Aug. 26, 1969 KAZUO TANAKA ET AL 3,462,939

MECHANICAL VIBRATOR FOR TIMEPIECE

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FIG. 1.

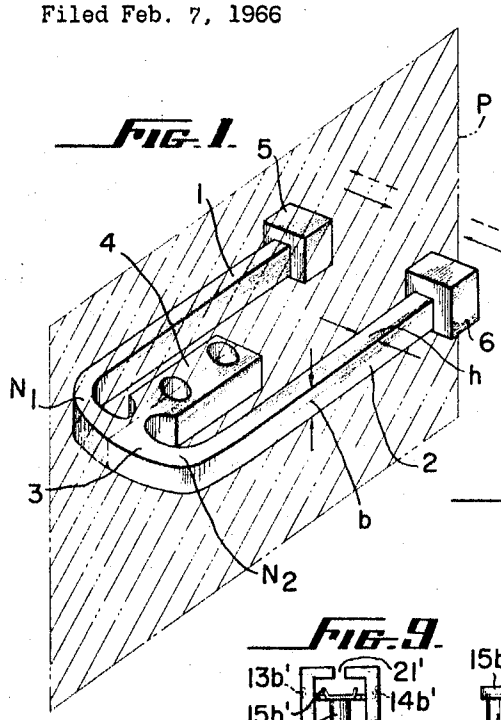


FIG. 5.

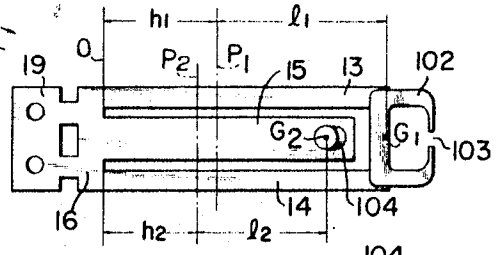


FIG. 6.

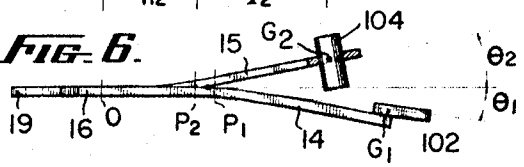


FIG. 9.

FIG. 8.

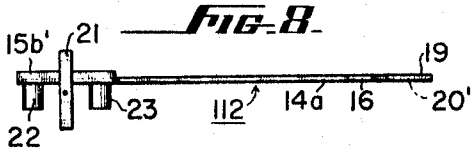


FIG. 4.

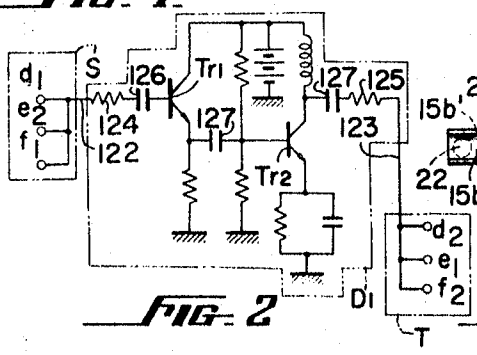


FIG. 7.

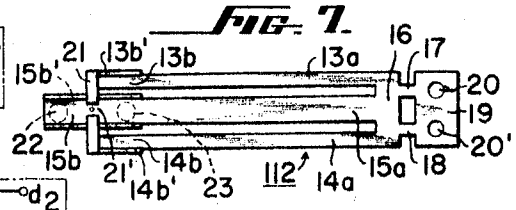


FIG. 2

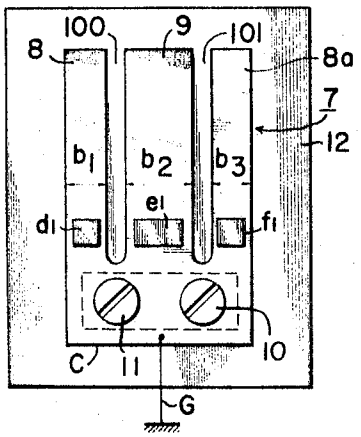
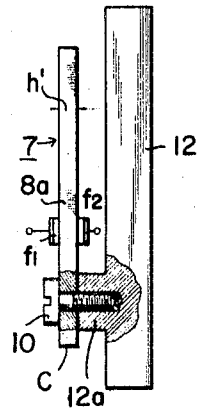


FIG. 3.



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FIG. 14.

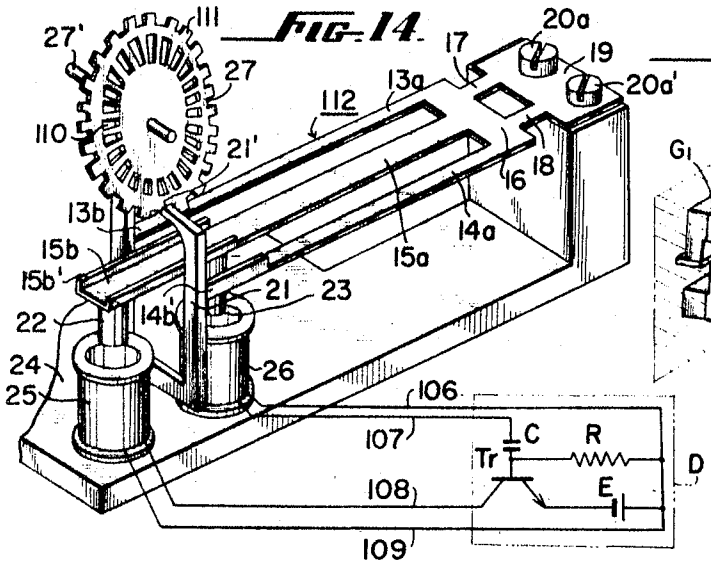


FIG. 21.

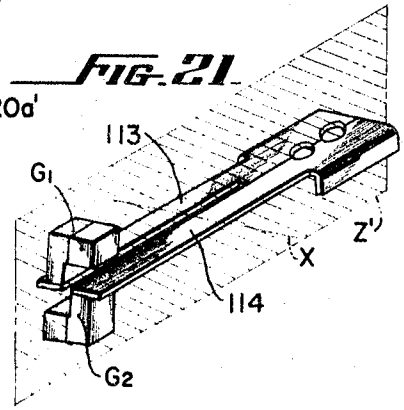


FIG. 19.

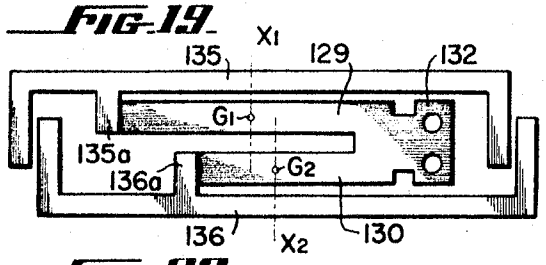


FIG. 20.

