Nov. 22, 1960 M. HETZEL 2,960,817

ELECTRICAL TIMEPIECE

Filed May 14, 1956 7 Sheets-Sheet 1

FIG. 1

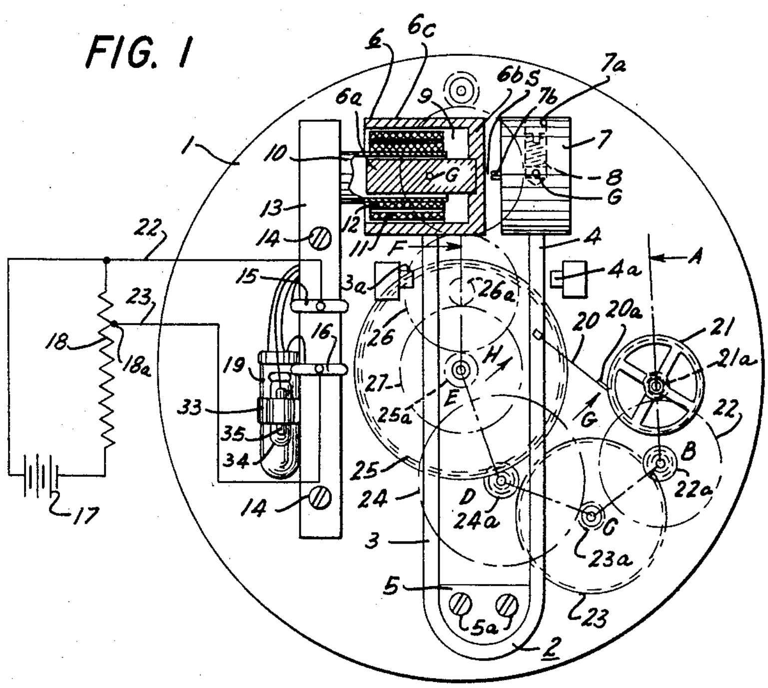
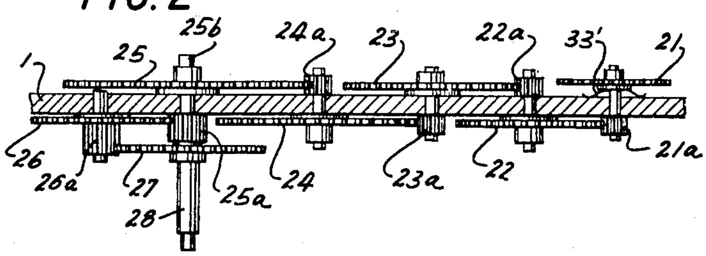


FIG. 2



INVENTOR.
Max Hetzel
BY: Michael S. Striker
Agt.

Nov. 22, 1960 M. HETZEL 2,960,817

ELECTRICAL TIMEPIECE

Filed May 14, 1956 7 Sheets-Sheet 2

FIG. 3

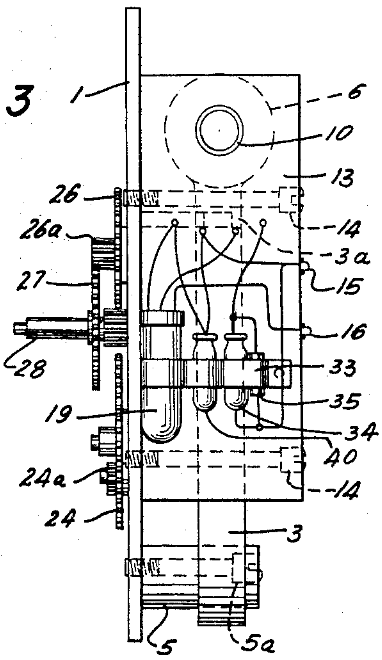



FIG. 6

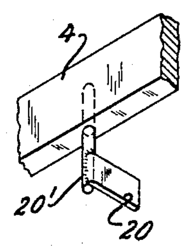



FIG. 5

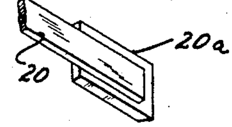



FIG. 4

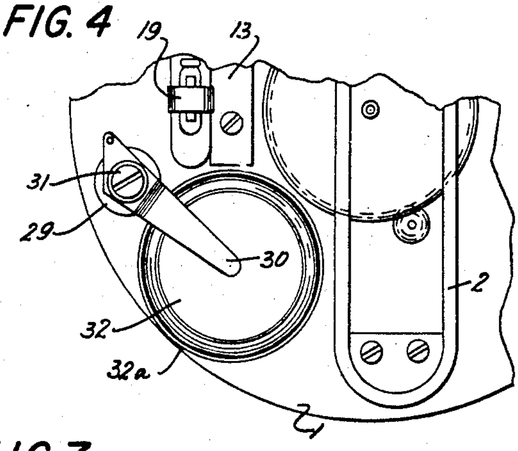
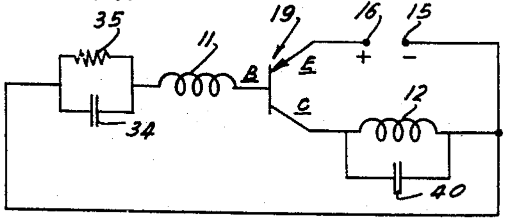



FIG. 7




INVENTOR:
Max Hetzel
BY: Michael S. Striker
Agt

Nov. 22, 1960

M. HETZEL

2,960,817

ELECTRICAL TIMEPIECE

Filed May 14, 1956

7 Sheets-Sheet 3

FIG. 8

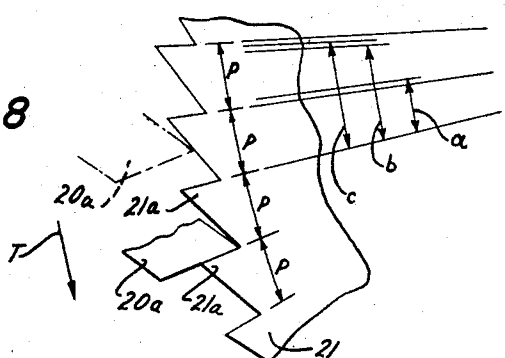



FIG. 9

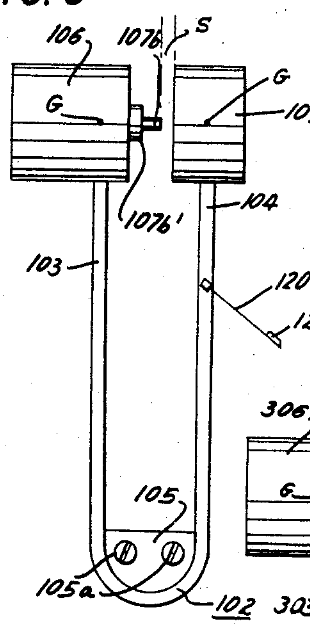



FIG. 10

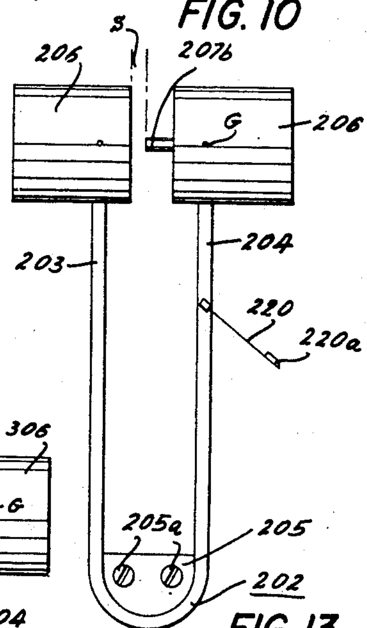
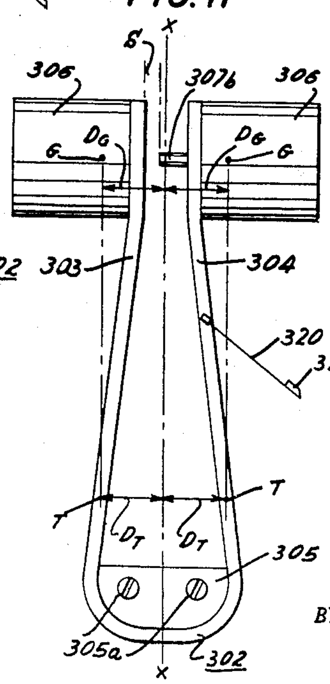



FIG. 11



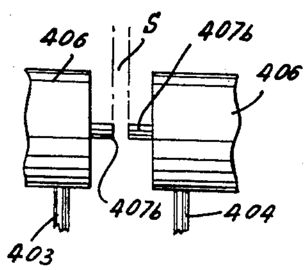
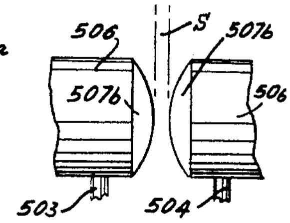




FIG. 12

FIG. 13




INVENTOR:
Max Hetzel
BY: Michael S. Striker
Agt.

