mounting of the resonance member, and the blade of the pawl of the transformer means is arranged parallel to the said two arms.

3. An electro-mechanical means as claimed in claim 1, wherein said resonance member comprises two resilient arms between which is disposed a rigid arm.

4. An electro-mechanical means as claimed in claim 1, wherein said resonance member comprises two rigid arms between which is disposed a resilient arm.

5. An electro-mechanical means as claimed in claim 1, wherein the resonance member comprises a single rigid arm at each end of which is disposed one of two masses, the control part of said arm being shaped in such a way as to form a space between the masses, wherein a single resilient arm is situated attached to the rigid arm and positioned so as to be in alignment with the axis joining the centres of gravity of the masses.

6. An electro-mechanical means as claimed in any one of claims 2 to 5, wherein the centre of gravity of one of the masses can be positioned eccentrically in relation to the axis where it is mounted on the rigid arm of the resonance member, in order to vary the frequency of oscillation of the resonance member.

7. An electro-mechanical means as claimed in any one of claims 2 to 6, wherein one of the said masses of the resonance member constitutes a magnet which cooperates with an electromagnet.

8. An electro-mechanical means as claimed in claim 3, wherein one of the said masses of the resonance member constitutes a coil which cooperates with a magnet.

9. An electro mechanical means as claimed in claim 1, wherein the resonance member comprises a compound piezoelectric strip, having one end clamped on to a support, and the other end secured to a mass and to one end of an arm the other end of which carries a second mass and the pawl of the transformer means, the arm and the compound strip being parallel to one another, the blade of the pawl being arranged in a position perpendicular to the compound strip and the pawl being situated in the neighbourhood of clamped end of the compound strip.

10. An electro-mechanical drive means as claimed in claim 9, wherein the compound strip cooperates with a device which limits the displacement of the axis of oscillation when a shock is applied in a direction perpendicular to the compound strip.

11. An electro-mechanical drive means substantially as described herein with reference to and as illustrated by the accompanying drawings.

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1,227,173 COMPLETE SPECIFICATION
3 SHEETS
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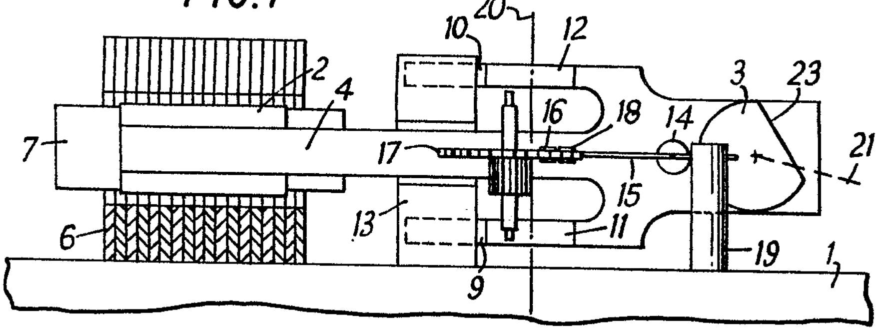
SHEET 1

