United States Patent

[11] **3,599,420**

[72] Inventor **Henri Oguey**
Peseux, Switzerland
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[73] Assignee **Centre Electronique Horloger S.A. Neuchatel, Switzerland**
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[33] **Switzerland**
[31] **9115/67**

[54] **ELECTROMECHANICAL TIMEPIECE**
12 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** .... **58/23 V,** 310/25
[51] **Int. Cl.** **G04c 3/00**
[50] **Field of Search** .... 58/23, 23 D, 23 TF, 23 V, 116; 310/25, 36

[56] **References Cited**

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Primary Examiner—Richard B. Wilkinson
Assistant Examiner—E. Simmons
Attorneys—Robert E. Burns and Emmanuel J. Lobato

ABSTRACT: This disclosure is concerned with an electronic mechanical timepiece using a torsion resonator and having two extended masses oscillating in opposite phase around a common axis, the torsive axis of the resonator being at least approximately parallel to the plate of the timepiece and the oscillating masses being connected by a first torsion spring and connected each to a common support by separate springs.

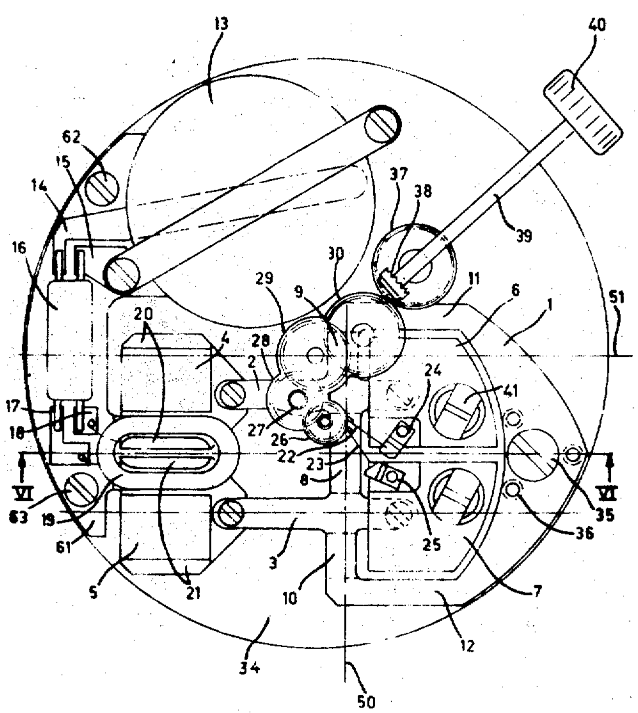


FIG.1
PRIOR ART

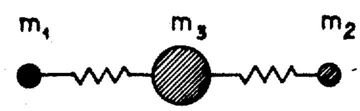


FIG.2
PRIOR ART

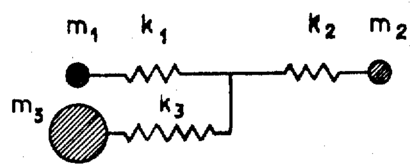


FIG.3

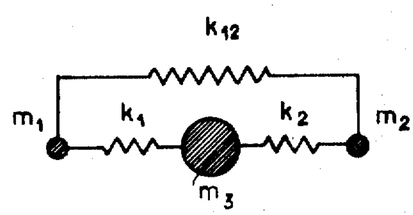
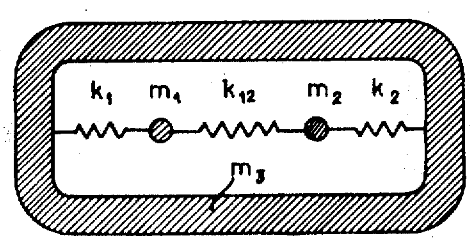
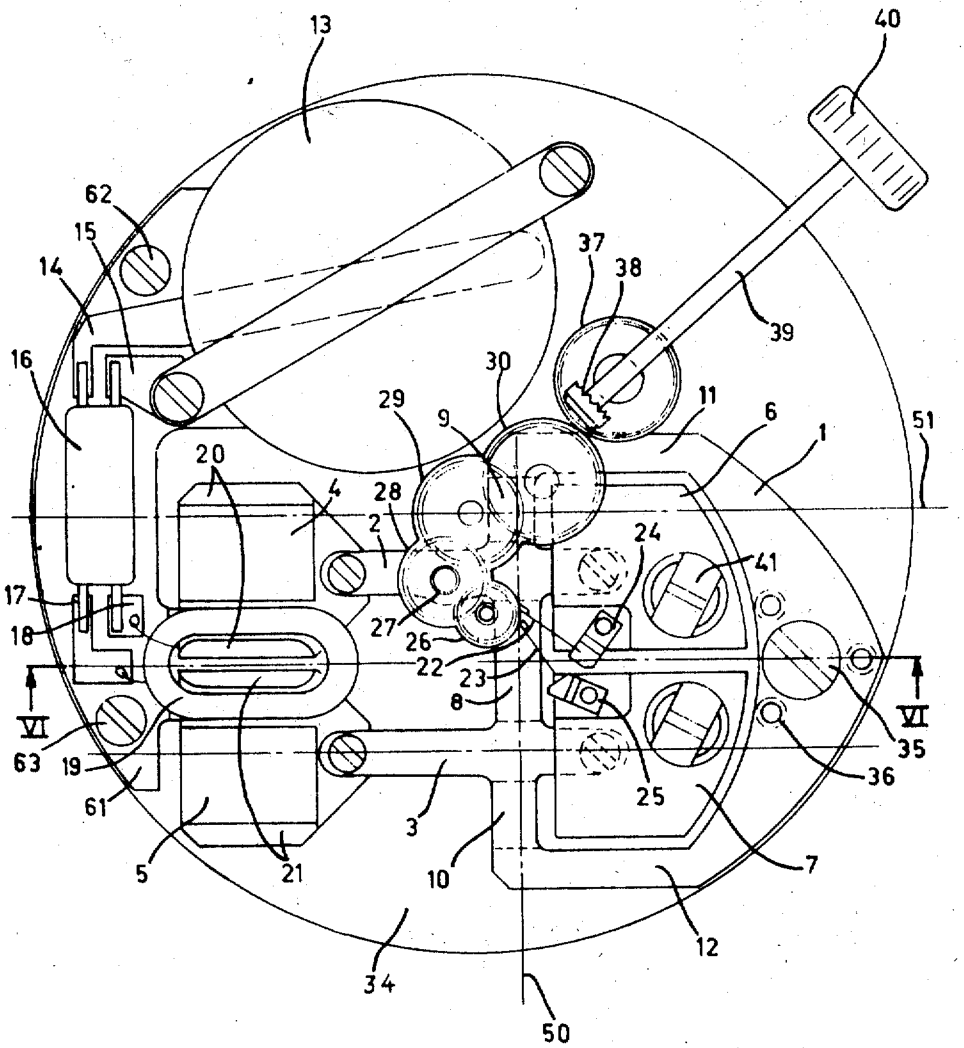