Nov. 22, 1960

M. HETZEL

2,960,817

ELECTRICAL TIMEPIECE

Filed May 14, 1956

7 Sheets-Sheet 4

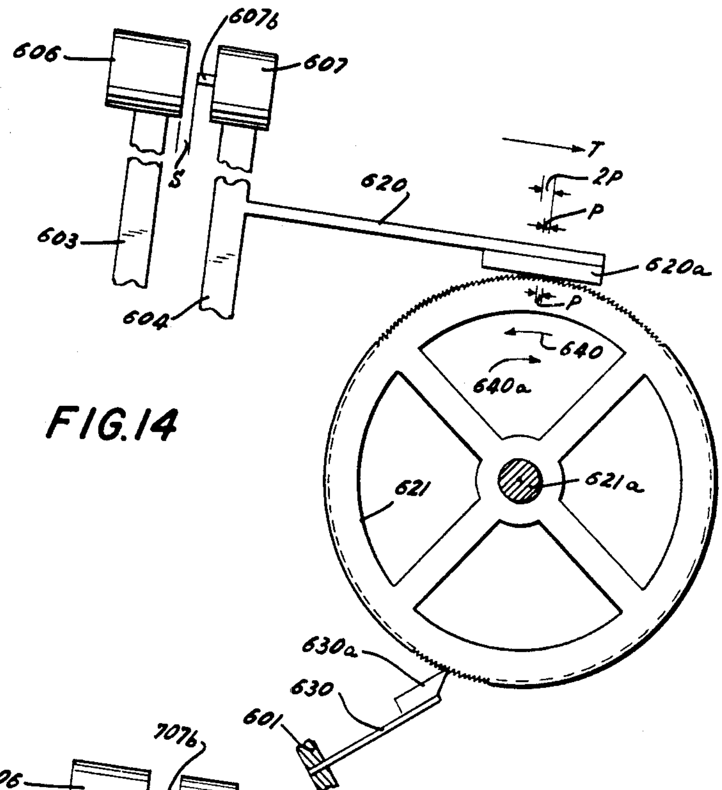



FIG. 14

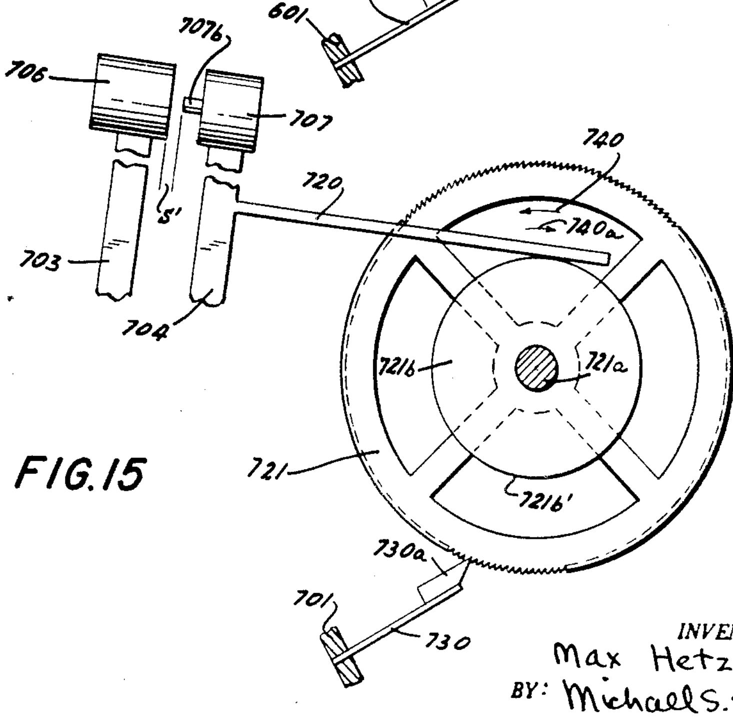



FIG. 15

INVENTOR.
Max Hetzel
BY: Michael S. Striker
agt.

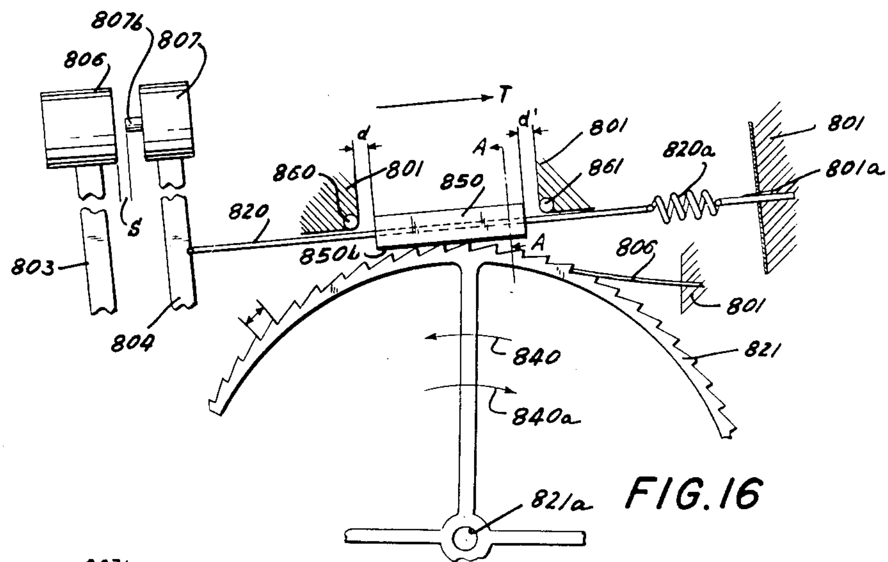



FIG. 16

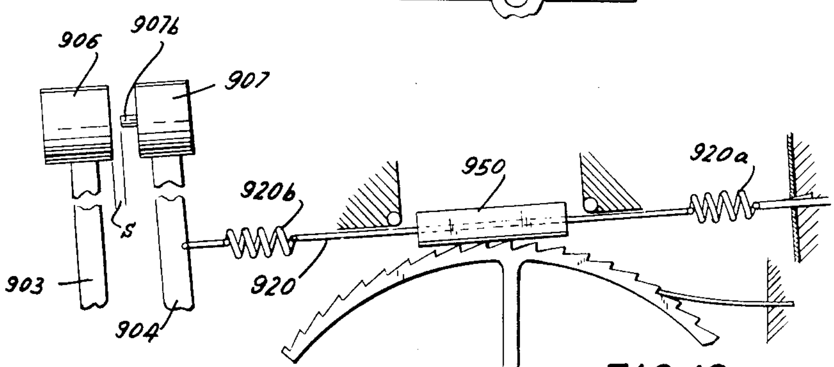



FIG. 18

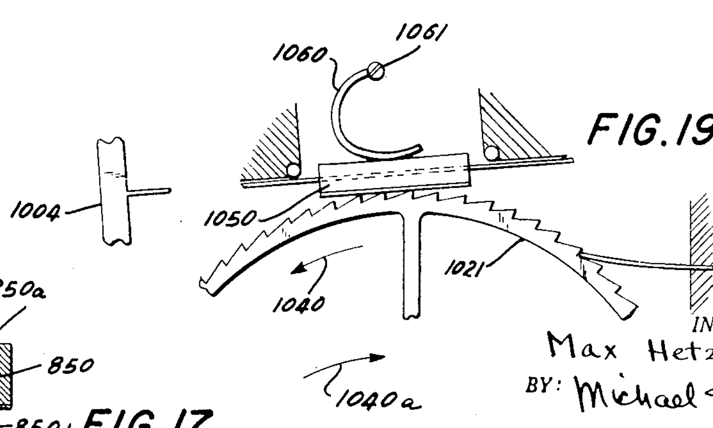



FIG. 19

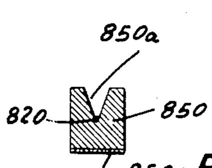
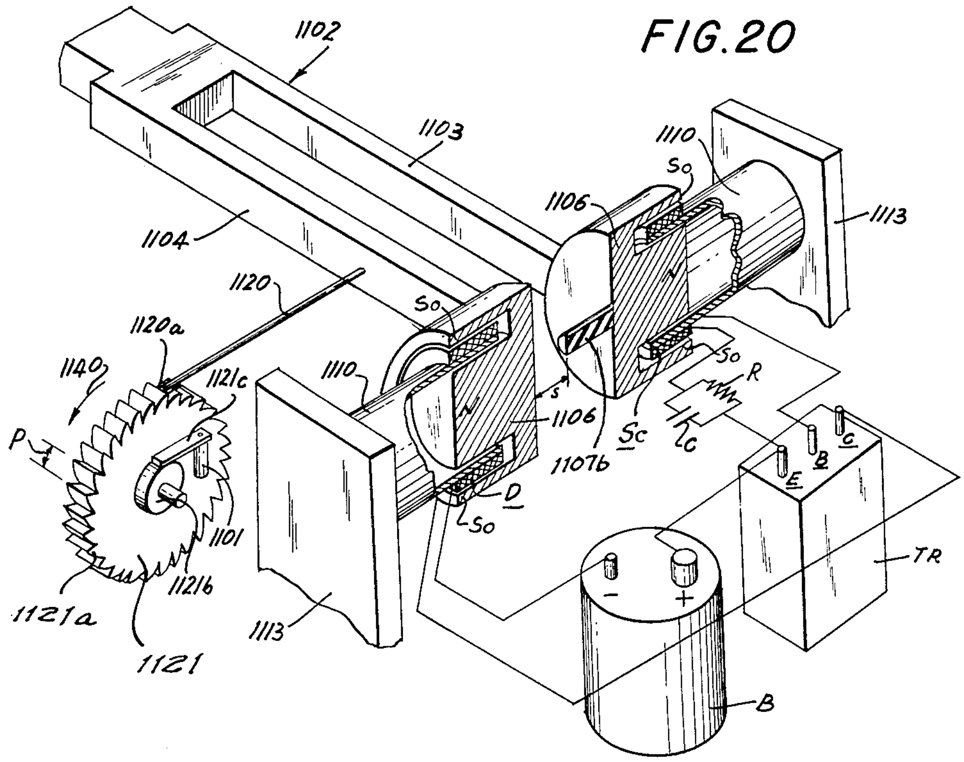



