March 7, 1967 AKIRA NAKAI ET AL 3,308,361

ELECTROMAGNETIC VIBRATOR

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FIG. 1

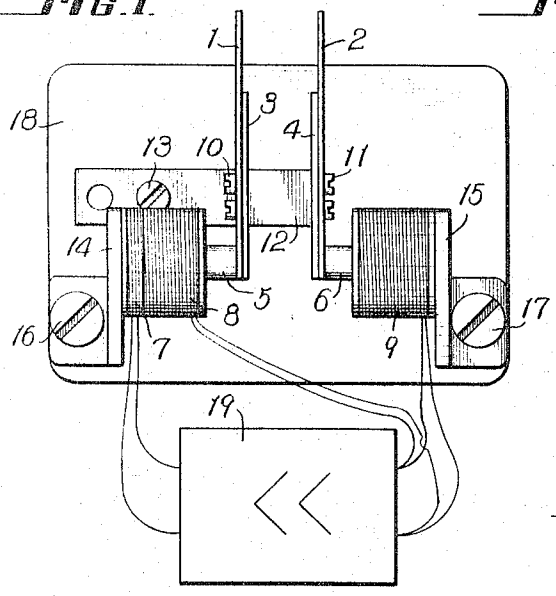
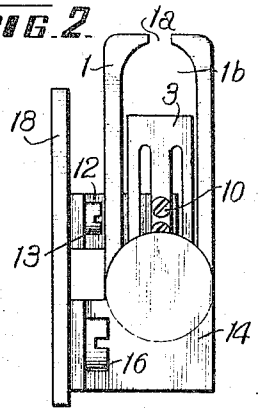


FIG. 2



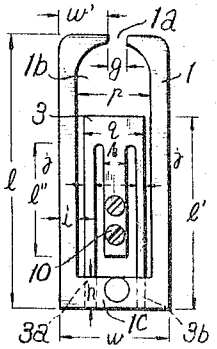


FIG. 3

FIG. 4

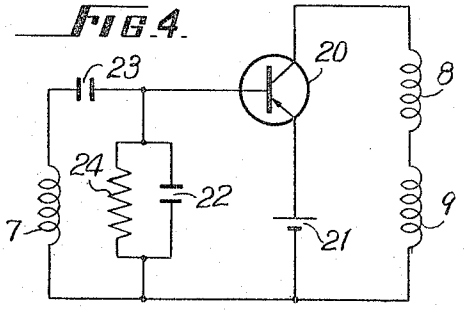


FIG. 6

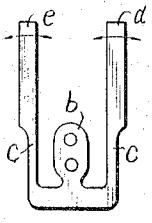


FIG. 5A

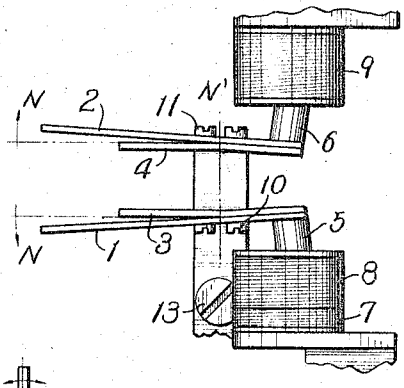


FIG. 5B

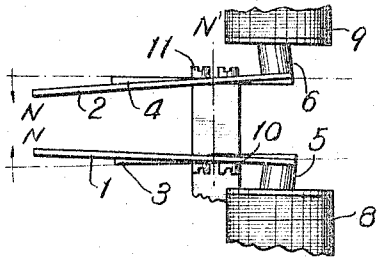
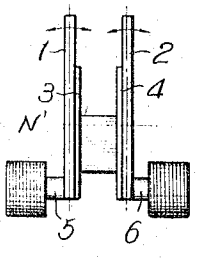


FIG. 7



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FIG. 8.