FIG.4



Inventor:
HENRI OGUEY
By Robert E. Burns
Attorney

FIG. 5



Inventor:
HENRI OGUEY
By Robert E. Burns
Attorney

FIG. 6

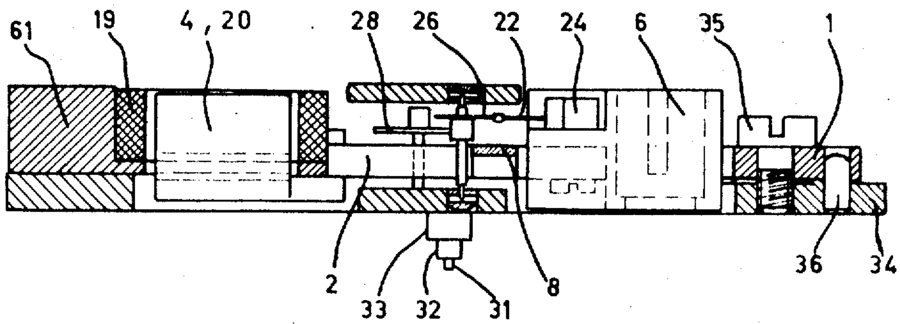
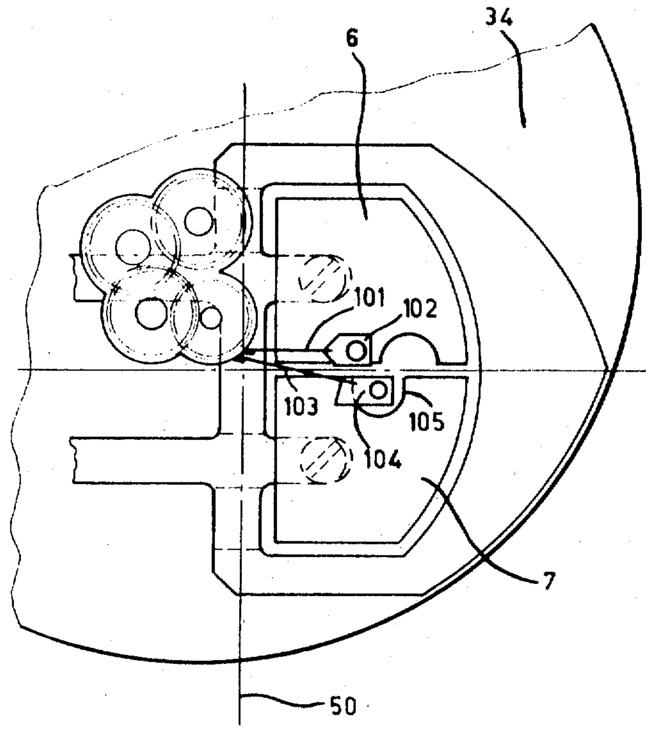
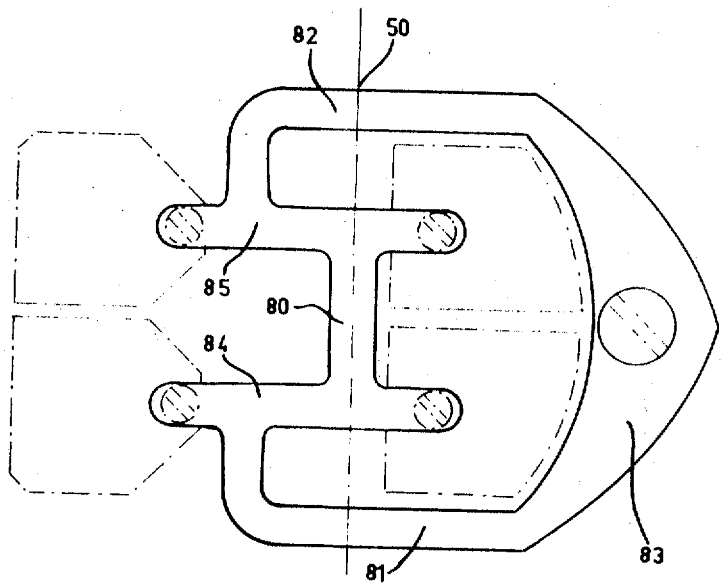


FIG. 7



Inventor:
HENRI OGUEY
By Robert E. Burns
Attorney

FIG. 8



Inventor:
HENRI OGUEY
By Robert E. Burns
Attorney

ELECTROMECHANICAL TIMEPIECE

This invention is concerned with an electromechanical timepiece comprising a mechanical resonator constituted by two masses oscillating in opposite phase.

In the accompanying drawing:

FIGS. 1 and 2 are schematic illustrations of prior art concepts for mounting such a timepiece;

FIG. 3 is a schematic representation of a resonator mounting embodying this invention;

FIG. 4 is a modified schematic illustration of the embodiment of FIG. 3;

FIG. 5 is a plan view of a device embodying the invention;

FIG. 6 is a sectional view taken along the line VI–VI of FIG. 5.

FIG. 7 is a partial view of the device of FIG. 5 and illustrates a modified driving pawl configuration; and

FIG. 8 is a partial plan view illustrating another modification of the device of FIG. 5.

Mechanical resonator for a timepiece, as defined above is generally composed of two oscillating masses connected elastically to a support. FIG. 1 of the accompanying drawing shows a first means for fastening a resonator to its support which consists in connecting the meeting point of springs k_1 and k_2, at whose extremities are secured the oscillating masses m_1 and m_2, to a casing having mass m_3 and this in a rigid manner. This resonator is theoretically insensitive to a variation of mass m_3 when it is perfectly balanced, but it is not usable, because a slight flaw in balance renders its natural frequency dependent upon mass m_3, which is not workable for a portable timepiece resonator.