FIG. 17

INVENTOR:
Max Hetzel
BY: Michael S. Striker
agt

FIG. 20



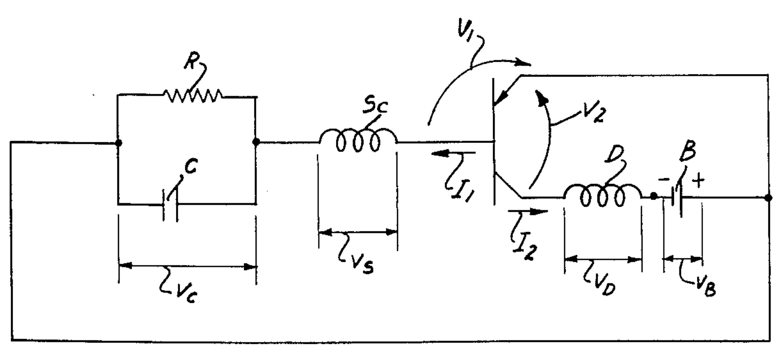




FIG. 21

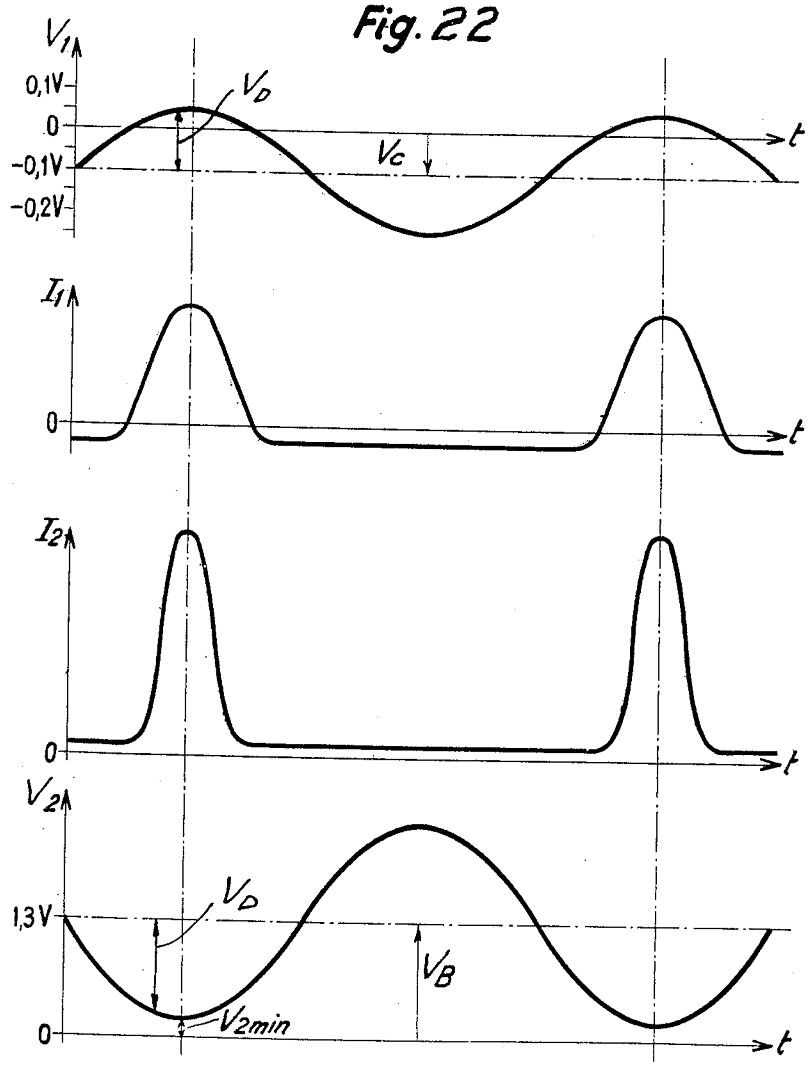
INVENTOR:
Max Hetzel
BY:
Michael S. Striker
agt.

Nov. 22, 1960 M. HETZEL 2,960,817

ELECTRICAL TIMEPIECE

Filed May 14, 1956 7 Sheets-Sheet 7

Fig. 22




Inventor:
Max Hetzel
By: Michael S. Striker
agt.

United States Patent Office

2,960,817

Patented Nov. 22, 1960



2,960,817

# ELECTRICAL TIMEPIECE

Max Hetzel, New Hyde Park, N.Y., assignor to Bulova Watch Company, Inc., Jackson Heights, N.Y.

Filed May 14, 1956, Ser. No. 584,709

Claims priority, application Switzerland May 12, 1955

3 Claims. (Cl. 58—23)

The present invention relates to an electrical timepiece.

More particularly, the present invention relates to an electrical timepiece incorporating a motion transformer capable of transforming the oscillations of a vibrator into rotary movement, which vibrator is oscillated by suitable means which are operatively associated therewith, the electrical timepiece being of the type disclosed in copending applications Serial No. 436,949 filed June 15, 1954, Serial No. 547,510 filed November 17, 1955 (said application Serial No. 547,510 being a continuation of application Serial No. 463,462 filed October 20, 1954, now abandoned), Serial No. 565,451 filed February 14, 1956, now Patent No. 2,888,582, May 26, 1959, Serial No. 565,452 filed February 14, 1956, Serial No. 570,958 filed March 12, 1956, and Serial No. 580,813, filed April 26, 1956 and entitled "Motion Transformer," now Patent No. 2,908,174, October 13, 1959. This application is a continuation-in-part of said copending application Serial No. 580,813.

It is an object of the present invention to provide an electric timepiece which incorporates a motion transformer adapted to transform the oscillations of a vibrator into the rotary movement of the hands of the timepiece.

It is another object of the present invention to provide an electric timepiece wherein the action of the vibrator is controlled in such a manner as to insure the accuracy of the timepiece.

It is a still further object of the present invention to provide an electric timepiece wherein the amplitude of oscillation of the vibrator is controlled in such a manner as to insure the accuracy of the timepiece.

The objects of the present invention also include the provision of an electric timepiece wherein suitable means are provided for oscillating the vibrator which serves to cause rotary movement of the hands of the timepiece.

It is an additional object of the present invention to provide an electric timepiece the operation of which requires an extremely small amount of power.

It is yet another object of the present invention to provide an electric timepiece wherein the means for oscillating the vibrator also control the amplitude of such oscillation.

It is still a further object of the present invention to provide an electric timepiece which is composed of simple and ruggedly constructed parts which may be mass-produced at low cost.

The objects of the present invention further include the provision of an electric timepiece which may be easily assembled and constructed and thus be readily mass-produced.

Also included among the objects of the present invention is the provision of an electric timepiece which is extremely accurate and reliable in operation and which will operate for very long periods without requiring winding or any other attention whatsoever.

With the above objects in view, the present invention mainly consists in that improvement in a timepiece having a timepiece mechanism which includes reciprocatable



driving means for driving the timepiece mechanism, a vibrator connected to the driving means for reciprocating the same, and means for oscillating the vibrator.