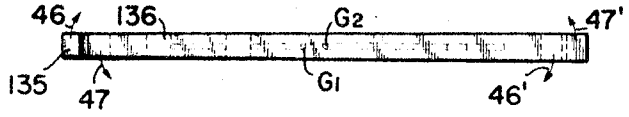


FIG. 12.

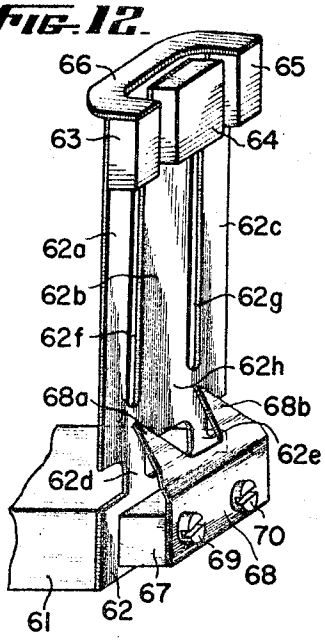


FIG. 10.

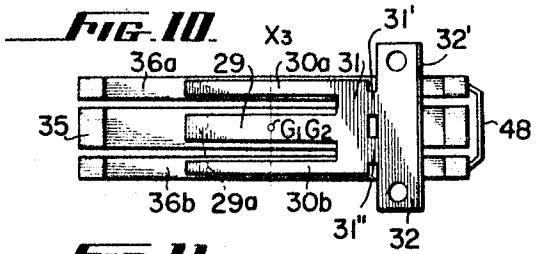
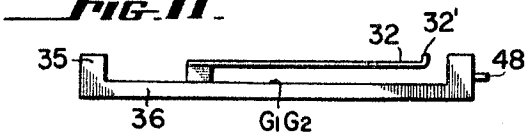


FIG. 11.



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FIG. 22

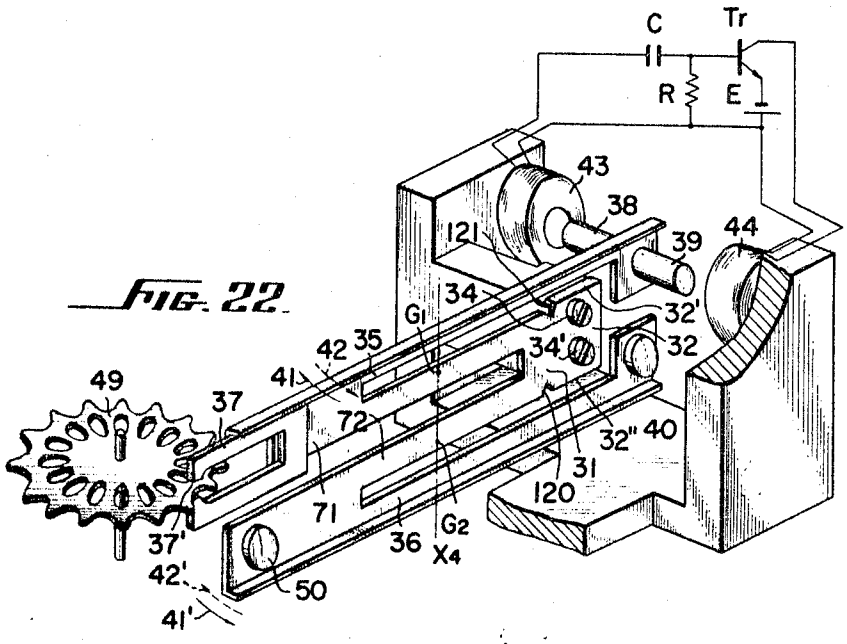


FIG. 16

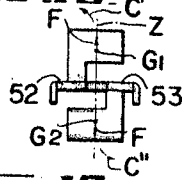


FIG. 15

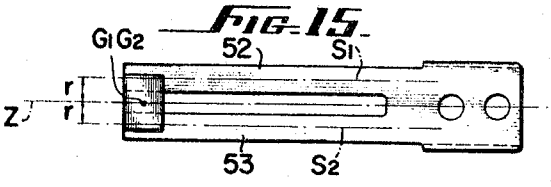


FIG. 17

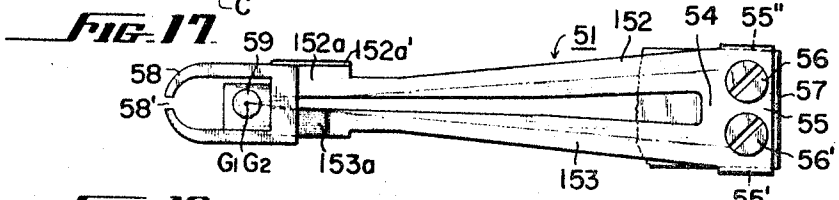


FIG. 18

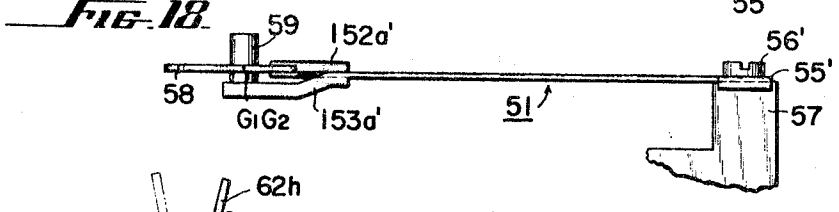
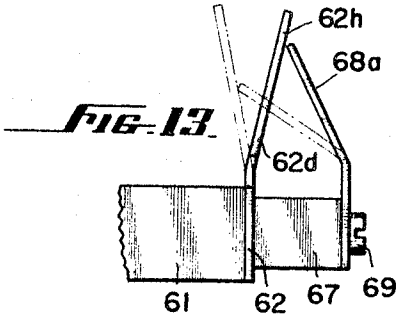


FIG. 13



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Patented Aug. 26, 1969

3,462,939

MECHANICAL VIBRATOR FOR TIMEPIECE

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Int. Cl. G04c 3/00
U.S. Cl. 58—23 3 Claims

ABSTRACT OF THE DISCLOSURE

A mechanical vibrator for use as a time base in a timepiece is provided with at least two oscillatory arms extending parallel to each other in a common plane with a base portion. An oscillation sensing device and an energizing device are secured on opposite surfaces of each of said oscillatory arms in close proximity to the root end of each of said oscillatory arms to maintain the proper oscillation of the arms relative to each other in a direction perpendicular to the common plane.