FIG. 2 shows another way of connecting the resonator to a support of mass m_3 by means of a support spring k_3. The effect of this spring is to stabilize the natural frequency when the balancing is not perfect and when mass m_3 varies. The resonators actually used in horology are of this type, in particular of the tuning fork type whose branches correspond to springs k_1 and k_2 and the leg to spring k_3. It is however impossible to make two such vibrating elements whose natural frequency is exactly identical. In addition, it is possible to establish mathematically that the frequency ratio it is possible to establish mathematically that the frequency ratio of the resonator, that is the natural frequency which the resonator would have if mass m_3 was zero and of the frequency of the support, that is to say the natural frequency which the system of the resonator and its support would have if the two masses m_1 and m_2 were rigidly connected one to the other and if mass m_3 were infinite, is one of the important factors in the stability of frequency. The greater this ratio is, the less is the system sensitive to a lack of equilibrium and to a variation in mass m_3. However, if the natural frequency of the resonator is imposed, which practically amounts to imposing the free frequency, a high ratio of the frequency relative to the frequency of the support can be obtained only by lowering the frequency of the support and if this frequency is too low, the system losses its mechanical stability and becomes sensitive to impacts.

However, the free frequency can be high without modifying the frequency of the support by means of an additional spring connecting directly masses m_1 and m_2, according to an arrangement which has already been proposed and in conformity with FIG. 3 of the accompanying drawing. The increase in the frequency stability can also be justified mathematically by a decrease in the amplitude of oscillation of the support.

The resonator according to FIG. 3 additionally offers the following advantages: the condition of equilibrium causes the interplay of elements m_1, m_2, k_1 and k_2 while the natural frequency still depends upon spring k_{12}. This offers the possibility of first adjusting the equilibrium by means of one of these four first parameters and then of modifying the frequency by means of spring k_{12} without modifying the equilibrium. Such a possibility naturally is not present in the resonator of FIG. 2.

In the resonator of FIG. 2, the three springs k_1, k_2 and k_3 meet in a common point. The mass associated to this point modifies the behavior of the resonator relative to its ideal behavior. In particular, this mass renders balancing more delicate. Nothing of the sort occurs in the resonator of FIG. 3 for which the extremity of each spring terminates in a useful mass. This resonator is easier to balance and the choice of springs makes it possible to unite an approximate tolerance of balance with a great stability of frequency while reducing the number of adjustment to a minimum.

FIG. 4 shows a modification of the resonator of FIG. 3 which obtains the same results, but in which springs k_1 and k_2 are placed on either side of masses m_1 and m_2, support m_3 assuming the shape of an elongated frame. The resonator being secured to the support at two points spaced from one another, there results for the same frequency a better rigidity of the system in directions of deformation which are not desired than in the resonator with leg of the type of FIG. 2. The elimination of parasitic resonances is easy and the sensitivity to impacts is less.

Additionally if suspending springs k_1 and k_2 are made of a material whose modulus of elasticity has a positive temperature coefficient, and if connecting spring k_{12} is formed of a different material whose modulus of elasticity has a negative temperature coefficient (or vice versa), it is possible to select the value of the return coefficients of the springs in such a way that the temperature coefficient of the natural frequency of the resonator cancels. Springs k_1 and k_2 varying in the same way with the temperature, the equilibrium will not be sensitive to temperature variations. The possibility of making simultaneously the frequency and the equilibrium insensitive to temperature does not exist in this form in the resonator of FIG. 2 for which it is necessary to resort to other solutions such as a single material thermocompensated or springs formed each of two different materials.

The present invention precisely has for its object an electromechanical timepiece comprising a mechanical torsion resonator comprising two extended masses oscillating in opposite phases around a common axis and taking advantage of the above mentioned features.

This timepiece is characterized by the fact that the torsion axis of the resonator is at least approximately parallel to the plate and that the oscillating masses are connected by a first torsion spring and connected each to a common support by a second and a third spring respectively.

The accompanying drawing shows by way of example one embodiment of the invention.

The wrist watch shown in the drawing comprises a torsion resonator comprising two extended masses formed of two branches 2 and 3 each connecting an active mass 4 and 5 to a counterweight 6 and 7 respectively and three elastic parts, that is to say a central torsion blade 8 and two lateral torsion blades 9 and 10 secured to two uprights 11 and 12 fast on support 1, which is secured to plate 34 by a screw 35 and three positioning washers 36.