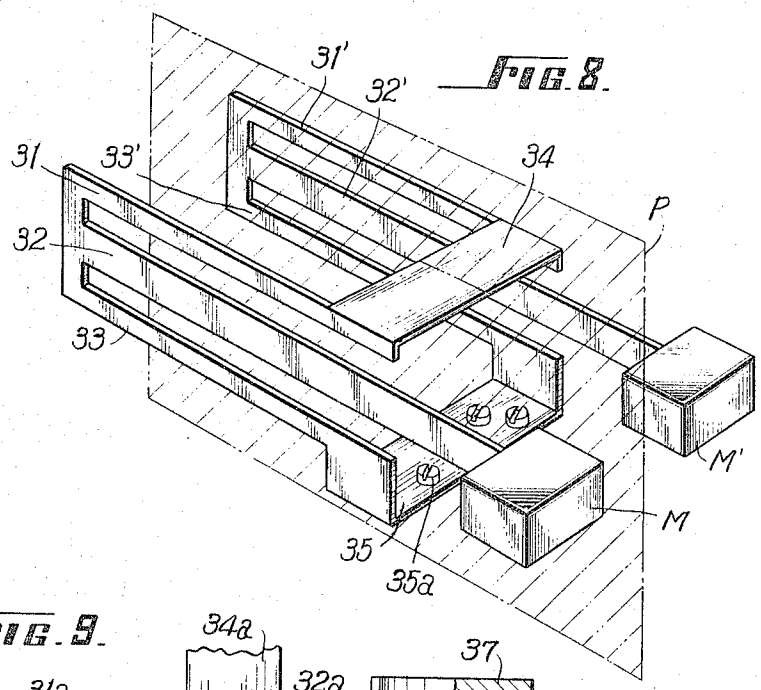


FIG. 9.

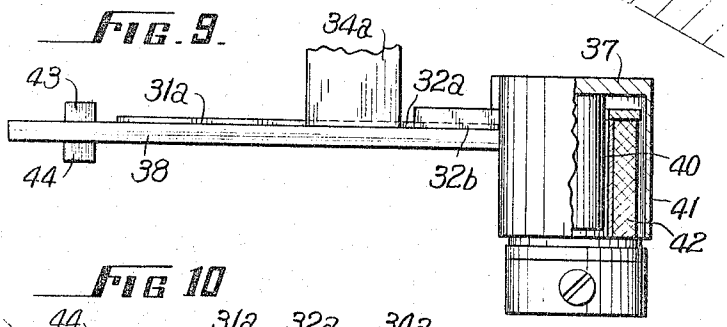


FIG 10

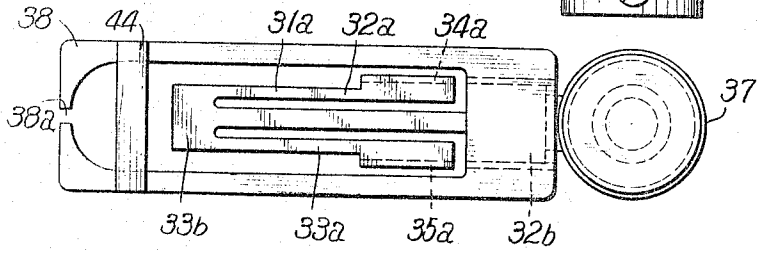
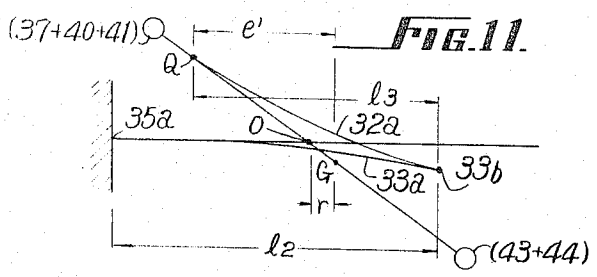


FIG. 11.



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ELECTROMAGNETIC VIBRATOR

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10 Claims. (Cl. 318—128)

This invention relates generally to electromagnetic vibrators. More specifically it relates to small vibrators especially adapted for use as the time base of smaller timepieces, although the invention is not limited to such usage only.

Hitherto various tuning fork- and tuning bar type vibrators have been proposed and find considerable use, especially in the timepiece industry.