More particularly, the present invention resides in that improvement in such a timepiece wherein the driving means are operatively associated with the timepiece mechanism in such a manner that the timepiece mechanism is driven by the driving means when the length of the stroke of reciprocation thereof is between a predetermined minimum stroke length and a predetermined maximum stroke length, wherein the vibrator reciprocates the driving means with a stroke the length of which is a function of the amplitude of oscillation of the vibrator, and wherein the means for oscillating the vibrator are electrical means and oscillate the vibrator at an amplitude at which the stroke length of the driving means is between the predetermined minimum and maximum stroke lengths.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims; the invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

Fig. 1 is a plan view of the interior of a timepiece according to the present invention when seen from the rear of the timepiece. Fig. 1 showing diagrammatically how the electrical leads may be connected to a storage battery or the like when the timepiece is used, for example, as an automobile clock, Fig. 1 further showing the timepiece as incorporating one preferred embodiment of a motion transformer mechanism capable of transforming oscillations of a vibrator to rotary motion;

Fig. 2 is a sectional elevational view taken along line A—B—C—D—E—F of Fig. 1 in the direction of the arrows;

Fig. 3 is a side elevational view of the structure of Fig. 1 as seen from the left side of the latter;

Fig. 4 is a fragmentary plan view similar to Fig. 1 showing a variation according to which the structure of Fig. 1 may be connected to a different source of electrical energy;

Fig. 5 is a fragmentary perspective view of a part of a pawl of the present invention as seen in the direction of arrow G of Fig. 1;

Fig. 6 is a perspective view illustrating the connection of a pawl to the tine of a tuning fork, the structure of Fig. 6 being shown in the direction of arrow H of Fig. 1;

Fig. 7 is a wiring diagram of the electrical circuit of the timepiece shown in Figs. 1 to 6;

Fig. 8 is a diagrammatic view illustrating the interaction of a pawl and ratchet wheel incorporated in a motion transformer of the type illustrated in Fig. 1;

Fig. 9 is a diagrammatic showing of a modified embodiment of the present invention;

Fig. 10 is a diagrammatic view of another modified embodiment of the present invention;

Fig. 11 is a diagrammatic view of yet another modified embodiment of the present invention;

Fig. 12 is a fragmentary diagrammatic view of a still further modified embodiment of the present invention;

Fig. 13 is a fragmentary diagrammatic view of yet another modified embodiment of the present invention;

Fig. 14 is a fragmentary diagrammatic view of a modified embodiment of a motion transformer mechanism incorporated in a timepiece of the type illustrated in Fig. 1;

Fig. 15 is a fragmentary diagrammatic view, on an enlarged scale, of another modified embodiment of a motion transformer mechanism;

Fig. 16 is a fragmentary diagrammatic view, on an enlarged scale, of yet another modified embodiment of a motion transformer mechanism;

Fig. 17 is a sectional view taken along line A—A of Fig. 16;

Fig. 18 is a fragmentary diagrammatic view, on an enlarged scale, of a still further modified embodiment of a motion transformer mechanism;

Fig. 19 is a fragmentary diagrammatic view, on an enlarged scale of a still further modified embodiment of a motion transformer mechanism;

Fig. 20 is a fragmentary perspective view, partly in section and on an enlarged scale, of a tuning-fork type vibrator, a pawl and ratchet type motion transformer mechanism actuated by the vibrator, and electrical means for oscillating the vibrator;

Fig. 21 is a wiring diagram of the electrical circuit of the electrical means shown in Fig. 20; and

Fig. 22 is a graphical representation of certain voltages and currents as a function of time.

Referring now to the drawings, it will be seen that the timepiece includes a base plate **1** which is made of a circular plate having a substantially constant thickness. A vibrator **2** which is preferably of a tuning fork type is fixed to a member **5** as by soldering or welding or the like, this member **5**, in turn, is fixed to the base plate **1** by a pair of screws *5a*. As is clearly shown in Figs. 1 and 3, the member **5** is connected to the tuning fork **2** only at that part thereof which interconnects the tines **3** and **4**, so that the latter are maintained in spaced relation to the base plate **1** and are free to oscillate.

At the free end of the tine **3** there is located a permanent magnet **6** in the form of a hollow cylinder which is open at one end and which has an end wall *6b* closing the cylinder *6c*, this end wall *6b* carrying a magnetic bar *6a* which is of very strong magnetic material, as for example, Alnico.

The other tine **4** of the tuning fork **2** carries at its free end a balance weight **7** which may simply be in the form of a cylindrical block fixed in the manner shown in Fig. 1 to the free end of the tine **4**. The tines **3** and **4** and the masses of the permanent magnet **6** and the balance weight **7** are so chosen that the tine **3** and the permanent magnet **6** on the one hand and the tine **4** and the balance weight **7** on the other hand have approximately the same natural frequency so that the tuning fork will not require an undesirable large amount of damping. Also, the arrangement of the parts is such that the centers of gravity G of the permanent magnet **6** and the balance weight **7** are in alignment with the tines **3** and **4**, respectively. As a result, it is possible for the tines **3** and **4** to oscillate at constant frequency while requiring an almost negligible amount of energy, as set forth in copending application Serial No. 565,451.

The counter weight **7** carries an abutment element *7b* which is preferably made of non-magnetic material, as, for example, brass. The abutment element *7b* extends toward the permanent magnet **6** and is spaced therefrom a distance *s*.

As is well known, the tines of a vibrating tuning fork type vibrator normally oscillate toward and away from each other, i.e., inward movement of one tine from its normal rest position is accompanied by a corresponding inward movement of the other tine and outward movement of one tine is accompanied by a corresponding outward movement of the other tine. Also, the inward deflection of each tine is equal to its outward deflection, so that the amplitude of oscillation of each tine is equal to twice the deflection of each tine from its rest position to its inner deflected position.

It will be seen, therefore, that the maximum amplitude of oscillation of each tine **3** and **4** is equal to the length of the distance *s* inasmuch as the maximum possible inner deflection of each tine is equal to one-half *s*.

The purpose of the abutment element *7b* and the factors influencing the selection of the distance *s* will be discussed below.

Also, suitable abutments *3a* and *4a* are carried by the base plate **1** and serve to limit the outwardmost deflection of the tines **3** and **4**, respectively. The distances between the abutment *3a* and the tine **3** and between the abutment *4a* and the tine **4** are considerably greater than the above described distance *s*, so that the tines will engage these abutments only when the timepiece is exposed to excessive shocks. Thus, the abutments are normally not contacted by the tines but serve only to protect the same from damage in the event the timepiece is subjected to very large shocks.

If desired, the balance weight **7** may be provided with a threaded bore *7a* in which a screw member **8** is threadedly located. The screw member **8** is shorter than the length of the threaded bore so that the screw member may be shifted toward or away from the tine **4** along a line forming an extension of the latter. In this way, the center of gravity of the balance weight **7** is shifted along this line simply by varying the position of the screw **8**. As a result, the natural frequency of the tine **4** may be varied, the center of gravity of the balance weight **7**, however, at all times remaining in registration with the tine **4**. Inasmuch as the natural frequency of the entire tuning fork **2** is the average of the natural frequency of the two tines, it is possible to change the natural frequency of the entire tuning fork by shifting the screw **8**. In this way, it is possible to regulate the time which is kept by the timepiece. Thus, if there are relatively small variations between the natural frequencies of the tines and the weight and permanent magnet, respectively carried thereby, such small variations in the natural frequencies will not influence the operation of the timepiece. When the latter is first manufactured, the relative natural frequencies of the tines and the parts carried thereby are so regulated, as, for example, by filing off a part of one tine, that the timepiece keeps perfect time to within plus or minus three minutes, for example. By shifting the screw member **8** in the balance weight **7** it is possible to provide a very fine adjustment which will enable the timepiece to keep accurate time within this range of plus or minus three minutes per month.

The above described adjusting or compensating arrangement is described in copending application Serial No. 565,452.

In the chamber **9** within the drum magnet **6**, there is located a tubular carrier **10** which is fixed to a support **13**, the latter in turn being fixed to the base plate **1** by means of screw members **14**, as is shown in Figs. 1 and 3. The tubular member **10** freely surrounds the core *6a* without contacting the latter, and the tubular member **10** carries a pair of coils **11** and **12**, the coil **12** having approximately five to six times as many turns as the coil **11**. The core *6a* has sufficient clearance within the tube **10** to avoid contacting the latter during oscillations of the tines **3** and **4** of the tuning fork. Thus, the coils form with the permanent magnet **6** a transducer which, together with the tuning fork **2**, forms a tuning fork oscillator of the same general type as that disclosed in copending application Serial No. 436,949.

At the left face of the support **13**, as viewed in Fig. 1, and as is shown in Fig. 3, there is fixed a resilient strap **33** which serves to mount on the support **13** a capacitor **34**, a resistor **35**, a transistor **19**, and a capacitor **40**. Furthermore, the support **13** carries a pair of insulated electrical terminals **15** and **16** which are electrically connected to the lines **22** and **23** which in turn are connected to a source of electrical energy. According to the embodiment of the invention shown in Fig. 1, the source of energy is the storage battery **17** of an automobile. In general the voltage of such an automobile battery is too great for the purposes of operating a timepiece of the type disclosed, so that this battery is not connected directly to the timepiece. The lines **22** and **23** are connected in the manner shown in Fig. 1 to the resistor **18**, and the end **18***a* of the line **23** forms with the resistor **18** a voltage divider, this voltage divider being located outside of the timepiece, although it could of course be located within the casing of the timepiece and fixed to the base plate **1**, if desired.