The electrical upkeep of the resonator includes a battery 13 and its connections 14 and 15, an electronic modulus 16 containing the electrical circuit for the upkeep of the resonator and welded to two intermediate plates 17 and 18, a coil 19 plunging in the magnetic field of movable magnets 4 and 5 and of their magnetic circuits 20 and 21.

The pawls comprise two driving pawls 22 and 23 fixed on counterweights 6 a nd 7 by means of adjustable supports 24 and 25 and driving in counter phase a wheel 26, the first wheel of the wheel work being represented by wheels 28, 29 and 30 and by the shafts for the second hand 31, minutes 32 and hours 33.

The setting mechanism is schematically shown by return wheel 37, field pinion 38, stem 39 and button 40.

The counterweights carry additionally two elements for adjusting the frequency of the resonator and consisting of two cylinders 41 and 42 having flattened sections and a slot for the screw which makes it possible to effect the adjustment by rotation of these cylinders.

The center of gravity of the resonator is located on axis 50 which is simultaneously the common rotational axis of the oscillating masses for the ideal case. Owing to the equilibrium of the system, the masses oscillate in opposite phase with an amplitude such that the total kinetic moment of the system is zero. The equilibrium condition being perfectly realized, owing to the tolerances along the moments of inertia of the masses and of the return coefficient of springs 9 and 10, there results a reaction on the support which is all the greater as springs 9 and 10 are more rigid relative to spring 8. It should be recalled additionally that the return coefficient of a torsion spring is inversely proportional to its length and depends upon its width and thickness. In the resonator shown in the drawing, the moments of inertia of the two masses are selected so as to be equal and each of about a tenth of that of the plate. The three springs have the same thickness and the same width and the length of spring 9 is equal to that of spring 10 and equal to half of that of spring 8. There results a ratio of the frequency of the support with respect to the free frequency, as defined in the introduction, equal to 0.707 and for an equilibrium error 0.7 percent, a slip frequency extremely small of 10^{-6}, that of about one-tenth of a second per day, between the instance when the watch is worn and that when it is laid on a table. The choice of dimensions of these springs is also favorable from another point of view: the maximum of the shearing stresses is the same for the three springs.

It is possible to fasten the resonator to the plate by two attachments to the ends of springs 9 and 10. This solution is not desired for the following reasons:

1. the fitting would not be perfect (screw fastening, gives poorly defined contact points) whence a most unstable natural frequency sensitive to temperature variations.
2. transmission of rotation from one side to the other of the resonator by the plate which would become deformed.
3. the material of the plate being subject to internal losses, there would result a lowering of the quality (Q) factor of the resonator.
4. the great rigidity of the fastening in the axial direction would cause a considerable isochronal error.

The solution here proposed extends torsion springs 9 and 10 by means of uprights 11 and 12 which have a well defined rigidity and which form a whole with these springs and with part of support 1. The following advantages are obtained:

1. the resonator including arms 2 and 3 supporting the masses, the three springs 8, 9 and 10, uprights 11 and 12 and support 1 is of a single piece, without connections, of a material of good elastic quality and having very stable properties. As a result the stability of the frequency is excellent.
2. the resonator is secured to the plate by a single screw and finds support on this plate in three very close points, thus eliminating deformation of the plate.
3. the torsion couple of the resonator is practically not transmitted to the plate, whence a very small reaction to this support with these advantages; high quality factor, stable frequency and reduced energy consumption.
4. the flexibility of uprights 11 and 12 renders negligible the contribution of the axial effort to the isochronal error.
5. the entire resonator can be made by stamping followed by milling of the elastic parts.

Under the effect of the couple transmitted by springs 9 and 10, the uprights deform and their extremities where they are attached to the springs move in opposite phase perpendicularly to the plane of FIG. 5. If the axis of springs 9 and 10 were to pass through the center of gravity of the movable masses, there would result an oscillation of this axis and as a result transmission of a couple around an axis 51 perpendicular to the axis of the centers of gravity causing a reaction of the support and consequently a decrease in the frequency stability and the quality factor. To palliate this effect, the fastening point of springs 9 and 10 is staggered relative to the axis of the centers of gravity in the direction opposite the support by an amount such that the movement of the centers of gravity be reduced to a minimum. The elasticity of the uprights also has an influence on the natural frequencies *fl* and *s*, but this influence is small and constant and changes neither the stability of the frequency nor the quality factor of the resonator. The purpose of each counterweight 6 and 7 is to move away as much as possible the center of gravity of the corresponding extended mass, considered in its entirety, of the center of gravity of active mass 4, 5 respectively. It is advantageous that the mass of the counterweights be greater than that of the active masses in such a way that the kinetic energy of the movement be constituted in greater part by the kinetic energy of the active mass. It is thus that the best yield of electromechanical conversion is obtained.