Conventional vibrators do not, however, provide the precise isochronism necessary for use as time bases, on account of incomplete obviation of position errors and easy disturbance of the resonance frequency in the presence of outside vibrations. In addition, an inherent drawback in conventional vibrators of the kind referred to is insufficient sharpness of the resonance frequency. Further, reactive forces induced are not balanced out in the vibrating system, but are dissipated externally, which results, naturally, in a high consumption of the input power. When the vibrator is used with a battery-powered timepiece, a lower power consumption is also of the utmost importance. Unbalanced arrangements of vibrating masses and the like cause inherent to the conventional small vibrators give rise to development of considerable noise, which is a further drawback to be noted. Almost all of the conventional electromagnetic vibrators for use with transistorized timepieces must be fitted with a manual starter so as to provide initial energizing torques to the vibrator for the initiation of oscillation, to an extent sufficient to bring about a resonant oscillation.

A main object of the invention is therefore to provide an efficient and novel electromagnetic vibrator capable of substantially obviating possible position errors, thereby to realize a highly stabilized, constant frequency of oscillation of the vibrator.

A further object is to provide a unique vibrator of the kind above referred to which is highly stable in its frequency characteristic even in the presence of disturbing vibrations having an external origin.

A further object is to provide a novel vibrator of the kind above referred to which is capable of suppressing vibration noises.

Still a further object is to provide an improved vibrator of the kind above referred to which requires no manual starting means.

These and other objects and advantages of the invention may be readily ascertained by referring to the following description and illustration in which:

FIG. 1 is a schematic top plan view of a preferred embodiment of the vibrator assembly of the invention, illustrating a transistor amplifier schematically in block form;

FIG. 2 is an end elevation view of the vibrator proper, as viewed from the left-hand side of FIG. 1 and rotated through 90°;

FIG. 3 is a side elevation view of one vibrator looking toward the outside of FIG. 1, with the magnetic armature and its drive coil omitted for simplification, the entire figure being rotated through 90°;

FIG. 4 is a wiring diagram of the transistor amplifier shown only by a rectangular block in FIG. 1;

FIGS. 5A and 5B illustrate two modes of vibration as

executed by the vibrator assembly shown in FIGS. 1, 2 and 3;

FIG. 6 is a schematic representation of the working mode of a conventional tuning fork oscillator;

FIG. 7 is a schematic representation, similar to that shown in FIG. 6, illustrating the working mode of the vibrator assembly constructed according to the preferred embodiment of the invention;

FIG. 8 is a schematic perspective view of a second embodiment of the invention, somewhat modified from that shown in FIGS. 1, 2, 3, 5 and 7;

FIG. 9 is a top plan view of part of a further modified embodiment of the invention, shown as partially sectioned;

FIG. 10 is a front elevation view of the vibrator shown in FIG. 9; and

FIG. 11 is a schematic view of the vibrator shown in FIGS. 9 and 10, illustrating the dynamic performance of the vibrator.

Referring now to the accompanying drawings, especially FIGS. 1–5, a first embodiment of the invention will be described in detail.