This invention relates to improvements in and relating to mechanical vibrators used as the time base for timepiece, especially portable watches.

It is the main object of the invention to provide a mechanical vibrator for use as the time base, having a relatively low operating frequency, a high operating performance, a highly easy workability from the stock, yet capable of performing a unique oscillating mode well-balanced, especially when compared with conventionally employed tuning fork vibrators.

These and further objects, features and advantages of the invention will be more fully understood as the description proceeds.

The accompanying drawings and the following description illustrate several preferred embodiments of the time base mechanical vibrator according to the invention in its particulars of operation and structure.

FIG. 1 is a perspective view of a conventional tuning fork type mechanical vibrator, only schematically illustrated for better understanding of its operating mode.

FIG. 2 is a top plan view of essential parts of a preferred embodiment of the mechanical vibrator, kept in its rest position and specifically shaped into a triple arm type one.

FIG. 3 is a partially sectioned side view of the vibrator, when seen from the right-hand to left-hand side of FIG. 2.

FIG. 4 is a schematic wiring diagram of a transistorized drive circuit adapted for use with the vibrator shown in FIGS. 2–3.

FIG. 5 is a top plan view of mechanical vibrator slightly modified second embodiment from that shown in FIGS. 2–3, in that the free ends of the both outside arms are united rigidly together.

FIG. 6 is a side view thereof, showing the vibrating mode of the vibrator.

FIG. 7 is a top plan view of a still further modified third embodiment from those shown in FIGS. 2–6.

FIGS. 8 and 9 are a side view and a front view, respectively, thereof.

FIGS. 10 and 11 are a top plan view and a side view of a fourth embodiment of the mechanical vibrator according to the invention, specifically shaped into a triple-arm type basically in the similar way to the type shown in the several foregoing embodiments.

FIG. 12 is a perspective view of modified fourth embodiment of the inventive vibrator, yet specifically provided with a damping means against spurious vibration.

FIG. 13 is an enlarged side view of a part of the vibrator shown in FIG. 12, illustrating a mode of the spurious vibration.

FIG. 14 is a perspective view of an inversed or drive escape wheel arrangement employing as the driving vibrator that shown in FIGS. 7–9.

FIG. 15 is a top plan view of a sixth embodiment of the mechanical vibrator according to this invention, specifically shaped into a twin-arm vibrator.

FIG. 16 is a front view thereof.

FIGS. 17 and 18 are a top plan view and a side view, respectively, of a slightly modified seventh embodiment from that shown in FIGS. 15–16.

FIGS. 19 and 20 are a top plan view and a side view of an eighth embodiment of the invention, similarly shaped into a twin arm vibrator.

FIG. 21 is a perspective view of the sixth embodiment of the mechanical vibrator shown in FIGS. 15–16.

FIG. 22 is a perspective view of reversed or drive magnetic escape wheel arrangement employing a modified twin-arm mechanical vibrator shown in FIGS. 19–20, a transistor drive circuit for said arrangement being shown schematically as connected thereto.

Before entering into the detailed description of several preferred embodiments and modifications of the invention, a conventional, yet comparative tuning fork type mechanical vibrator will be briefly and preliminarily described in reference to FIG. 1.

In this figure, numerals **1** and **2** represent a pair of vibratory arms which are rigidly connected at their root ends with each other by means of a rigid U-bend **3**.

This bend **3** is integrally fitted with a fixing stem **4**. These four parts **1**, **2**, **3** and **4** of the tuning fork may be shaped mechanically from one-piece stock having a permanent elasticity, or, alternatively, a length of bar stock of the above kind is bent up into a U comprising the said three parts **1**, **2** and **3**, and then the fixing stem **4** which has been separately prepared, is welded to the bend **3** at its central portion.

The vibratory arms **1** and **2** may be fitted at their free ends rigidly with respective additional masses **5** and **6**. The attachment of these masses is employed when a smaller tuning fork, yet having a lower natural frequency, is desired.

This kind of mechanical vibrator is arranged to operate in a symmetrical way about the meridian plane as at **P**, illustrated in FIG. 1 by chain-dotted lines. The vibrating motion of the vibratory arms **1** and **2** is shown schematically by two pairs of small arrows. The direction of this vibrating movement is naturally perpendicular to the imaginary plane **P** and in the plane including the vibrator, and the distances of the free ends of the arms measured at any instance from the plane **P** are equal to each other at any time in the course of the oscillating movement of the vibrator. Before using this kind of mechanical vibrator as the time base, it is absolutely necessary to adjust the natural frequencies of the arms **1** and **2** acting as respective vibratory cantilevers, to be precisely equal to each other, which means a troublesome and time-consuming job in the manufacture of the timepiece which is fitted with the vibrator.

In FIG. 1, b and h represent the width and thickness of each of the vibratory arms of the tuning fork vibrator, while N_1 and N_2 are nodal points of the arms. In order to make this kind of vibrator to oscillate at a relatively low natural frequency thereof, the following drawbacks would become predominant, as will be easily understood from the foregoing:

Since the nodal points N_1 and N_2 do not coincide with the junction point of the fixing stem **4** with the U-bend

3, the junction will conjoin with the oscillating movement of the bend when the vibrator is kept in oscillation. Therefore, there is a positive and considerable tendency that the fixing stem is subjected to a linear oscillation along the imaginary meridian plane P, although the stem is in practice fixedly mounted in the timepiece. A kind of stray vibration will thus be produced in a considerable amount and transmitted from the stem **4** to its mounting stationary member such as a pillar plate of the timepiece, This will invite a considerable amount of energy loss in the oscillative movement of the vibrator and result in lowering the sharpness in resonance, generally expressed by Q by those skilled in the art, as well as, in accelerating the fluctuation of the natural frequency of the vibrator.

Now assuming that the natural frequency of each of the vibratory arms of the tuning fork be f, the weight mass of each of the oscillating additional masses be m and the length of the vibratory arm be a constant, the following formula will be given:

$$f \propto h \tag{1}$$

where the additional masses m are negligibly small.

When the additional mass m is large enough relative to the weight of the oscillating mass, we can obtain:

$$f \propto \sqrt{\frac{bh^3}{m}} \tag{2}$$

From observation of these formulae, it would be acknowledged that, when assuming that the material of the oscillatory arm be of a certain predetermined resilient nature and the weight mass of the additional mass be of a certain constant, a relative dimensional error of b will influence upon the natural frequency f in the order of less than half the error, while that of h will affect upon the frequency in a corresponding manner, or even in the manner accentuated by 1.5 times.