FIG. 1



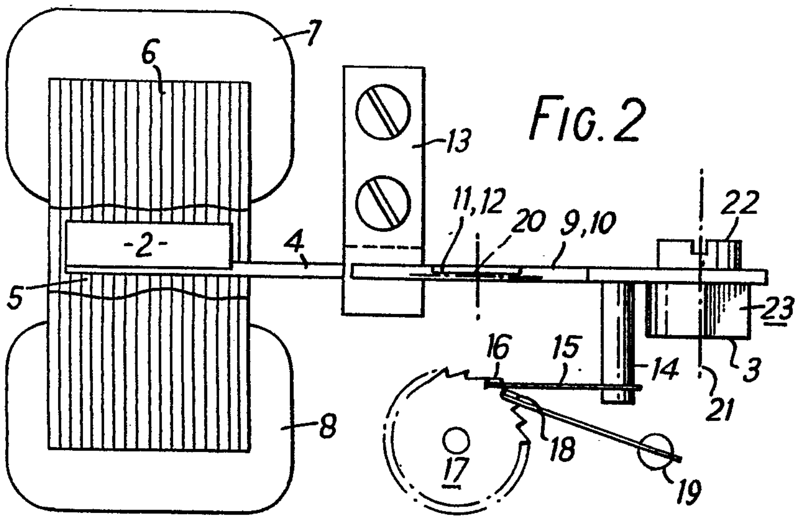


FIG. 2

FIG. 3

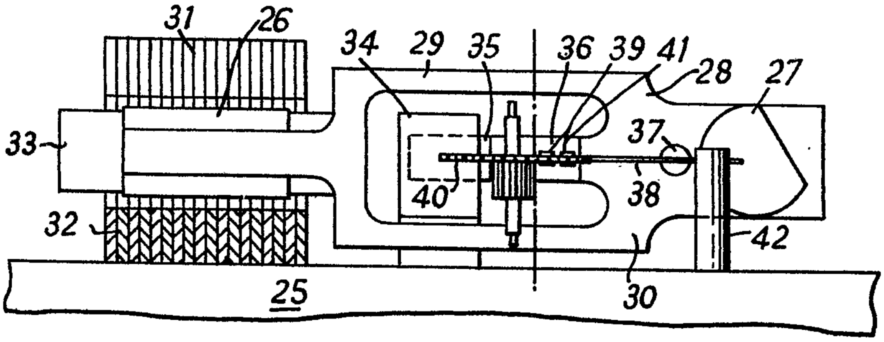


FIG. 4

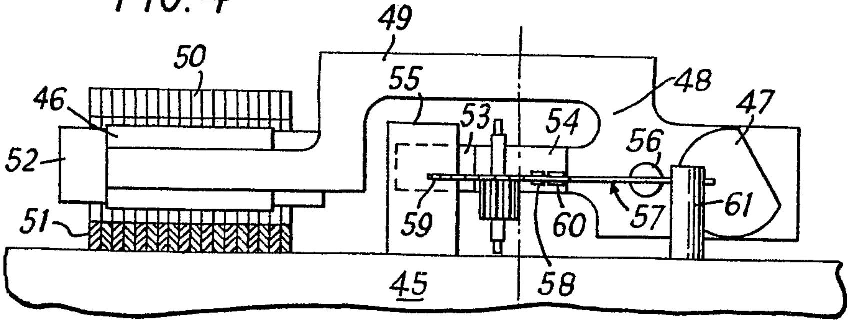


FIG. 5

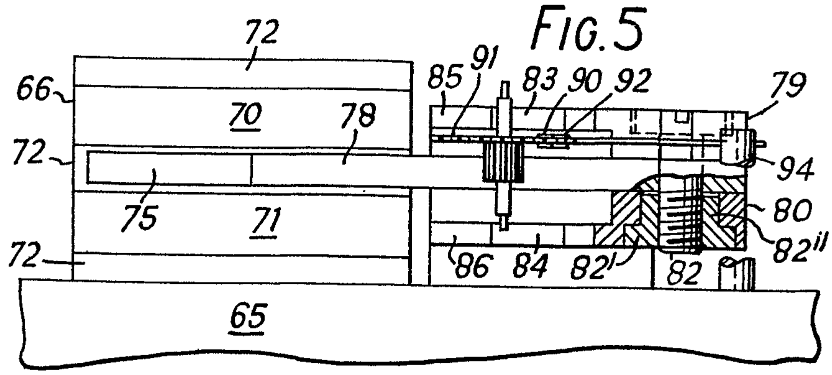
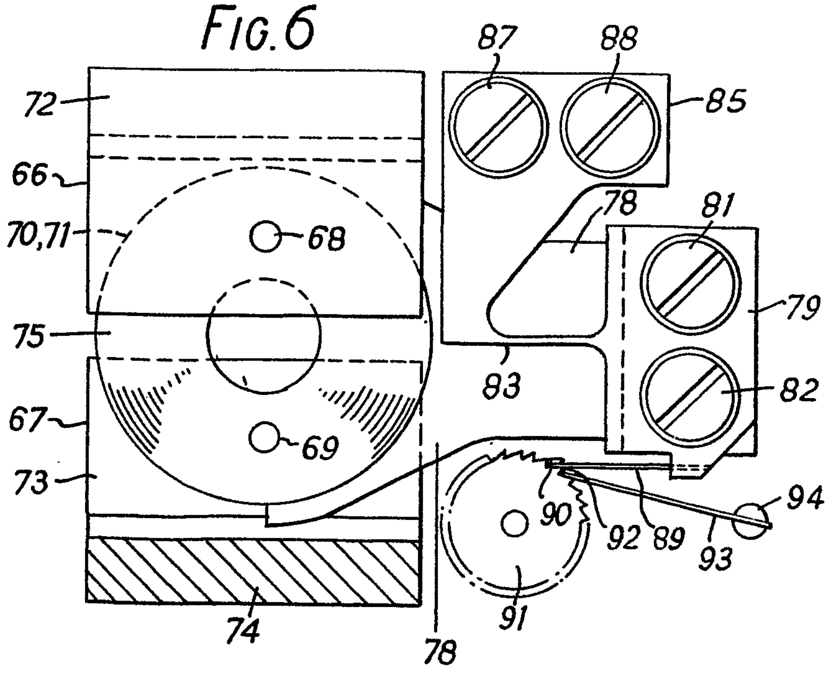