In FIGS. 1 and 2, numeral **1** denotes a vibrator element having a generally rectangular configuration formed with an open gap **1***a* and an inside open area **1***b*. Such configuration is, however, only illustrative and various other geometrical forms can be employed as occasion may desire. The element **1** made from a metal strip, especially of a magnetic material. Another vibrator element **2** has a similar configuration and is made from the same metal strip as the first element **1**, and arranged physically in opposition thereto, but separated a considerable distance therefrom. **3** denotes a resilient mounting member made from a spring strip into a generally E-shape. The free extreme ends of the two outer and longer limbs **3***a* and **3***b* are fixedly attached to the base chord **1***c* of the element **1** as by sticking, fusing, riveting, or the like convenient conventional means (see FIG 3). Another substantially identical member **4**, identical with member **3**, is similarly fixed to the other vibrator element **2**. Permanent magnets **5** and **6**, preferably shaped as rigid cylinders having identical dimensions, are stuck onto the surfaces of the base chords of the vibrator elements **1** and **2** opposite to those to which the lead plates are fixedly attached as above mentioned. Sensing coil **7** and drive coil **8** are physically united into an assembly and adapted to cooperate electromagnetically with the movable magnet **5**, which assembly is fixedly mounted on a stationary bracket **14**, although the fixing means are not shown. In turn, bracket **14** is mounted fixedly, by means of a set screw **16**, on a conventional mounting or frame plate **18** as shown. Another drive coil **9** is arranged to electromagnetically cooperate with magnet **6** and mounted fixedly on a stationary bracket **15** which, in turn, is fixed, by means of a set screw **17**, on the plate **18**. The central tongues of the both lead plates **3** and **4** are fixedly attached, intermediate their ends, to a common support **12**, by means of respective fixing screws **10** and **11**. Support **12** is fixed on the plate **18** by means of a set screw **13**. A conventional transistor amplifier **19**, shown in FIG. 1 schematically only by a rectangular block, is electrically connected to coils **7**, **8** and **9** as illustrated in FIG. 4. The amplifier **19** is, by way of example, the emitter-earthed type which may be replaced by any conventional amplifier known to those skilled in the art. Thus, the invention is not to be limited to the specific amplifier illustrated.

The first vibrating system, comprising members **1**, **3** and **5**, and the second, comprising similar members **2**, **4** and **6**, have such arrangements and dimensions that they have exactly or substantially one and the same natural frequency of vibration and oscillate in the opposite sense relative to each other.

When a slightest vibration is given from outside to the first vibrator element **1**, the attached magnet **5** is caused to oscillate correspondingly, which causes in turn to induce a voltage in the sensor coil **7**. This induced voltage is amplified by means of the amplifier **19**, including transistor **20**, current source **21**, condensers **22** and **23** and resistor **24**, and applied to drive coils **8** and **9**, respectively, so as to accelerate the initiated vibration above mentioned. This accelerating will continue until the both vibrating systems attain and maintain the common natural frequency. In this case, both vibrating systems seem generally to oscillate as if they were the two fork elements of a tuning fork; yet there are considerable differences from the standpoint of the mode and characteristics of vibration, as will become apparent from the following description.

The vibration-participating members **1**, **3** and **5** of the first system and those **2**, **4** and **6** of the second system are so designed and dimensioned that the centers of gravity of the two systems will fall precisely or substantially upon the centers of oscillation, thus providing minimized position errors. In adidtion, the two vibration systems are so arranged that they oscillate in phase opposition to each other. Thus, although reactions induced by the vibrating members of both systems will be transmitted to the common support **12**, they substantially cancel each other, thereby minimizing possible propagation of the vibration energy from the support **12** to the frame plate **18** and, at the same time, increasing amazingly the sharpness of resonance, generally denoted "Q" by those skilled in the art, on the one hand, and substantially obviating possible support errors, on the other hand. These characteristics are of great value especially when considering battery-powered smaller timepieces where the current source is highly valuable and an elongation in its durable life is of utmost importance.

FIGS. 5A and 5B represent schematically the vibrating modes of the vibrator assembly according to this invention. In each of these figures, chain lines N indicate the stationary positions of the two vibrating systems, while a traversing chain line N′ denote the center line about which the vibrating systems oscillate. As already mentioned, the vibration-pertaining masses of each of the two systems are so designed and dimensioned that the centers of gravity thereof fall upon these lines. In FIG. 5, the vibrating elements have been drawn in an enlarged scale five times the practical sizes. For reference, the actual weight of the vibration-pertaining masses of each system amounts to about .2 gram, and the whole weight of the assembly is 2.8 grams.

Considerable differences between a tuning fork vibrator and the novel vibrator according to the invention, when viewed from the theory of dynamics, will be described now with reference to FIGS. 6 and 7.