Especially in such a case, where a small size tuning fork vibrator with a relatively low natural frequency is desired to be fitted, possible dimensional deviations of b or h will affect upon the natural frequency the more considerably with the lower natural frequency to be adopted.

When the vibrator is utilized as the time base of a smaller timepiece such as a watch, it is liable to be subjected to outside disturbing accelerations and it is commonly known that the ratio b/h should be as large as possible, especially when the oscillating frequency is a lower value, a practical example of the ratio being 3 at a frequency of 300 cycles per second.

When a tuning fork vibrator with its fixing stem is fabricated from an one piece sheet stock through the way of pressing job, it is highly difficult from the practical point of view to select the value of h smaller than b. Therefore, it must generally be necessary to select substantially equal to b preliminarily and the arm must be finished to provide the aforementioned desirous dimensional ratio through the way of a separate and troublesome machining job.

It should be further noted that the formation of the U-bend at the root of the vibrator will cause a considerably time-consuming job to be adopted. In addition, a considerable amount of residual bending stresses may frequently be preserved which will vary considerably with extended time period and result in a nonnegligible deviation from the design natural frequency and in a lowered sharpness in resonance. According to this invention, these drawbacks may be obviated to a satisfying degree as will become clear from the following detailed description.

In the first embodiment of the present invention, generally illustrated by numeral **7** in FIGS. 2 and 3, the vibrator is fabricated from a spring sheet stock having a suitably selected permanent elasticity by machining a pair of parallel open slots **100** and **101**. In this way, the vibrator **7** is formed with three parallel arms **8**, **9** and **8***a* adapted for acting as vibratory elements and extending from a common connecting and mounting base part denoted by C, the latter acting substantially in the same manner as the bend **3** in the foregoing conventional tuning fork, wherein the vibratory connection of the both vibrating arms **1** and **2** is realized by a bending deformation of the bend **3**, while in the present novel vibrator embodiment shown in FIGS. 2 and 3, the vibratory connection of the triple arms is carried out substantially by a torsional deformation of the base part C, as will be more fully understood as the description proceeds. Explaining more particularly the function played by the base part C, the points on this base part which are distant a certain distance from the root ends of the vibratory arms as well as those points on the base part which are in the proximity of the closed ends of the open slots are immobile with relation to the fixed coordinates. Thus the vibratory connection as above described is realized by the remaining area on this base part. Such remaining area shown by a number of inclined, chain-dotted lines, can be designed as desired with a widely extending area or square measure so the desired mounting is easily obtainable by having this area of the vibratory member mounted on a mounting projection **12***a* forming a part of a base plate **12**. In the embodiment shown therein, there are provided a pair of reception openings within this area, through which fixing screws **10** and **11** are led to pass and screwed into a mounting projection **12***a* forming a part of a base plate **12** which is in turn fixedly mounted on a timepiece, for instance, a watch, although the fixing means have been omitted from the drawing for clarification thereof.

In the present embodiment, the outer arms **8** and **8***a* are caused to oscillate in unison and the central arm **9** is forced to oscillate in the opposite phase as will be fully understood by consultation with a more detailed description as set forth hereinbelow in connection with FIG. 3, the oscillation planes of the three oscillatory arms directing at right angles to the plane of the vibrator as established when it is at rest. As will be well undestood, the mode of oscillation of each of these three arms is of the type of bending cantilever, as in the case of each of the oscillating arms of a tuning fork.

The vibratory arms **8**, **8***a* and **9** are so designed and finished that the natural frequency of each one of the arms is equal to the operating frequency of the vibrator. This kind of vibrator may perform a well-balanced oscillation because of that the space resultant of the vectors of vibratory inertia forces of the arms can be reduced substantially to nil, and further, that the resultant of moments of these inertia forces can be made again to substantially nil, and this kind of desirous operating feature could not be realized in the case of the traditional tuning fork vibrator.

Still further, according to the present invention, the aforementioned drawbacks inherent in the conventional tuning fork can be substantially obviated in the following manner:

At first, since the above-mentioned novel vibrator is not provided with a fixing stem in the form of a meridian projection as at **4** in the preceding conventional embodiment and the connecting base part or web of the vibrator does not conjoin with the oscillating motion thereof substantially in any way, a vibration leakage does not develop and is not transmitted from the vibrator to the stationary part of the timepiece to which the vibrator has been fitted, thereby considerably improving the sharpness in resonance and the stability of the oscillating frequency of the vibrator.

Each of the oscillatory arms **8**, **8***a* and **9**, is attached or stuck fixedly in close proximity of their root ends with a pair of piezoelectric elements d_1 and d_2; e_1 and e_2; and f_1 and f_2, respectively, which are covered on the exposed surfaces with conductive foils made from, for instance,

copper, said foils or electrodes being electrically connected through a transistored drive circuit D1 shown in FIG. 4. This circuit is an amplifier known per se, comprising transistors Tr1 and Tr2; matching resistors 124 and 125; coupling condensers 126, 127 and 127 and further minor circuit elements as shown. One of each pair of said piezoelectric elements serves as sensing or searching element which develops weak voltage current when the related oscillatory arm is caused to oscillate, while the other of the related pair of piezoelectric element will act as driver when the correspondingly amplified current is received by the element. It will seem that in this way the arms 8 and 8*a* is caused to oscillate in the opposed phase relative to the oscillation of the central arm 9. In this case for better understanding of this oscillation mode, attention should be given to the reference symbols attached to the piezoelectric elements.

Referring to FIGURES 2 and 3 of the drawings, the operation of the vibrator can be described as follows. When an operator (the bearer of the timepiece) desires to initiate the operation of the timepiece movement fitted with the present vibrator assembly, it is only necessary to close a main switch, not shown. By this manipulation, an initial pulse of current is fed simultaneously to all of the drive side piezoelectric elements d_2, e_1 and f_2 which cause the piezoelectric elements to be distorted. It may be assumed that the mechanical distortion of each of said piezoelectric elements is of such a nature as to elongate the elements along the respective axes of the related vibratory arms. In this case, it may be further assumed that the arms 8 and 8*a* will be resiliently urged to elevate their free ends from the normal plane (or the plane of the paper as viewed in FIGURE 2) toward the viewer and to lower the free end of the remaining arm 8 from the plane of the paper downwardly or, more specifically, in the opposite direction relative to arms 8 and 8*a*.

These bending deflections of the arms are sensed by the respective sensing piezoelectric elements d_1, e_2 and f_1 in which are induced minor voltages, the latter being conveyed to the respective inlet terminals of the amplifying circuit. The amplified voltage is delivered to the respective drive side piezoelectric elements d_2, e_1 and f_2. These elements are then distorted in the direction for accellerating the initial driven movements of the arms. It will be clear that by the provision of the amplifier and the sensing and drive piezoelectric elements that the bending movements of the respective arms will advance until the distortional resistance is brought into balance with the bending force. At this time the movement of each arm is reversed and the return stroke of the vibratory movement of the related arm begins.