When the above described electronic circuit is connected to the source of energy, the electrical circuit is closed and the oscillations of the tuning fork are started and are maintained by the source of energy. The tuning fork starts oscillating as soon as the circuit is closed because it is quite sensitive and picks up any vibrations which are present in the surrounding atmosphere or in the base plate **1**. With an arrangement as described above it is possible to obtain a frequency constant to two parts in $10^7$, while for a timepiece of the type described above a frequency constant to one part in $10^5$ is more than adequate. The oscillations of the tuning fork must be converted into a rotary movement in order to be useful in the timepiece, and this conversion can take place by the transmission means illustrated in Figs. 1, 2, 5 and 6.

A pawl **20** is carried by the tine **4** of the tuning fork **2**, this pawl **20** being in the form of a relatively light leaf spring and being fixed to the tine **4** by means of a pin **20'**, as shown in Fig. 6. The tine **4** is formed with a relatively shallow bore which does not extend more than one quarter of the way through the tine **4** and into which bore the pin **20'** is pressed, so that in this way the natural frequency of the tine **4** is influenced to but a very negligible extent. The leaf spring **20** is fixed to the pin **20'**, as by being soldered thereto, in the manner shown in Fig. 6, and at its free end leaf spring **20** carries the tooth member **20***a* made of a very hard material such as glass or hardened steel. Also, precious or semiprecious stones such as rubies or sapphires are particularly suitable for this purpose. As is evident from Fig. 5, the member **20***a* is wider than the leaf spring **20** and extends beyond the latter, and this member **20***a* is fixed to the leaf spring **20** by a suitable adhesive material, for example. The member **20***a* is preferably formed with a sharp edge.

This member **20***a* of the pawl cooperates with the teeth of the ratchet wheel **21** so that the oscillations of the tine **4** transmit turning impulses to the ratchet wheel **21** through the pawl **20**. In this way the ratchet wheel **21** is turned through a predetermined angle at every oscillation. As is evident from Fig. 2, the ratchet wheel **21** and the pinion **21***a* are fixed to a common shaft which extends through the base plate **1**. In addition, this common shaft extends through an opening of a dished spring **33'** which bears against part of the ratchet wheel **21** and urges the latter away from the base plate **1**, so that dished spring **33** acts as a brake retarding the turning movement of the ratchet wheel **21**. The spring **33**, the ratchet wheel **21**, as well as the pawl **20** and member **20***a* are carefully designed and chosen so that at each oscillation the turning movement transferred to the ratchet wheel **21** by the leaf spring **20** will result only in a turning of the ratchet wheel in the desired direction through a distance of one tooth. In other words the arrangement is such that the ratchet wheel **21** cannot overrun or turn freely beyond the distance through which it is turned by the pawl. Furthermore the frictional resistance provided by the spring **33** is such that during the return movement of the pawl **20** the ratchet wheel **21** also does not turn and the tooth member **20***a* runs over a tooth of the ratchet wheel, to engage in the next space between the teeth. In this way a turning movement is imparted to the ratchet wheel **21** which compels the latter to rotate at a rate, i.e., at a number of revolutions per unit time, which has a direct relation to the rate of oscillation of the tuning fork **2**.

Inasmuch as the tuning fork oscillates at a constant rate, the ratchet wheel **21** also turns at a constant speed and in one direction. A gear train is provided to transmit the turning of the ratchet wheel **21** to the hands of the clock, and this gear train includes the pinion **21***a*, the



gear **22** meshing with the pinion **21***a* and turning together with the pinion **22***a* which meshes with the gear **23** which turns together with the pinion **23***a*. The pinion **23***a* meshes with the gear **24** which turns the pinion **24***a*, the latter meshing with the gear **25** which turns together with the pinion **25***a*. The gear **25** is fixed as by a press fit to the shaft **25***b* to which the pinion **25***a* also is fixed, and this shaft **25***b* extends all the way up to the unillustrated face of the clock which carries the numbers.

The frequency of oscillations of the tuning fork and the number of teeth of the ratchet wheel **21** as well as the different transmission ratios between the several driving and driven gears are so chosen that the shaft **25***b* makes one complete revolution in an hour. Thus, the minute hand is fixed to the shaft **25***b*.

The speed of the minute gear **25** is reduced to one twelfth in a known way. Thus, the gear **25***a* meshes with a gear **26** which turns together with the pinion **26***a*, the latter in turn meshing with a gear **27** affixed to the sleeve **28** freely turnable on the shaft **25***b*. These gears **25***a*, **26**, **26***a*, and **27** give to the sleeve **28** a speed of rotation which is one twelfth that of the shaft **25***b*, so that the sleeve **28** turns through a complete revolution in twelve hours, and thus the hour hand is fixed to the sleeve **28**.

If, for example, the tuning fork oscillates at 175 cycles per second, then the various pinions and gears can have the following numbers of teeth to provide the desired transmission to enable accurate time to be kept from the tuning fork.

| Pinion or gear: | Number of teeth |
|---|---|
| Ratchet wheel **21** | 360 |
| Pinion **21***a* | 6 |
| Gear **22** | 30 |
| Pinion **22***a* | 6 |
| Gear **23** | 36 |
| Pinion **23***a* | 6 |
| Gear **24** | 42 |
| Pinion **24***a* | 6 |
| Minute wheel **25** | 50 |
| Pinion **25***a* | 10 |
| Gear **26** | 30 |
| Pinion **26***a* | 8 |
| Hour wheel **27** | 32 |

A consideration of the above numbers of teeth will show that the minute wheel makes one revolution an hour and the hour wheel makes one revolution in twelve hours.

With the above described embodiment of the timepiece the source of energy is located outside of the timepiece and is in the illustrated example the battery of an automobile. However, the timepiece of the invention, which may be a wrist watch instead of an automobile clock, may carry its own source of energy within its own housing. Thus, Fig. 4 shows an arrangement where the base plate **1** is provided with a depression which receives a miniature battery **32** which may have a terminal voltage of 1.3 volts, and this battery **32** is maintained within the depression **32***a* of the base plate **1** by an electrically conductive springy member **30** which is affixed by a screw **31** to a block **29** of insulating material, this block being fixed in a known way as by a screw or the like to the base plate **1**. The force of the spring **30** keeps the battery **32** in position within the recess **31**. The casing of the battery **32** which engages the electrically conductive base plate **1** forms the negative pole of the battery while the positive pole thereof is formed by the cover of the battery which engages the member **30**. This member **30** is insulated from the base plate **1** by the block **29**, although if desired the member **30** can also be insulated from block **29** and screw **31** in any suitable way as by suitable washers and a suitable sleeve into which the screw **31** extends. With the arrangement of Fig. 4 the electrically conductive springy member **30** is connected with a suitable lead to the positive terminal **16** carried by the support **13** while the negative terminal **15** is in this case connected electrically with the base plate **1**.

Fig. 7 is a wiring diagram illustrating the electrical circuit of the means for oscillating the tines of the vibrator. These means include a transistor which is preferably a germanium junction-type transistor, the base, emitter and collector electrodes of which are indicated at B, E, and C respectively. The positive terminal **16** of the voltage source (not shown) is electrically connected to the emitter E while the collector C is connected to one terminal of the coil **12** which is approximately five to six times the number of turns of the coil **11**, as was pointed out above. The other terminal of the coil **12** is connected to the negative terminal **15** of the voltage source. A capacitor **40** is connected in parallel with the coil **12**, the capacitance of the capacitor **40** and the inductance of the coil **12** being so selected that the capacitor **40** and the coil **12** together form a tuned circuit which has a resonant frequency that corresponds substantially to the natural frequency of oscillation of the vibrator. In this way, the capacitor **40** serves to prevent undesired oscillations. Also, the capacitor **34** and resistor **35** are connected in parallel with each other and this parallel circuit is serially connected to one terminal of the coil **11** and to the negative terminal **15** of the voltage source. The circuit is completed by connecting the other terminal of the coil **11** to the base B of the transistor.

The above circuit, the operation of which will be more detailedly described below, is a self-regulating one in that it will cause the tines to vibrate not only at their natural frequency, but also at a substantially constant amplitude. In practice, the amplitude of oscillation of the tines will be maintained between certain predetermined minimum and maximum amplitudes. The significance and desirability of this will become evident upon further consideration of the specification.

It will be seen from the above that the reciprocation of the pawl **20** is brought about by the oscillation or vibration of the vibrator **2**, the length of the stroke of reciprocation of the pawl being a function of or dependent upon the amplitude of oscillation of the tine **4**. It will also be understood that the arrangement of the parts is such that normally each reciprocation of the pawl brings about an angular rotation of the ratchet wheel which corresponds to the pitch of each ratchet tooth. Thus, the stroke length of the pawl must not only be sufficiently great so that the pawl will, during successive reciprocation, engage different teeth, but also, the stroke length of the pawl should not be so great that the pawl engages, during successive reciprocations, non-successive teeth. If the latter were to occur, i.e., if, during successive reciprocations, the pawl were occasionally to engage alternate teeth, that particular reciprocation of the pawl would be accompanied by a double angular displacement of the ratchet wheel. Since, in practice, a timepiece particularly of the watch type is often subjected to shocks, the amplitude of oscillation of the tuning fork may become sufficiently great, at least temporarily, so as to cause the pawl to engage, during successive reciprocations, non-adjacent or non-successive ratchet teeth. This, in turn, would bring about inconstant and inaccurate activation of the timepiece mechanism.