In FIG. 6, the conventional tuning fork vibrator will oscillate with nodes as at *b* and *c*. Vibrating forks *d* and *e* will oscillate about the centers or nodes *c* so as to follow arc-shaped vibration paths. Thus, with use of this type of vibrator, it is absolutely impossibl eto bring the center of gravity of either vibrating system *d* or *e* into coincidence with the respective center of oscillation *c*, so that adversely affecting propagation of reactive energy, induced by the oscillative movement of the masses, will inevitably be invited. In this case, a possible external vibration, when it takes place, will act strongly upon the natural frequency of the tuning fork so as to alter the vibration characteristics of the latter. It will be further clear that position errors are invited, which results naturally in an unreliable time base.

The vibrator assembly schematically represented in FIG. 7 comprises, as already described, two vibrating systems, each having its center of oscillation positioned at the neutral axis N′, which systems oscillate in phase opposition to each other, and the center of gravity of each system is situated exactly or substantially at the said axis,

whereby inherent drawbacks, such as described above in the conventional tuning fork, can be substantially obviated.

A further advantage of the invention resides in that the vibrator may have a length ten and more times that of the corresponding tuning fork, resulting in a correspondingly increased amplitude of vibration without inviting any loss of efficiency.

As already mentioned, the sharpness of resonance, Q, can be highly increased in comparison of those attainable according to the conventional technique. As commonly known, the value Q may be expressed by the following formula:

$$Q\frac{\pi}{\delta}=2.3\pi\Big/\frac{1}{n}\log\frac{y_1}{y_{n+1}}$$

wherein,

δ=logarithmic damping coefficient;
π=the circular constant;
n=number of vibrations per second;
y_1=amplitude at the initial oscillation; and
y_{n+1}=amplitude at the $(n+1)$th oscillation.

In practice, Q is determined by measuring the time interval from the initiation of the vibration to a time point in which the amplitude amounts to one-half the original largest value, and by use of the above formula. As commonly known, the higher the Q-value, the smaller will be the energy consumed, and the more accurate the frequency characteristic, there thus being obtainable a more efficient and reliable time base.

By comparison, several numerical and experimental examples will be set forth as follows:

When a tuning bar, 1.0 x 0.4 x 0.03 cm., of the cantilever type, was supported through the intermediary of suitable supporting means, such as a conventional timepiece plate, on a piece of brass plate, 0.9 x 2.7 x 2.7 cm. (weight: 58 grams), and the Q-value amounted to about 700. When the same vibrator attached to a conventional timepiece plate was placed on a sheet of foam rubber, 3.0 x 5.0 x 6.0 cm. (weight: 2.5 grams) the Q-value amounted to 500.

When a vibrator according to the invention, having dimensions, referred to FIG. 3, as follows:

w'=1.8 mm.; w=4.0 mm.; l=10.0 mm.
g=0.26 mm.; t (thickness)=0.3 mm.
p=2.7 mm.; q=2.3 mm.; l'=7.0 mm.
l''=4.4 mm.; h=1.2 mm.; i=0.65 mm.
j=0.35 mm.; k=0.6 mm.

was placed on the brass plate mentioned above, the Q-value amounted to 1350. When the same vibrator is supported on the foam rubber sheet mentioned above, the Q-value was measured as 1300. Both examples show how efficiently the novel vibrator functions.

A preferred embodiment of the transistor amplifier circuit, shown in FIG. 4, for driving the vibrator assembly so far shown and described, may have, by way of example the following circuit data:

Transistor **20**: 2SB–113, manufactured by Nippon Electric Company, Tokyo; condenser **22**: 3μf.; oscillation suppressing condenser **23**: 0.002μf.; biasing resistor **24**: 5 megohms; sensing coil **7**: 12μφ, 4053 turns, 5.44 kilohms; drive coil **8**: 12μφ, 5076 turns, 6.81 kilohms; drive coil **9** (same as before); current source **21**: 1.5 volts; and frequency of oscillation: 100 cycles.

As an oscillation receiving member driven by the aforementioned vibrator assembly, there may be a Cliford's escapement wheel which may be coupled electromagnetically with both vibrator elements **1** and **2** at their open gaps, as at *la*, although the gap of the latter element is not shown. The Cliford's wheel is employed in this case, however, not as an escapement, but as a mechanical power generator energized by the vibrator assembly, when the inventive principles are applied to the time base of a

watch. It is, however, to be noted that the vibration transmitting means is not limited to the Cliford's wheel. For instance, a combination of resilient pushers, driven from the vibrating systems with a common sprocket wheel, may be employed. Further, the application of the invention should not be limited to timepieces and various other applications may also be conceivable.