During the return stroke, the arms will act in the opposite direction to that described above and the functions of the related piezoelectric crystals will be reversed.

The above-described operation of the vibratory element with respect to FIGURES 2 and 3 would be similar when applied to a two-arm vibratory member since the same principles of operation are involved.

The thickness, as at h' in FIG. 3, of each of the vibratory arms can be selected to be equal so that the sheet stock from which the vibrator is to be fabricated, and, therefore, possible dimensional errors in this respect could be minimized while in the course of the fabricating job. In addition, the widths b_1, b_2 and b_3 (FIG. 2) of the oscillatory arms can be easily fabricated to the corresponding design values by precisely machining the corresponding open slots 100 and 101, which is also a highly simple job in practice.

As can be easily seen, the present vibrator is rather of a simple design and can be fabricated substantially relying upon the press job, thus assuring a high precision product with a minimum loss of material and to be manufactured on an economical and industrial mass production scale. When it is desired to realize a mechanical vibrator having a considerably low natural frequency, it will suffice to adopt a corresponding thinner sheet stock.

In a modified embodiment shown in FIGS. 5–6, the vibrator is again formed into a triple arm type, having two outer and longer vibratory arms 13 and 14 and a shorter central vibratory arm 15. The former arms 13–14 are rigidly connected with each other at their free end by means of a rigid channel member 102 having an air gap 103. This channel- or U-member is arranged to act as a common additional mass, the center of gravity of which is shown in G_1. The central arm 15 is provided at its free end with an additional mass 104 in the form of a rigid cylinder, having a center of gravity G_2. The oscillating mode is substantially similar to that described hereinbefore with reference to FIGS. 2–3 and as clearly illustrated in FIG. 6.

In a still further modified vibrator 112 formed again into a triple arm type shown in FIGS. 7–9, the main part of the vibrator is fabricated from a sheet of spring material having a permanent elasticity, which material may be, for instance, "Elinver," "Ni Span-C" or the like, as commonly employed in the timepiece industry. This vibrator 112 is composed of two shorter and outer oscillatory arms 13*a* and 14*a* and a longer central arm 15*a*, all being rigid and integrally connected at their root ends with a common connecting part 16 which is in turn connected with a rigid and integral mounting piece 19 by means of a pair of considerably narrowed connecting bridges 17 and 18, for effectively preventing the vibratory influences from the oscillating arms 13*a*, 14*a* and 15*a* when the vibrator is caused to oscillate in the manner as will be more fully described hereinafter. Opening 20 and 20' are also provided for the reception of fixing screws similar to those shown by 10 and 11 in the first embodiment illustrated in FIGS. 2 and 3. Similar parts illustrated by 16, 17, 18, 19, 20 and 20' are provided also in the foregoing modified embodiment shown in FIGS. 5–6,

In the connecting zone where in the narrowed connecting bridges 17 and 18 are provided, the cross-section of the vibrator has been substantially reduced when compared with the neighboring parts 16 and 19 by the provision of side notches and a central rectangular opening.

As clearly seen, the free ends 13*b*, 14*b* and 15*b* of the oscillatory arms 13*a*, 14*a* and 15*a* of the vibrator are reinforced so as to increase the rigidity at these limited areas by the provision of respective bent-up side flanges at 13*b*', 14*b*' and 15*b*'. The central arm 15*a* is provided at its reinforced free end 15*b* with a pair of depending rigid cylinders 22–23 adapted for acting in combination as an additional oscillatory mass.

The outer arms 13*a* and 14*a* are provided at ther extreme free ends with a substantially channel-shaped connecting piece 21 which connects the extreme free ends of the outer arms 13*a* and 14*a* rigidly together and is adapted for acting as a common oscillatory mass. These masses 21, 22 and 23 may be only weight masses, or made of magnetic material, depending upon the purpose for which the vibrator is utilized, as will become more clear as the description proceeds. The rigid zone 15*b* passes through the inside open space of the connecting piece 21 with ample plays so that the first oscillating element comprising outer arms 13*a* and 14*a* in combination with the oscillatory mass 21, on the one hand, and the second oscillating element comprising central arm 15*a* carrying the masses 22–23, on the other hand, are capable of performing the respective oscillating movements in the perpendicular directions relative to the plane of FIG. 7 and in an opposed manner.

When the natural frequencies of the both oscillatory elements are equal to each other and if the dynamic conditions as will be set forth hereinbelow be satisfied while performing the oscillating movements in the correctly opposite phases, the oscillatory leakage in the aforementioned sense can be effectively prevented as was ascertained by our profound experiments, thus providing a highly improved mechanical vibrator having a damping coefficient

considerably minimized and highly adapted for use with the watch which is frequently subjected to outer disturbing forces.

Now referring again to FIGS. 5–6, the above-mentioned dynamic conditions will be described:

In the following description, mathematical symbols affixed with suffix "1" concern with the first oscillatory element comprising outer arms **13–14**, while those affixed with suffix "2" relate with the second oscillatory element comprising the central arm **15**.

Nomenclatures will be:

Center of gravity of an oscillating element ..... G_1
Concentrated mass assumed to appear at the center of gravity of the element ..... m_1
Moment of inertia about the center of gravity of the element ..... J_1
Center of gyration of the element ..... P_1
Distance between P_1 and G_1 of the element ..... l_1
Rotational angle of the element ..... θ_1
Distance between lines θ and P_1 ..... h_1
where $i=1$ or 2.

From the balanced condition of forces as established in a translation motion of concentrated masses,

$$m_1 \cdot 1.\theta = m_2 l_2 \ddot{\theta}_2 \quad (3)$$

From the balanced condition of moments of the masses relative to the origins of the respective oscillating resilient arms,

$$m_1 l_1 \theta_1 (h_1 + l_1) + J_1 \theta_1 = m_2 l_2 \theta_2 (h_2 + l_2) + J_2 \theta_2 \quad (4)$$

When the Formula 4 is rearranged with respect of $\ddot{\theta}_1$ and $\ddot{\theta}_2$, then

$$\{m_1 l_1 (h_1 + l_1) + J_1\} \ddot{\theta}_1 = \{m_2 l_2 (h_2 + l_2) + J_2\} \ddot{\theta}_2 \quad (4')$$

When terms of $\ddot{\theta}_1$ and $\ddot{\theta}_2$ are driven out from Formulas 4' and 3, we obtain

$$h_1 + l' + \frac{J_1}{m_1 l_1} = h_2 + l_2 + \frac{J_2}{m_2 l_2} \quad (5)$$

Equation 5 is the formula representing the twin element oscillatory system above referred to. In addition to this, it is a requisite condition that the traveling passages of G_1 and G_2 are in a plane perpendicular to a plane including the vibrator as being shown also in FIGS. 5–6, in order to realize the dynamic balance of the oscillation, which can be substantially satisfied by the vibrator as constructed in accordance with the novel teaching proposed by the present invention.