As may best be seen in Fig. 8, the pawl should move in such a manner that the tooth **20***a*, in a direction T tangential to the ratchet wheel at the point of engagement between the tooth **20***a* and the ratchet wheel, reciprocates with a stroke the length of which is greater than the distance P and smaller than twice this distance, the distance P representing the pitch of the ratchet teeth. It is clear that if the tooth **20***a* does not reciprocate with a stroke the length of which exceeds the distance P, the tooth **20***a* would not, during successive reciprocations, engage successive teeth but would instead simply remain in engagement with the same tooth. Also, it will be seen that if the tooth **20***a* reciprocates with a stroke the length of which exceeds the distance 2P, the tooth **20***a* would engage non-consecutive or alternate teeth. If this were to occur then each reciprocation during which the stroke length of the tooth **20***a* exceeded the distance 2P would bring about a double angular displacement of the ratchet wheel **21**.



It will be readily understood that the stroke length of the tooth **20***a* in the direction T is a function of or is dependent upon the amplitude of oscillation of the tine **4**. Thus, in order for the tooth **20***a* to reciprocate in the direction T with a stroke length equal to at least P, and, in practice, with a stroke length *a* which is somewhat greater than P, the tine **4** will have to oscillate with a certain minimum amplitude. The above described electrical means shown schematically in Fig. 7 are capable of oscillating the tine **4** at at least such minimum amplitude.

Also, it will be understood that in order for the stroke length of the tooth **20***a* not to exceed 2P, and, in practice, not to exceed a length *c* which is somewhat smaller than 2P, the amplitude of oscillation of the tine **4** may not exceed a certain maximum. The above described electrical means are so constructed as to oscillate the tines at an amplitude which does not exceed a certain operating or normal maximum, which corresponds to reciprocation of the tooth **20***a* with a stroke length shown at *b*. As is clearly shown in Fig. 8, the stroke length *b* is not only smaller than 2P but is also somewhat smaller than the stroke length *c*. However, shocks or other extraneous forces to which a timepiece is very often exposed may be sufficient to cause the tine 4 to oscillate at an excessive amplitude, i.e., at an amplitude which exceeds that normal maximum and which causes the tooth **20***a* to reciprocate with a stroke length greater than *b*. Such excessive oscillation may, prior to being damped to below the normal maximum amplitude, persist throughout a considerable number of cycles during each of which the ratchet wheel is advanced an angular distance exceeding that corresponding to the pitch P.

The abutment 7*b* is therefore provided, and serves to prevent the tines **3** and **4** from oscillating above an amplitude corresponding to the distance *s*, as set forth above. Accordingly, the distance *s* is so selected that the tines **3** and **4** may oscillate at an absolute maximum amplitude which corresponds to reciprocation of the tooth **20***a*, in the direction T, with a stroke length less than 2P, for example with the stroke length shown at *c*. In this way, the tooth **20***a* cannot, during oscillation of the tuning fork, skip any of the teeth **21***a* of the ratchet wheel **21**, irrespective of whether the tooth **20***a* is reciprocated by the tine **4** during normal oscillation thereof under the influence of the above-described electrical means or whether the tooth **20***a* is reciprocated by the tine **4** during excessive oscillation thereof under the influence of extraneous vibrations. Consequently, each oscillation of the tuning fork and consequently each reciprocation of the pawl **20** brings about an angular movement of the ratchet wheel **21** which corresponds to the pitch P of the ratchet teeth **21***a*, as disclosed in copending application Serial No. 570,958.

In practice, the electrical means for oscillating the tuning fork are so constructed and arranged that the tines are oscillated at such amplitude as will bring about reciprocation of the tooth **20***a* in the direction T with a stroke length equal to approximately 1.5P. Thus, in Fig. 8 the forwardmost position of the tooth **20***a* is shown in solid lines whereas the normal backwardmost position is shown in dotted lines.

It will be understood, therefore, that the electrical means normally oscillate the tines at the amplitude, or within the amplitude range, necessary to cause reciprocation of the tooth **20***a* with the proper stroke length. The abutment element 7*b* is thus called upon to limit the amplitude of oscillation of the tines to the above described absolute maximum only when the timepiece is exposed to shocks or other extraneous forces of such magnitude as to cause the tines to oscillate at an amplitude greater than the normal maximum amplitude.

In the embodiment illustrated in Fig. 9, the tuning fork **102** having tines **103** and **104** is adapted to be mounted on the base plate of the timepiece mechanism by means of the member **105**, the latter being screwed onto the base plate by means of screws **105***a*. The tines **103** and **104** respectively carry a permanent magnet **106** and a balance weight **107**, the respective centers of gravity of these members being in registration with the respective tines. The tine **104** carries a pawl **120** having a tooth **120***a*, as described above. The instant embodiment differs from the above described one in that the abutment element **107***b* instead of being carried by the balance weight **107** is carried by the permanent magnet **106**. As described above, the element **107***b* may be made of non-magnetic material, such as brass. If desired, however, the element **107***b* may be made of magnetic material but be magnetically insulated from the permanent magnet **106** by means of a partition element **107***b'* which is made of non-magnetic material. The right free end of the element **107***b*, as viewed in Fig. 9, is spaced a distance *s* from the balance weight **107**, and the function and mode of operation of the device is identical to that of the above described embodiment.

In the embodiment illustrated in Fig. 10, the tuning fork **202** having tines **203** and **204** is adapted to be secured to the base plate of a timepiece by means of a member **205**, the latter being screwed onto the base plate by means of screws **205***a*. The tine **204** carries a pawl **220** having a tooth **220***a* adapted to cooperate with the ratchet wheel in the manner described above. The tines **203** and **204** each carry a permanent magnet **206**, the respective centers of gravity of which are in alignment or registration with the respective tines, so that the instant embodiment differs from the above described one in that two permanent magnets are provided, there being no balance weight corresponding to the element **7** of Fig. 1. In the instant embodiment of the electrical means for oscillating the tuning fork may be of the constructions described in the above mentioned copending application Serial No. 436,949. One of the permanent magnets **206** carries an abutment element **207***b* which is spaced from the other permanent magnet a distance *s*, the function and operation of the device being identical to the above described ones.

In the embodiment illustrated in Fig. 11, the tuning fork **302** includes a pair of tines **303** and **304**, the axis of symmetry of the tuning fork being indicated by the line X—X. As in the above described embodiments, a member **305** serves to mount the tuning fork onto the base plate of a timepiece, as, for example, by means of screws **305***a*.

The tines of the tuning fork are inclined toward each other and converge toward each other as they approach their free ends so that the tuning fork **302** has the substantially triangular configuration indicated in Fig. 11. A pair of permanent magnetic drums **306** are fixed at their end faces respectively to the outer faces of the free ends of the tines, it being understood that one of the drums **306** may be replaced by a suitable balance weight of the type described in connection with the embodiments illustrated in Figs. 1 and 9. The arrangement of the parts is such that the center of gravity of each magnet is spaced a distance $D_G$ from the axis of symmetry X—X. This distance is so selected as to be substantially equal to the distance $D_T$ which is the distance that each point T is spaced from the axis of symmetry X—X. The point T of each tine represents that axis about which the center of gravity of each magnetic drum or balance weight oscillates or pivots. In practice, the axis T of each tine will be located in the lowermost third of the tine.

As a result, the frequency of oscillation of the tuning fork is maintained constant at a desired value and only a minimum amount of energy is required to maintain the vibrations or oscillations, as is set forth in full in copending application Serial No. 565,451.

The tine **304** carries a pawl **320** having a tooth **320***a* which is adapted to cooperate with a ratchet wheel, in the manner described above, and one of the tines carries the abutment element **307***b* which is fixed to the inner face of the free end portion of the tine. As is clearly shown in Fig. 11, the free end of the abutment element **307***b* is spaced a distance *s* from the inner face of the free end portion of the other tine so as to limit the maximum amplitude of oscillation of the tuning fork.

In the embodiment illustrated in Fig. 12, each of the tines **403** and **404** carries a permanent magnet **406**, it being understood that one of the permanent magnets may be replaced by a suitable balance weight. The instant embodiment differs from the above described ones in that each of the permanent magnets **406** carries an abutment element **407***b*, these elements being spaced from each other a distance *s* and cooperating with each other in such a manner that when the amplitude of oscillation of the tines is equal to the maximum permissible amplitude, the abutment elements will engage each other thereby preventing the tines from oscillating at an amplitude greater than this maximum amplitude.

In the embodiment illustrated in Fig. 13, the tines **503** and **504** each carry a permanent magnet **506**, it being understood that one of the permanent magnets may be replaced by a suitable balance weight. In the instant embodiment, each of the permanent magnets **506** either carries or is formed with an abutment portion **507***b* which may be substantially frusto-conical or dome-shaped as shown in Fig. 13. The respective inwardmost parts of the portion **507***b* are spaced from each other a distance *s*, thereby limiting the maximum amplitude of oscillation of the tines.