A modified embodiment of the invention is shown in FIG. 8. In this case, all the vibration-pertaining parts are made of a spring material, such as a Ni-Cr-Fe alloy, having a small linear thermal expansion coefficient and a small and practically constant temperature coefficient of elastic modulus. This may apply also to the first embodiment shown in FIGS. 1–5.

The vibrator of FIG. 8 consists of two vibrator elements, of which one comprises spring parts **31**, **32** and **33** fabricated from a strip and a vibrating mass M fixedly attached to the free end of the middle or longest limb **32** of the united vibrator element which is shaped substantially as an E. Another vibrator element, also shaped as an E has constituent spring parts **31'**, **32'** and **33'** and a vibrating mass M', corresponding in their design and function to those of the first element indicated with corresponding numerals with no primes. The free ends of the upper limbs of the two E's are bridged by a connecting strip **34** which is made integral with the limbs **31** and **31'** and extends laterally of the longitudinal neutral axis of each of the vibrating systems. In a similar way, a fixing strip **35** bridges the free ends of the lowermost limbs **33** and **33'**, in a lateral direction relative to the neutral axes, and is integral with the related limbs. The two vibrating systems are arranged symmetrically relative to a vertical neutral plane P, and a common fixing strip **35** is fixed by means of a plurality of fixing screws **35***a* onto a stationary member, such as a timepiece plate, not shown.

In a still further modified embodiment shown in FIGS. 9 and 10, the vibrating masses or magnetic blocks are formed into a hollow cylinder **41** which is closed at one end by an end wall **37** provided with an integral central core **40** projecting inwardly from the wall.

In both the vibrating arrangement shown in FIG. 8 as including the masses M and M', and the vibrating arrangement shown in FIGS. 9 and 10 and including the magnetic blocks in the form of a hollow cylinder with a core projection, the free ends **32***b* of the central limb **32***a* of the E-shaped mounting plates are enlarged. A permanent magnet plate **38**, shaped substantially as an elongated C, is permanently fixed at its closed end, by sticking or any other suitable technique, to the enlarged limb end **32***b*. Balance weights **43** and **44** are provided on the magnet plate **38** at a suitable position nearer to the open gap **38***a* of the plate. Members similar to those denoted with **38** and **38***a* are also provided for the second vibrating system are arranged symmetrically about the neutral plane P relative to those in the first vibrating system. These magnetic plates serve also as the driving members for the movements of a timepiece, as in the case of the first embodiment of the invention, when the principles of the invention are applied to the timepiece technique. For cooperation with each of the magnetic blocks, there is provided a drive coil **42** which is positioned fixedly on a stationary member, such as a timepiece plate, and electrically connected with a transistor amplifier, as in the case of the first embodiment. The conventional sensing coil, as at **7** in FIG. 1, has been omitted from the drawing for purposes of simplification thereof.

When energized electromagnetically, the magnetic blocks are caused to oscillate in a manner similar to that described for the first embodiment.

The two vibrating systems are energized, as in the preceding embodiment, so as to oscillate in phase opposition to each other, and thus both magnetic blocks will come nearer to each other at one time and separate from each other at another time, with equal amplitudes and frequencies and in a common horizontal vibration plane perpendicular to the neutral plane P.

It will be seen from the drawing that the connecting strip **34** has a considerable width and is separated a considerable distance from the common fixing position of the two vibrating systems. The provision and arrangement of connecting strip **34**, rigidly connected between the two systems, contributes considerably to increasing the mutual dependency of the two vibrating systems. Thus the induced forces and turning moments in each strip may be compensated over a large range, so that a highly stable vibrator is assured.