In the specific embodiment shown in FIGS 7–9, dimensions are such that: $h_1=h_2$ and $l_1=l_2$. Thus, G_1 is in coincidence with G_2

In a further embodiment, being shown in FIGS. 10–11, of the present invention formed again into a triple-arm vibrator, there are provided a central oscillatory resilient arm **29** and a pair of outer oscillatory resilient arms **30***a* and **30***b*, all being of a same length and arranged in parallel with each other. These arms **29**, **30***a* and **30***b* are made integral with a common connecting part **31** and further to a mounting piece **32'** by means of narrow connecting bridges **31'** and **31''** as in the same way shown in FIGS. 5 and 7, for effectively preventing oscillatory influence from being transmitting from the side of the oscillation-pertaining parts of the vibrator to the mounting piece **32** so as to reduce the otherwise possible oscillation energy loss to a minimum. The piece **32** is formed along its remote side edge from the vibrator proper with a bent-up flange **32''** so as to increase the stiffness of the piece **32**.

At the free end of the central arm **29**, there is a connecting piece **29***a* rigidly attached thereto, such as by fusing or the like fixing means, through which an additional oscillatory rigid mass **36** having an elongated channel-shape when viewed in its side elevation in FIG. 11, is fixedly attached to the arm. These parts **29**, **29***a* and **35** constitute in combination a first oscillating element, while a second element comprises in combination the outer oscillatory arms **30***a* and **30***b* carrying at their free ends respective masses **36***a* and **36***b* through the intermediary of fixedly attached connecting pieces similar to that denoted by **29***a*. Dimensions and configurations of the constituting parts of the both oscillating elements are selected so that the both perform respective oscillations in opposite phases to each other and have one and the same neutral axis of oscillation as at X_3, the centers of gravity of these elements as at G_1 and G_2 being selected to fall practically upon a common point on the axis X_3. Since the centers of gravity G_1 and G_2 fall practically upon the neutral axis X_3, position errors liable to adversely affect upon the natural frequency of the vibrator can effectively be suppressed. There is provided a connecting element at **48**, fixedly attached to the both oscillating masses **36***a* and **36***b* at their one side ends, for assuring a common oscillative movement of the outer arms **30***a* and **30***b*.

In a modified embodiment of the triple-arm vibrator shown in FIGS. 12 and 13, numeral **61** denotes a part of the conventional pillar plate of the timepiece in which the present vibrator is fitted, and **62** denotes the vibrator proper comprising three parallel arms **62***a*, **62***b* and **62***c* of equal length. These oscillatory arms are at their root ends rigidly and integrally joined together with a lateral connecting part **62***h*, and further united with a mounting part **62** by means of a plurality, preferably two, of narrowed connecting bridges **62***e* and **62***d*, by forming recesses, openings, perforations and/or the like at the corresponding area of the sheet stock from which the main part of the present vibrator proper is to be fabricated. As in the first embodiment shown in FIGS. 2–3, the formation of three arms is carried into effect by the provision of two parallel, open and elongated slots **62***f* and **62***g* in the sheet stock, said connecting part **62***h* being substantially defined by the lowermost ends of said slots, on the one hand, and by the uppermost ends of said connecting bridges **62***d* and **62***e*. **63**, **64** and **65** are additional oscillatory masses which are rigidly carried, respectively, by the three arms at their free ends and the two outer masses **63** and **65** on respective arms **62***a* and **62***c* are physically connected with each other rigidly by a U-shaped bridging member **66**. **67** denotes a rigid spacer which serves for rigidly positioning the mounting part **62** in position relative to the pillar plate **61**, on the one hand, and for rigidly mounting a resilient damping means **68** in its operative position, on the other hand, by means of fixing screws **69** and **70**. Damping means **68** is provided with resilient suppressers **68***a* and **68***b* which have respective pointed ends which are kept in slight pressure contact with the connecting area **62***h* and at the extensions of the longitudinal axes of spacing slots **62***g* and **62***f* which represent nearly perfectly immobile parts of the vibrator proper. This pressure contact arrangement serves effectively for damping undesirous spurious vibration of the oscillatory arms, yet providing no hindrance to the regular oscillation of these arms which constitute two oscillatory elements for performing an oscillating motion in an accurately opposed phase relationship, as was described hereinbefore throughout several preceding embodiments.

If the vibrator shown in FIGS. 12–13 should perform a spurious vibration caused by a some or other outside cause, the upper part of the vibrator above the recesses and perforations defining the bridges **62***d* and **62***e* in the queer directions relative to the longitudinal axis of the vibrator, thereby the damping elements **68***a* and **68***b* being subjected to an elastic deformation and slipping over the contacting surface of the connecting part **62***h*. The thereby exerted frictional resistance will effectively serve for the purpose of damping the spurious vibration in rapid manner.

The frictional damping means as referred to above is

given only by way of example. Various modifications and changes will easily occur to those skilled in the art. As an example, an enveloping member such as a lead sleeve may be employed for enclosing each of the bridges **62***d* and **62***e*, wherein the band will provide a considerable frictional resistance when subjected to a spurious vibration as was referred to above. In addition, such vibration damping means may equally apply to any of the foregoing embodiments.

It is commonly known that the above kind of spurious vibration frequently caused to take place in the timepiece by outside shocks, sudden and accidental changes in the load, and the like, is highly difficult to obviate in the prior art, especially when the mass of the stationary parts such as pillar plates of the timepiece movement is considerably large in comparison with the oscillating mass of the vibrator as time base. By employing the aforementioned damping means, this difficulty can effectively be obviated.

In the arrangement shown in FIG. 14, the vibrator **112** illustrated in reference to FIGS. 6–8 hereinbefore in applied as a drive time base in cooperation with a reverse magnetic escape wheel **27** so as to drive a watch movement, not shown. Numerals **13–19** and **112** are employed to show same parts as in FIGS. 7–9.