Additionally, it will be understood that any suitably shaped abutment means may be provided for limiting the maximum amplitude of oscillation of the tines. For example, the abutment means may be connected to or be integral with the tines proper. Also, it is not essential that the abutment means be located between the free end portions of the tines, and they may be so arranged as to be located physically exteriorly of the space between the tines.

Figs. 14 to 19 illustrate, on an enlarged scale, different embodiments of motion transformer mechanisms adapted to be incorporated in a timepiece of the character described. In each of the following embodiments the structural details of the timepiece, including the tuning-fork type vibrator, the electrical means for oscillating the tines, and the abutment means for limiting the maximum amplitude of oscillation of the tines may be identical to any of the above-described arrangements. The motion transformer mechanisms shown in Figs. 14–19, which are disclosed in copending applications Serial No. 547,510 and Serial No. 580,813, filed April 26, 1956, and entitled "Motion Transformer," differ from the motion transformer described above in that driving means are provided which are connected to the vibrator for movement therewith and which frictionally engage rotary means that serve to drive the timepiece at a rate directly proportional to the speed of rotation of such rotary means. Additionally, suitable means are provided for limiting the rotary means to continuous rotation in one direction.

In the embodiment illustrated in Fig. 14, the tuning fork has a pair of tines **603** and **604** carrying a magnetic drum **606** and a balance weight **607**, respectively, the latter carrying an abutment element **607***b* the free end of which is spaced a distance *s* from the drum **606** when the tines are at rest. The tine **604** also carries a driving means composed of a leaf spring **620** firmly secured at one end to the tine **604** and a friction element **620***a* carried by the leaf spring **620** at its free end. The friction element **620***a* may be made of a suitable synthetic material or of a precious or semi-precious stone, as, for example, ruby or sapphire, and is adapted to engage the crests of the teeth of the ratchet wheel **621** which is rotatably mounted at **621***a* and serves to drive the timepiece mechanism of the timepiece. The crests constitute a discontinuous outer peripheral friction surface so that when the driving means is reciprocated in a direction T tangential to the ratchet wheel at the point of engagement between the friction element **620***a* and the ratchet wheel, the ratchet wheel is oscillated about its turning axis **621***a*. Thus, the ratchet wheel is rotated in a counter-clockwise direction, shown by arrow **640**, when the driving means moves leftwardly, as viewed in Fig. 14, whereas the ratchet wheel is rotated in a clockwise direction, shown by arrow **640***a*, when the driving means moves rightwardly.

A pawl means is provided for limiting the ratchet wheel **621** to continuous rotation in the direction of the arrow **640**. The pawl means includes a leaf spring **630** firmly secured at one end to the timepiece base plate **601** and a pawl element **630***a* carried by the leaf spring **630** at its free end.

With the pitch of the ratchet teeth being indicated at P, it will be understood that the pawl means prevents rotation of the ratchet wheel **621**, in the direction of the arrow **640***a*, an angular distance exceeding an angular distance corresponding to the pitch P, so that continuous rotation of the ratchet wheel is limited to rotation in the direction of the arrow **640**. It will also be understood that in order for each oscillation of the tine **604** to be accompanied bv angular displacement of the ratchet wheel a distance corresponding to the pitch P, the length of the stroke of reciprocation of the driving means should be not less than P and not greater than 2P.

As set forth above, the stroke length of the driving means is a function of or dependent upon the amplitude of oscillation of the tines of the vibrator, so that the tines will have to oscillate with a certain minimum amplitude to cause the driving means to reciprocate with a stroke length at least equal to P. The above described electrical means shown in Fig. 7 are capable of oscillating the tine **604** at at least such minimum amplitude. Furthermore, the distance *s* is so selected that the absolute maximum amplitude of oscillation of the tines is one at which the stroke length of the driving means does not exceed 2P. As set forth above, the electrical means will oscillate the tines at an amplitude not exceeding a normal maximum amplitude which is not only smaller than 2P but which is also smaller than the absolute maximum at which the tines may oscillate. Thus, the abutment element **607***b* serves mainly to prevent excessive oscillation of the tines in the event the timepiece is exposed to relatively severe shocks or other extraneous forces.

In practice, the electrical means are so constructed as to oscillate the tines with such an amplitude that the driving means reciprocates with a stroke length equal to approximately 1.5P. It will be understood from the above that the pawl means will, during successive reciprocations of the driving means, be engaged by successive ratchet teeth.

In this way, each oscillation of the tines first displaces the ratchet wheel **621**, in the direction of the arrow **640**, an angular distance corresponding to approximately 1.5P and thereafter, in the direction of the arrow **640***a*, an angular distance corresponding to approximately 0.5P. The net or effective displacement of the ratchet wheel during each oscillation of the tines is therefore an angular distance corresponding to exactly 1.0P in the direction of the arrow **640**, so that the timepiece mechanism is driven at a rate directly proportional to the frequency of oscillation of the vibrator. Since the same has an extremely high degree of constancy, the timepiece mechanism is driven very accurately.

In order to insure proper operation, the natural frequency of the driving means is considerably greater than that of the vibrator. In practice, the natural frequency of the leaf spring **620** and the friction element **620***a* should be at least twice as great as that of the tines of the vibrator.

In the embodiment illustrated in Fig. 15, the tuning fork has a pair of tines **703** and **704** carrying a magnetic drum **706** and a balance weight **707**, respectively. The balance weight carries an abutment element **707***b* the free end of which is spaced a distance *s'* from the drum **706** when the tines are at rest. The tine **704** further carries a driving means constituted by a leaf spring **720** firmly secured at one end to the tine **704**. The free end of the leaf spring **720** is adapted frictionally to engage the outer peripheral friction surface **721***b'* of a friction wheel **721***b* which, together with the ratchet wheel **721**, forms a rotary means for driving the timepiece mechanism, the rotary means being turnably mounted on the base plate of the timepiece at **721***a*. A pawl means is provided for limiting the rotary means to continuous rotation in the direction of the arrow **740**. The pawl means includes a leaf spring **730** firmly secured at one end to the base plate **701** and a pawl element **730***a* carried by the leaf spring **730** at its free end.

The operation of the device is identical to that of the embodiment illustrated in Fig. 14. It will be understood, however, that the selection of the distance *s'* will be influenced by the ratio $r_1/r_2$, with $r_1$ being the radius of the friction wheel **721***b* and $r_2$ being the radius of the ratchet wheel **721**.

In the motion transformer illustrated in Figs. 16 and 17, the tuning fork has a pair of tines **803** and **804** carrying a magnetic drum **806** and a balance weight **807**, respectively. The balance weight carries an abutment element **807***b* the free end of which is spaced a distance *s* from the drum **806** when the tines are at rest. The tine **804** is connected to a driving means for converting the oscillations of the vibrator to rotation of the ratchet wheel **821** which is rotatably mounted on the timepiece base plate **801** at **821***a*. The driving means includes a wire one end of which is fixed to the tine **804** and the other end of which is fixed to a coil spring **820***a*, the latter being secured to the base plate. Preferably, the mounting of the coil spring **820***a* is such that one of its ends is introduced into a bore within which it is retained by a tapered pin or wedge **801***a*. In this way, not only is the wire resiliently coupled to the vibrator, but also, the tension of the spring **820***a* and consequently the tension of the wire **820** may be adjusted.

It will be seen that the wire **820** thus reciprocates during oscillation of the tines of the vibrator, the coil spring **820***a* being tensioned during leftward movement of the tine **804** and serving to draw the wire **820** during rightward movement of this tine.

The wire **820** seats within the longitudinal groove **850***a* of a friction element **850**, the underside of which bears with a slight pressure on the discontinuous outer peripheral friction surface of the ratchet wheel formed by the crests of the ratchet teeth. The friction element **850** is preferably of a very light material and may have its underside lined with a suitable plastic material **850***b* in order to improve the friction between the underside of the friction element and the ratchet teeth and also so as to prevent excessive wear of the underside.

The friction between the friction element **850** and the wire **820** is sufficiently great so that the friction element moves with the wire and thus reciprocates during oscillation of the vibrator. As a result, when the tine **804** and consequently the friction element **850** move leftwardly in a direction T tangential to the ratchet wheel at the at the point of contact between the ratchet wheel and the friction element, the ratchet wheel **821** is turned in a counter-clockwise direction, shown by arrow **840**, and when the friction element **850** moves rightwardly, the ratchet wheel is turned in a clockwise direction, shown by arrow **840***a*.

Suitable pawl means are provided for preventing continuous rotation of the ratchet wheel **821** in the direction of the arrow **840***a*, and may include a very thin resilient leaf 806 preferably made of a plastic, one end of which leaf bears with a slight pressure on one of the ratchet teeth. As a result, when rotation of the ratchet wheel 821 in the direction of the arrow 840a is prevented during rightward movement of the friction element 850, the same slides over the discontinuous outer peripheral friction surface constituted by the crests of the ratchet teeth.