If, on the contrary, the pair of vibratory systems should be severed at the middle of the connecting strip and rigidly supported thereat by means of fixing screws or the like driven into the timepiece plate, considerable amounts of vibrating energy will be dissipated from the vibrators through such fixing means to the mounting plate, which phenomenon results in a considerable damping in the oscillative movement of the vibrator assembly. Therefore, in this case, there will be a considerable loss of energy for the maintenance of the oscillation. With the use of the aforementioned several embodiments of the invention, these drawbacks, inherent in the conventional technique, may be substantially obviated, and a highly reliable and stable electromagnetic vibrator, consuming a minimum vibration energy and especially adapted to use for the time base for a small timepiece, can be provided.

The number of oscillations, denoted f will be, as commonly known, proportional to $\frac{3}{2}$ power of the thickness, T, and $\frac{1}{2}$ power of the width, W, of the spring part of the vibrator element, thus:

$$f \propto T^{\frac{3}{2}} \cdot W^{\frac{1}{2}}$$

The vibrator of the present invention can be fabricated, substantially, from a rolled metal strip, with the exception of the vibrating masses or magnetic blocks, which assures a predetermined uniform thickness of the spring element of the vibrator and thus helps also, in this respect, to assure a constant and stabilized maintenance of the desired oscillation. In addition, the two vibrator elements consisting a vibrator assembly can be easily assured of corresponding configurations, because the substantial parts thereof may be commonly fabricated, preferably by way of punching and bending operations, and the coincidence of vibrating frequencies of both vibrating systems will be substantially realized.

The necessary conditions for the realization of a superior vibrator assembly capable of substantially obviating possible position errors will be described more in detail hereinbelow with reference to the last embodiment shown in FIGS. 9 and 10.

Again, in this embodiment, the overall arrangement and dimensions of each of the two vibrating systems are so selected that the center of gravity of the rigid masses, or more specifically, magnetic core **40**, magnetic cylinder yoke **41** and balance weights **43** and **44**, of the vibrator is situated precisely or substantially at the center of deflection of the spring element, for the purpose of obviating position errors.

Now assume that there is a vibrating system comprising a rigid mass fixedly attached to one end of a resilient strip having its other end mounted fixedly, and the mass is caused to oscillate with small amplitudes in a plane and about a certain point on the neutral axis of the strip. The natural frequency of the vibrating system depends upon the moment of inertia of the vibratory mass relative to the oscillation axis passing through said point, the spring constant of the resilient strip, and the like parameters.

When the vibrator is placed in a gravity field, the gravity acts upon the center of gravity of the vibrating mass and the restoring moment of the spring will be subject to a change which induces a position error.

Now denoting the distance between the center of gravity of the rigid mass and the oscillation axis by l_1; the radius of gyration of the mass by r; the fundamental number of oscillations of the vibrating system by f_0; and the induced position error by Δ_p, then

$$\Delta_p \propto \frac{l_1}{1_1^2+r^2} \cdot \frac{l}{f_0^2}$$

Now assuming $l_1=0$, then

$$\Delta_{p=}0$$

It is clear that the required condition is obtained when the center of gravity of the vibrating mass is brought into coincidence with the oscillation axis of the vibrating system.

In the case of the last mentioned embodiment shown in FIGS. 9 and 10, the desired condition will be if r be assumed to be nil:

$$2e=\frac{l_3^2+2.1_2 \cdot 1_3-1_2^2}{1_2+1_3}$$

where, referring also to FIG. 11:

l_2 is the distance from the fixed end **35***a* of spring chord **33***a* to the bight end thereof;

l_3 is the distance from the common bight end **33***b* of spring chord **32***a* to the opposite enlarged end **32***b* thereof carrying the magnetic block **37–40–41**;

r is the distance between the center of oscillation O of the vibrating system and the center of gravity G of the vibrating masses; and e is the distance from the enlarged end **32***b* of spring chord **32***a* and the center of gravity G.

If both vibrating systems of the vibrator assembly are designed and dimensioned so as to satisfy the above conditions set out for the lower vibrating system as viewed in FIG. 10, a superior vibrator may be easily realized.