The counterweights have two auxiliary purposes: the first is to serve as supports to two driving pawls 22 and 23, the use of two driving frictionally screwdriver, pawls offering the advantage, relative to a system using a driving and a stop pawl, of allowing, for the same pitch of the teeth and the same consumption, the use of a wheel of greater diameter, a greater division ratio, a lesser movement of the pawl and a more regular movement of the gear. The second function of the counterweights is the fine adjustment of the watch by means of cylinders 41 and 42. These are housed in cylindrical openings in the counterweights in which they can turn frictionally. By changing their position by means of a screwdriver, the moment of inertia of the counterweights is modified relative to the axis of rotation without moving the center of gravity thus without altering the balance of each extended mass. The advantage of having two cylinders is to maintain the equilibrium condition of the resonator in its entirety in the entire range of adjustment of operation.

The sensitivity of the frequency of the resonator to various positions is very small. It is zero as a first approximation since the centers of gravity of the masses are immobile.

The effect of accelerated impact is to produce a deformation of the resonator.

One of the main advantages of this resonator is to be very rigid against all deformation caused by a linear acceleration of the watch. This is due to the fact that the torsion springs are held in two points which are relatively far from one another but relatively near the centers of gravity of the extended masses.

The direction which is most sensitive to accelerations is perpendicular to the plane of the watch. The springs are subjected to a flexure in the direction of their greatest flexibility. But since they are short and the arm of the lever of the accelerated force of inertia is also short, the effect of the accelerations is small. In practice, a watch bracelet is not subjected to considerable accelerations in this direction.

The sensitivity to impacts is measured also by the ratio between the main natural frequency and the frequencies of the parasitic oscillations. However, the present resonator is characterized by high natural parasitic frequencies thus by a good resistance to accelerations. When the masses oscillate around an axis perpendicular to the plane of the watch, their moment of inertia is great but the elastic parts have a great rigidity against bending in this direction. When the masses oscillate around an axis in the plane of the watch and perpendicular to the main oscillation axis, the rigidity of the springs to bending is small, but the moment of inertia of the masses is very reduced. In the two cases, the natural frequencies of these oscillations can be selected so as to be sufficiently high to ensure a good stability of the resonator.

Transmission of the movement from the resonator to the gear work can take place either directly by means of pawls or indirectly by calling upon an auxiliary synchronous motor. It is the coupling by means of pawls which is represented here because it offers certain characteristics with respect to known processes.

The movement of the masses is essentially perpendicular to the main plane of the watch and takes place around an axis parallel to this plane. The pawl gear has an axis perpendicular to the plane of the watch and therefore also perpendicular to the oscillatory axis 50 of the resonator. In order that the movement of the pawl takes place essentially in the plane of the pawl wheel, it is secured to the counterweight in such a way that its extremity is located at a certain distance from the oscillatory axis, as close as possible to the plane passing through the oscillatory axis and parallel to the axis of the pawl wheel. The path of the pawl is equal to the path of the counterweight multiplied by the ratio of their respective distance to the oscillatory axis. This characteristic makes possible an adjustment of the path of the pawl by a simple modification in the position of the pawl wheel on its axis and vertical staggering of the pawl. The same conditions can be obtained in the case where the pawls are secured on the useful masses. This is true for both driving pawls.

Under these conditions, the compression of the springs of the pawls varies greatly during their movement. At the end of its course, the pawl which passes from advance to withdrawal exerts a strong pressure on the pawl gear and will tend to drive it into a backward movement while the pawl which passes from rear to front movement exerts a small pressure on the gear. This effect contributes to a small loss of energy since it is the first pawl which drives the gear without friction and the second which contacts a tooth. As soon as the second pawl in its advance movement meets a tooth, it determines the movement of the gear. At the same time its pressure will increase progressively while that of the first pawl decreases. There will be selected preferably a slope of 45° for the teeth of the pawl wheel.