The channel-shaped connecting piece **21** is fabricated from a sheet stock of a ferromagnetic material so as to act as a feed magnet and formed with an air gap at **21'**, while the mounting piece **19** of the vibrator is fixed to a rigid base **24** by means of fixing screws **20***a* and **20***a'* which passes through the openings **20** and **20'**, respectively, and are received in the corresponding tapped holes, not shown, drilled in the base **24**. Escape wheel **27** is also fabricated from a magnetically permeable substance, as is commonly known, and provided rigidly with a shaft **27'** which is rotatably mounted in a pair of bearings, not shown, which are mounted on a stationary member of the watch movement. The wheel **27** is formed with a number of equally spaced slots **110** arranged in a circle in close proximity of the rim of the wheel, a number of projecting teeth **111** being formed radially on the peripheral surface of the rim at equal angular spaces and kept in meshing relation with a member comprised in the conventional gear train of the movement, although not shown, for driving the train. The rim is arranged to cooperate magnetically with the drive magnet **21** and for this purpose, the wheel is kept from contact with the poles of the magnet, defining the air gap **21'**. Additional masses **22** and **23** are, in this case, formed as permanent magnet pieces and arranged so as to electromagnetically cooperate with respective coils **25** and **26** which are fixedly mounted on the base **24**, and at the same time to electrically cooperate through the intermediary of conductive leads **106–109** with a conventional transistored drive circuit D which comprises transistors *Tr*, battery E, condenser C and resistor R. Magnet **23** and coil **26** are arranged to search the oscillating movement of the vibrator and the induced voltage in the coil will be transmitted in the form of periodic pulses through the intermediary of leads **106–107** to the drive circuit D, from which amplified voltages are fed through leads **108–109** to coil **25** so as to cause magnet **22** to oscillate in unison with the carrying central arm **15**. The oscillating movement, thus caused to take place, of the first oscillating element comprising central arm **15** and magnets **22–23**, is transmitted to the second oscillating element comprising outer arms **13** and **14** and feed magnet **21**, the latter element being thus maintained in vibration and the oscillating motion being transmitted magnetically through the air gap **21'** to the escape wheel **27** for turning the latter in a regular stepwise manner, as is commonly known by those skilled in the art. The operating mode of such magnetic escape wheel through the aforementioned kind of magnetic coupling may well be understood, if necessary, by consulation with the prior known disclosures as set forth in U.S. patent application No. 2,571,085.

In FIG. 21, an embodiment of the vibrator of the simplest construction is illustrated. In this case, the vibrator comprises only two oscillatory arms **113** and **114** arranged in symmetry with each other about an imaginary meridian plane Z. In this embodiment, the dimensions and configurations of parts consisting the two oscillating elements are so selected that the centers of gravity G_1 and G_2 thereof are caused to move in the aforementioned meridian plane in a opposite phase with each other, when the vibrator is brought into forced oscillation.

In FIGS. 15 and 16, a twin-arm model of the novel vibrator according to this invention is illustrated. This vibrator comprises two oscillatory arms **52** and **53**, the respective longitudinal axes are shown by chain-dotted lines S_1 and S_2. The centers of gravity G_1 and G_2 of the both oscillatory elements comprising the arms **52** and **53**, respectively, and oscillatory masses having the said respective centers of gravity and attached rigidly to the free ends of the said arms are so designed and practised that they fall upon the meridian plane Z of the vibrator and are caused to oscillate in the same plane, as will be well understood from the drawing. The said longitudinal axes S_1 and S_2 are separated from the meridian plane a predetermined distance denoted by *r*.

Now assuming that when a pair of opposing forces are applied onto the centers of gravity G_1 and G_2, respectively, as shown in FIG. 16 by respective vectors F, the resilient arms **52** and **53** will be subjected respectively to a torsional moment *Fr* and if the arms should not have an enough torsional resistance thereagainst, the oscillating passages will deviate from the meridian plane Z of the vibrator as exemplified by small curved arrows C' and C'', respectively. This kind of deviation must therefore be suppressed to an allowable minimum by increasing the torsional rigidity of each of the oscillatory arms. If not, the required dynamic balance of the oscillation would be destroyed and a considerable loss energy would release from the vibrator to the surrounding mounting parts comprised in the time base and the required performance of the vibrator as the time base would be considerably affected in the adverse sense.

A modified vibrator shown in FIGS. 17–18 from that illustrated in FIGS. 15–16 is so designed that the vibrator is adapted for use in driving cooperation magnetically with a magnetic escape wheel in the similar manner as will be described hereinbelow with reference to FIG. 22.

51 denotes the vibrator proper made from a sheet of resilient material as was already referred to, and comprises a pair of oscillatory resilient arms **152** and **153** made integral with a common connecting and mounting piece **54** which is rigidly mounted on a base member **57** by means of fixing screws **56** and **56'**, in the similar manner as was described in the foregoing several embodiments. Also in the present case, the connecting and mounting piece **55** is formed with stiffening flanges **55'** and **55''** as shown. In the similar way, the free ends **152***a* and **153***a* of the oscillatory arms are reinforced by side flanges **152***a'* and **153***a'*, respectively. In the present modified embodiment, the arms are not in parallel with each other, but in an convergent manner when seen from their root to free end, so as to increase the torsional resistance of the both arms. For magnetic coupling with the escape wheel as shown in FIG. 14 or 22, the first arm **152** carries at its free end rigidly with a somewhat elongated horse-shoe-shaped drive or feed magnet **58** having an operating air gap at **58'**, the center of gravity of the magnet being shown by common symbol G_1 for better understanding the generalized nature of several embodiments of the invention. In the present embodiment, the other arm **153** carries a permanent magnet piece **59**, preferably in the shape of a rigid cylinder as shown, the center of gravity being shown by reference symbol G_2

as before. The magnet **59** is arranged to cooperate with a coil assembly comprising a sensing and a drive coil element, in the manner as commonly known.

In a modified embodiment shown in FIGS. 19–20, the vibrator comprises a longer and a shorter oscillatory arms at **129** and **130**, respectively, these arms being arranged in parallel to each other with a short distance therebetween and rigidly and integrally united with a common mount piece **132**. These arms are of course made from a spring material. It is preferable that the parts **129**, **130** and **132** are fabricated from one and the same sheet stock as in the foregoing several embodiments. The mount piece **132** is fixedly, yet detachably fixed to a stationary base member, as at **24** shown in FIG. 14. Additional masses **135** and **136** are shaped substantially in the form of elongated channels and formed at intermediate points between the end extremities with inwardly directing projections **135***a* and **136***a*, respectively, which are fixedly attached to the free ends of the oscillatory arms **129** and **130**, respectively. A first oscillating element of the vibrator comprises the parts **129** and **135** and has a neutral axis of oscillation X_1 and a second oscillating element comprising the parts **130** and **136**, has a similar axis X_2.