It is understood that although only several preferred embodiments have been shown and described herein by way of example for illustrative purposes they shall not be construed to constitute operative limitations for the application of this invention. Numerous modifications with regard to design, construction and end use are feasible without departing from the spirit of this invention.

We claim:

1. An electromagnetic vibrator assembly comprising two tuning vibrators operating in phase opposition to each other with equal amplitudes, each of said vibrators comprising a spring strip, a magnetic mass attached fixedly at one end of said strip, a support plate shaped into substantially an E-shape and having outer longer limbs thereof rigidly attached to said strip end, a common stationary support for both vibrators, the central shorter limbs of said support plates being fixedly attached at their free ends to said support, and a respective drive coil for each vibrator fixedly mounted on a stationary member mounting said assembly, said drive coils electromagnetically cooperating with the respective magnetic masses, the mass of each vibrator being so distributed that the center of gravity thereof is substantially in coincidence with the oscillation axis of the respective vibrator.

2. An electromagnetic vibrator assembly as set forth in claim **1**, which further comprises a transistor amplifier electrically connected with said coils for feeding the latter with current pulses in synchronism with the oscillating movements of said vibrators.

3. An electromagnetic vibrator assembly as set forth in claim **1**, wherein the mass of each vibrator is so distributed that the center of gravity thereof is substantially at the said common support.

4. An electromagnetic vibrator assembly comprising two tuning vibrators operating in phase opposition to each other with equal amplitudes, each of said vibrators

comprising a substantially E-shaped spring strip having a longest central limb, a magnetic mass attached fixedly at the free end of said central limb, a second strip rigidly connecting the free ends of the upper limbs of said E-shaped strips, a third rigid strip mounted fixedly on a stationary member mounting said assembly, said third strip connecting the free ends of the remaining shorter limbs of said E-shaped strips, and a respective drive coil for each vibrator fixedly mounted on said member and cooperating electromagnetically with the respective magnetic mass, the longitudinal axis of said first strip being in coincidence with that of said second strip when viewed laterally, the mass arrangement of each vibrator being so distributed that the center of gravity thereof is substantially in coincidence with the oscillation axis of the respective vibrator.

5. An electromagnetic vibrator assembly as set forth in claim **4**, which further comprises a transistor amplifier electrically connected with said coils for feeding the latter with current pulses in synchronism with the oscillating movements of said vibrators.

6. An electromagnetic vibrator assembly as set forth in claim **5**, which further comprises a sensing coil physically united concentrically with one of said drive coils and connected electrically with said amplifier for sensing the oscillative movement of the related magnetic mass and for feeding the sensed current pulses to said amplifier.

7. An electromagnetic vibrator assembly as set forth in claim **5**, wherein the mass of each vibrator bars is so distributed that the center of gravity thereof is substantially at the vibrator-mounting part of said common support.

8. An electromagnetic vibrator assembly comprising, in combination, a pair of tuning vibrators positioned in spaced parallel planes and operating in phase opposition to each other with equal amplitudes of vibration; each of said vibrators including an elongated C-shaped strip and an elongated E-shaped strip, the open ends of the two strips being at respective opposite ends of the associated vibrator and the end of at least one leg of each E-shaped strip being fixedly connected to the bight of the associated C-shaped strip; a respective magnetic mass secured to the fixedly interconnected ends of the two strips of each vibrator; a common stationary support for the two vibrators secured to and interconnecting, at the free ends thereof, another leg of each E-shaped strip; and a respective drive coil for each vibrator fixedly mounted on the stationary member mounting said assembly; said drive coil electromagnetically cooperating with the respective magnetic masses; the mass of each vibrator being so distributed that the center of gravity thereof is substantially in coincidence with the oscillation axis of the respective vibrator.

9. An electromagnetic vibrator assembly as set forth in claim **8**, wherein each magnetic mass is shaped as a rigid cylinder.

10. An electromagnetic vibrator as set forth in claim **8**, wherein each magnetic mass is shaped as a hollow cylinder closed at one end and provided with a central rigid magnetic core projecting axially from the closing end wall of said cylinder.

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