When an acceleration takes place perpendicularly to the plane of the watch, the pawl work may cause errors in counting as the deformation of the springs is accompanied by a rotation of the counterweights around axes parallel to **53** the consequence of which is to vary the relative phase of the pawls. This rotation can practically be eliminated by placing the center of gravity of the extended masses near the middle point of springs **9** and **10**.

Intermediate supports **24** and **25** furnish means for adjusting the pressure and the phase of the pawls.

The gear work is not critical. According to the space left by the resonator, it is necessary that the gears pass above or below. In the construction shown, an opening **27** has been made in one of the arms of the resonator to allow the passage of a shaft.

FIG. **7** shows a modification of the pawl works comprising a driving pawl attached to counterweight **6** by means of an adjustable piece **102** while a return pawl **103** is secured to plate **34** through another adjustable piece **104**. Counterweight **7** has a recess **105** which allows passage of the support of pawl **103**. The orientation of pawl **101** perpendicular to the axis of rotation **50** makes possible operation which is not sensitive to impacts.

FIG. **8** shows schematically a modified embodiment of the resonator in which the two lateral torsion springs **9** and **10** of FIG. **5** are replaced by flexure springs **81** and **82**, the intermediate spring **80** operating by torsion in the same manner as spring **8** of the preceding example, the torsion axis being again designated by **50**. Springs **81** and **82** are connected on the one hand to support **83** and on the other hand to extended masses **84** and **85** in points located between the torsion axis **50** and the extremities of these extended masses. For the rest, the resonator operates in the same manner as the previously described resonator.

What I claim is:

1. An electromechanical timepiece comprising a plate, a support on said plate, and a torsive mechanical resonator having two extended masses oscillating in opposite phase, said resonator having a torsion axis substantially parallel to said plate, a first torsion spring connecting said oscillating masses together and a second and third spring connecting each of said masses to said support wherein said first torsion spring has no interconnection with said support.

2. Timepiece according to claim **1**, wherein said second and third springs are torsion springs.

3. Timepiece according to claim **1**, wherein said second and third springs are flexion springs and are secured to said extended masses at points not located along said torsion axis.

4. Timepiece according to claim **1**, wherein said second and third springs are connected to said support by elastic elements.

5. Timepiece according to claim **4**, wherein said elastic elements have a component of elasticity in a direction parallel to said torsion axis of said resonator.

6. A timepiece according to claim **4**, wherein said second and third spring are torsion springs, and wherein said three torsion springs, said extended masses, and said elastic elements are made in one piece.

7. Timepiece according to claim **2**, wherein said second and third torsion springs have a center of gravity which is staggered with respect to the center of gravity of said extended mass to which they are respectively attached by an amount such that the deformation of said elastic elements connecting said springs to said support produce a minimum displacement of said center of gravity of said masses.

8. Electromechanical timepiece comprising a plate, a support on said plate, and a torsive mechanical resonator having two extended masses oscillating in opposite phase, said resonator having a torsion axis substantially parallel to said plate, a first torsion spring connecting said oscillating masses together and a second and third spring connecting each of said masses to said support, a first driving pawl secured on at least one of said oscillating masses, and a gear mounted with its axis perpendicular to said torsion axis of said resonator, said gear disposed adjacent said pawl for being driven by said pawl for advancing the time indicating means of said timepiece.

9. Timepiece according to claim **8**, wherein said pawl has an active end, said end being located as close as possible to the plane passing through the axis of oscillation of said mass and parallel to the axis of said gear.

10. A timepiece according to claim **8**, further comprising a second driving pawl, wherein said first and second pawls are mounted respectively on said two extending masses and are so positioned that they lie perpendicular to the plane of said gear passing through the contact points of said pawls and both cut the axis of oscillation of the said resonator, said second pawl disposed in driving relation to said gear.

11. Timepiece according to claim **8**, wherein said driving pawl is secured at one point of one of said oscillating masses and the trajectory of said point with the tangent to said gear at its contact point with said pawl makes an angle greater than 45°.

12. Timepiece according to claim **8**, wherein said driving pawl is perpendicular to the movement of its point of attachment resulting from the linear acceleration directed in the direction of the greatest flexibility of said elastic elements of said resonator.