When the first element is caused to oscillate about the axis X_1 in the direction shown by arrows **46** and **46'** in FIG. 20, the second element is driven in the opposite phase about the axis X_2 as shown by arrows **47** and **47'**. Dimensions and configurations of the constituent parts of the first oscillating element are so selected that the center of gravity G_1 thereof is positioned on the axis X_1. Equally, the center of gravity G_2 of the second element falls upon the axis X_2 which is in parallel with the former axis X_1 as shown. The masses **135** and **136** are off-set to each other a small distance longitudinally, when seen in the plan view of the vibrator as clearly illustrated in FIG. 19, so as to make the both elements to oscillate without interference.

As comparative examples, practical measurements of sharpness of resonance Q of conventional vibrator are shown. For instance, a specific mechanical vibrator disclosed in U.S. patent application No. 2,841,986, represents Q=500–700 at a peak-to-peak amplitude of 2 mm. and a number of oscillations per second of 100. In the case of a conventional tuning fork vibrator, about 50 mm. long, with a peak-to-peak amplitude of 0.4 mm. at a number of oscillations per second of 300, provides a Q-value of 4000. In comparision therewith, an embodiment of the twin-arm vibrator according to an aspect of the invention shown in FIGS. 10–11, having a length of about 50 mm. and a peak-to-peak amplitude of 2 mm. at a number of oscillations second of 100, has been proved to represent a Q-value of 4000.

In a reverse or drive type of magnetic escape wheel arrangement shown in FIG. 22 using a somewhat modified form of twin-arm vibrator as an aspect of this invention, a shorter oscillatory arm **71** and a longer arm **72** extend in parallel to each other from a connecting piece **31** made integral therewith and also with a mounting part **32**, provision being made of side notches **120** and **121** along the marginal imaginary line between the both parts **31** and **32**, so as to minimize the transmission of vibratory movement from the side of the vibrator proper to the mounting part **32**. The vibrator is detachably fixed by means of fixing screws **34** and **34'** which are similar to those denoted by **10** and **11**, respectively, in the first embodiment shown in FIGS. 2–3. In order to make possible adverse effects caused by occasionally loosened fixing screws **34** and **34'** upon the operating performance of the vibrator, the mounting part **32** is formed with bent-up side flanges **32'** and **32''** so as to increase the stiffness of the said part. The oscillatory arms **71** and **72** are provided with parallel extensions **35** and **36**, respectively, for increasing the stiffness thereof adapted to act as effective oscillatory masses. At one end of the extension of the shorter arm **71**, there is provided a substantially channel-shaped feed magnet **37** of the permanent type, having an air gap at **37'** and arranged to cooperate magnetically with a magnetic escape wheel **49** which is made from a magnetically permeable substance and operatively connected wtih the gear train of the timepiece for driving the train, although not shown. The magnetic poles defining the air *f* gap **37'** embraces, with ample plays for allowing the rotation of the wheel as well as the vibration of the magnet, the rim of the escape wheel. Search magnet **38** and drive magnet **39** are mounted on the opposite end of the said extension **35** of the arm **71**, in the form of oppositely extending projections so as to electromagnetically cooperate with stationary coils **43** and **44**, respectively. At the both ends of the extension **36** of another oscillatory arm **72**, there are fixedly mounted two balancing weight masses **40** and **50**. In this way, the extension **35** and permanent magnets **37**, **38** and **39** constitute, in combination with resilient and oscillatory arm **71**, one of the oscillatory elements, as at I, of the vibrator. The related constituent parts of this element are so designed and arranged that the center of gravity of the element, G_1, will fall on the neutral axis X_4 of oscillation of the element. On the other hand, stiffened extension **36** of another oscillatory arm **72** and the balance weights **40** and **50** constitute in combination a second oscillatory element II relying upon the another oscillatory arm **72**, and the related masses and configurations of constituent parts of this element are so designed and arranged that the center of gravity G_2 of the element will fall upon the axis X_4 which coincides, in this case, with that of the second oscillatory element. Of course, the natural frequency of the first element I is selected to be equal to that of the second element II.

Under these design conditions, when the first element I performs an oscillating movement as denoted by an arrow **41** or **42** in FIG. 22, the second element II will be caused to oscillate in the opposite direction shown by an arrow **41'** or **42'**, respectively, or more specifically in the opposite phase relation to each other.

If necessary, the oscillatory arms **71** and **72** and the related connecting and mounting part may be made from a nonmetallic material such as quartz and other parts may be fabricated separately therefrom from a metallic material and then rigidly united with the oscillatory arms.

It will be understood that each of the elements described hereinbefore, two or more together, may also find a useful application in other types of compound electronic units differing from the type described above.

While the invention has been shown and described as embodied in a hybrid circuit, it is not intended to limit the present invention to the details shown, since various modifications and structural changes may be made without departing from the spirit of the invention.

What is claimed as new and desired to be secured by Letters Patent is:

1. A mechanical vibrator for use as a time base in a timepiece, said vibrator being of one-piece construction and comprising a mounting part, a connecting part and at least two oscillatory arms extending parallel to each other in a common plane for vibration perpendicular to said plane, sensing and energizing means mounted on said vibrator comprising a pair of piezoelectric elements secured on opposite surfaces of each of said oscillatory arms in close proximity of the root end of each of said oscillatory arms for maintaining said arms in forced oscillation in opposition to each other at a predetermined period, a transistor amplifier electrically connected at its input with said means for sensing the oscillating movement of said vibrator and at its output with said means for energizing said vibrator and a current source electrically connected with said amplifier for feeding the oscillation-sustaining energy through said amplifier to said sensing and energizing means.

2. Mechanical vibrator as set forth in claim 1 further comprising cross-section reducing means such as recesses, openings and the like, formed between the connecting area and the mounting area of said part, for preventing possible oscillation leakage from said oscillatory arms through said mounting part to said timepiece.

3. In a drive motor for use as a time base in a timepiece, especially in a watch, comprising a mechanical vibrator, means mounted on said vibrator for sensing the oscillating movement thereof and energizing said vibrator for keeping the latter in forced oscillation at a predetermined period thereof, a transistor amplifier electrically connected at its input with the sensing part of said means and at its output with the energizing part of said means, and current source electrically connected with said amplifier for feeding the oscillation-sustaining energy through the latter to said means, said mechanical vibrator comprising a connecting and mounting part, three oscillatory arms extending in a plane and in the same parallel direction from said part, said arms and said means being

so designed and arranged that the central one of said arms, on the one hand, and the remaining outer two of said arms, on the other hand, are caused to vibrate in the perpendicular directions relative to said plane in opposed phases.

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