FIG. 6



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SHEET 3

FIG. 7

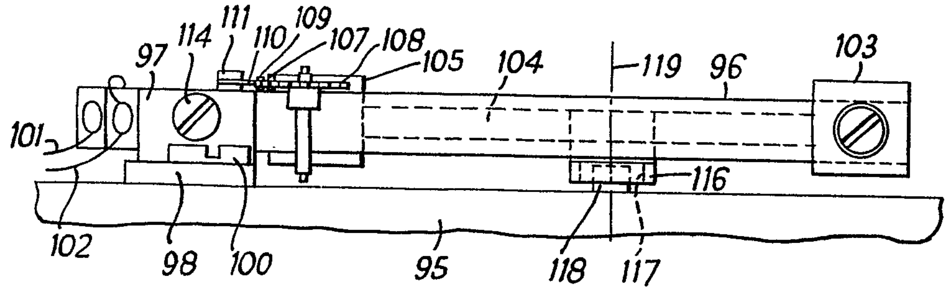


FIG. 8

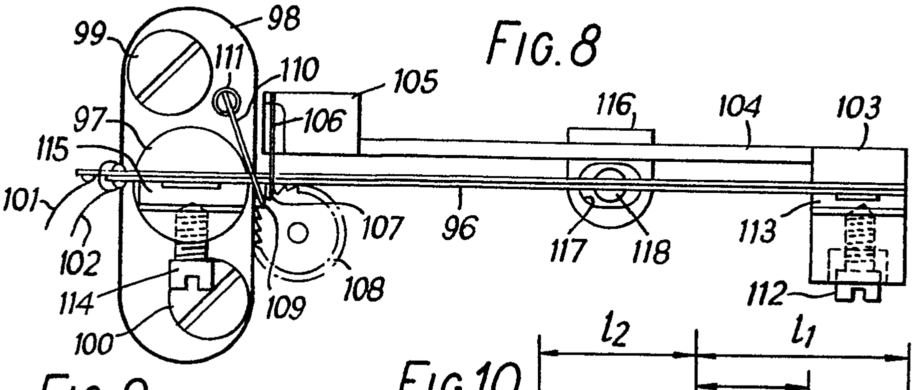


FIG. 9

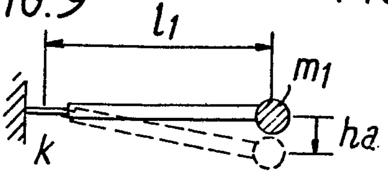
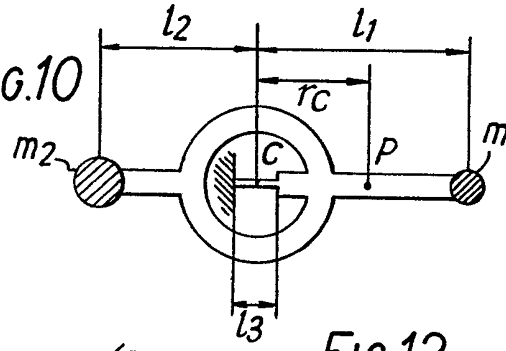


FIG. 10



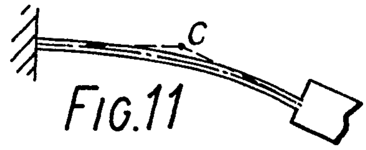
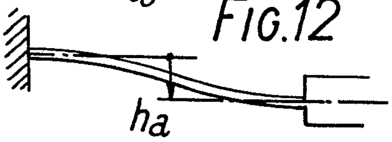


FIG. 11

FIG. 12



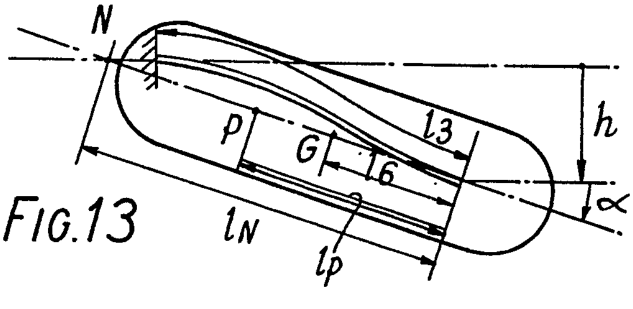


FIG. 13