For the reasons set forth above in connection with the embodiments illustrated in Figs. 14 and 15, the length of the stroke of reciprocation of the friction element 850 should be at least as great as P and not greater than 2P, with P being the pitch of the ratchet teeth of the ratchet wheel 821. While the maximum amplitude of oscillation of the tines is determined by the distance *s*, it is possible, according to the instant embodiment, to limit the stroke length of the friction element 850 directly, i.e., independently of the maximum possible amplitude of oscillation of the tines.

This may be accomplished by providing abutments or stops 860 and 861 adapted to be engaged by the opposite ends of the friction element 850, respectively. The distance between the stops 860 and 861, in the direction T, is greater than the length of the friction element 850 and, in any one position of the friction element, one of its ends is spaced a distance $d$ from the stop 860 and the other of its ends is spaced a distance $d'$ from the stop 861. As a result, the maximum length of the stroke of reciprocation of the friction element 850 is equal to $d+d'$. This sum should, for the reasons set forth above, be less than 2P.

It will also be understood, for the reasons set forth above, that the length of the stroke of reciprocation of the friction element 850 should not be less than P. Consequently, the sum $d+d'$ should be sufficiently great to permit the friction element 850 to reciprocate with a stroke length greater than P so that the following relation should be satisfied: $2P>d+d'>P$. Thus, when the tines are oscillated with an amplitude sufficient to cause the wire 820 to reciprocate with a stroke length greater than P, each oscillation of the tine 4 will be accompanied by an angular displacement of the ratchet wheel 821 in the direction of the arrow 840 an effective angular distance corresponding to the pitch of the ratchet teeth.

In practice, the tines are oscillated at such amplitude that the stroke length of the friction element 850 is approximately 1.5P, so that the stops 860 and 861 are engaged only when, as a result of shocks, excessive oscillations are imparted to the tine. In that event, the friction element will, at each end of the stroke, engage one of the stops, the wire 820 being free to slide relative to the friction element when movement thereof is prevented. In this way, shocks occurring when the friction element 850 engages the stops 860 and 861 are dampened.

In order to insure proper operation of the motion transformer, the natural frequency of the moving parts, such as the wire 820, the coil spring 820*a*, the friction element 850 and the ratchet wheel 821 should be higher than the frequency of oscillation of the tuning fork, preferably at least twice as great.

The embodiment illustrated in Fig. 18 differs from the above described one in that the friction element 950 is fixed to the wire 920. The latter is connected at one end to the base plate by means of a coil spring 920*a* and at the other end to the tine 904 by means of another coil spring 920*b*. In this way, shocks occurring when the friction elements 950 engages the stops are dampened.

As in the above described embodiment, the natural frequency of the moving parts, including that of the coil spring 920*b*, should be higher than the frequency of oscillation of the vibrator.

In each of the two embodiments shown in Figs. 16 to 18, the wire is so disposed that the friction element bears on the ratchet wheel with sufficient pressure to impart a rotary movement thereto. In some cases, it may be desirable to exert an additional pressure on the friction element in order to insure good frictional contact between the element and the teeth of the ratchet wheel.

Such positive contact may be attained in either of the arrangements shown in Figs. 16 to 18 by means of the construction shown in Fig. 19. An arched leaf spring 1060 is fixed at one end to the timepiece base plate by means of a pin or screw 1061, the other end of the spring bearing on the upper side of the friction element 1050. The spring 1060 is convex toward the tine 1004 so that when the friction element 1050 moves leftwardly, i.e., in a direction which brings about rotation of the ratchet wheel 1021 in the direction of the arrow 1040, the spring 1060 is compressed and exerts a greater force on the friction element 1050, whereas when the friction element moves rightwardly, i.e., in a direction which tends to bring about rotation of the ratchet wheel in the direction of the arrow 1040*a*, the pressure exerted by the spring 1060 tends to reduce.

While the motion transformers illustrated in Figs. 14 to 19 have been described as incorporating a tuning fork, a magnetic drum, a balance weight and an abutment element of the type shown in Fig. 1, it will be understood that any one of these motion transformers may incorporate any suitably shaped vibrator, as, for example, any one of the types shown in Figs. 9 to 11. Similarly, any one of motion transformers shown in Figs. 14 to 19 may be used in conjunction with a tuning-fork type vibrator each tine of which carries a magnetic drum rather than a tuning-fork type vibrator wherein one tine carries a magnetic drum and the other tine carries a balance weight. Also, the abutment means carried by the tines may include one or two abutment elements, or be otherwise suitably shaped, as, for example, in the manner described above and illustrated in Figs. 9 to 13.

Fig. 20 is a fragmentary perspective view, partly in section and on an enlarged scale, of a tuning-fork type vibrator 1102, and electrical means for oscillating the same. The instant embodiment differs from that shown in Fig. 1 in that each of the tines 1103 and 1104 carries an electric component which is part of the electrical means, there being no balance weight corresponding to the element 7 of Fig. 1.

The vibrator is operatively associated with a driving means which forms part of a motion transformer for converting oscillations of the vibrator to rotary movement of the hands of the timepiece. In the instant embodiment, the motion transformer is of the pawl and ratchet type shown, for example, in Fig. 1, but it will be understood that the vibrator may be used in conjunction with any suitable type of motion transformer, including any one of the types shown in the preceding figures.

The pawl and ratchet mechanism shown in Fig. 20 includes a pawl 1120 carried by the tine 1104, a tooth 1120*a* being provided at the free end of the pawl. The tooth cooperates with the ratchet teeth 1121*a* of a rotatably mounted ratchet wheel 1121 in such a manner that the ratchet wheel is caused to rotate in the direction of the arrow 1140 during oscillation of the tine 1104. A friction wheel 1121*b* which is mounted for rotation together with the ratchet wheel 1121 is engaged by a leaf spring 1121*c* which is carried by the base 1101 of the timepiece. The friction wheel 1121*b* and leaf spring 1121*c* constitute a brake for preventing rotation of the ratchet wheel under the influence of anything other than the pawl 1120. The braking action also acts to prevent backward rotation of the ratchet wheel when the pawl is retracted.

The ratchet teeth 1121*a* have a pitch P, so that stroke of reciprocation of the tooth 1120*a*, in a direction tangential to the ratchet wheel at the point of engagement of the tooth and the ratchet wheel, should be not less than P and not greater than 2P, for the reasons set forth in full above.

The electrical means for oscillating the tines comprise electro-mechanical driving means capable of converting electrical energy into mechanical energy for oscillating the vibrator, electro-mechanical sensing means capable of converting mechanical energy into electrical energy and responsive to the oscillation of the vibrator for producing an electrical signal which is a function of the amplitude thereof, and electrical energy supplying means connected in circuit with the driving means and the sensing means for supplying electrical energy to the former in a manner dependent upon or controlled by the electrical signal produced by the latter. Each of these electro-mechanical means includes a magnetic field producing component and a magnetic field responsive component which is in circuit with the electrical energy supplying means, one of which component is carried by the vibrator for movement therewith during oscillation thereof and the other of which components is carried by the base of the timepiece and cooperates with the one component in such a manner that oscillation of the vibrator is concomitant with the existence of a voltage across the magnetic field responsive component.

In the embodiment illustrated in Fig. 20, the magnetic field producing components of the electro-mechanical means are carried by the tines **1103** and **1104**, respectively. Each of these magnetic field producing components is constituted by a substantially cup-shaped permanent magnet **1106** which is formed with a rim portion and a central boss portion, the former being shown as constituting an S*o* pole and the latter as constituting a N pole. These portions define an annular space between themselves, as is clearly shown in the drawing. If desired, the central boss portion may be omitted and the magnetic characteristics may be imparted to the components **1106** by providing a permanent bar magnet in place of this boss portion so that the components **1106** resemble the magnet field producing means **6**, *6a* of Fig. 1.

One of the magnets **1106** carries an abutment element **1107*b*** the free end of which is spaced a distance *s* from the other magnet **1106**, thus establishing the absolute maximum amplitude at which the tines **1103** and **1104** can oscillate.

Each of the magnets **1106** cooperates with a magnet field responsive component which, in the embodiment shown in Fig. 20, is constituted by a coil. The coil associated with one of the magnets **1106** is a sensing coil indicated as S*c* and the coil associated with the other magnet **1106** is a driving coil indicated as D which has approximately five to six times as many turns as the sensing coil S*c*. Each coil is carried by a stationary tubular carrier **1110** which is fixed to a support **1113**, each support in turn being mounted to the base plate of the timepiece (not shown in Fig. 20). The arrangement of the parts is such that the coils extend into the annular spaces formed by the rim and boss portions of the respective magnets **1106**, there being sufficient clearance between the outer surface of each coil and the inner surface of the rim portion of the corresponding magnet as well as between the inner surface of each tubular carrier **1110** and the outer surface of the boss portion of the corresponding magnet to permit reciprocation of the magnets relative to the coils during oscillation of the tines. It will be understood, therefore, that oscillation of the tines is concomitant with the existence of a voltage across the coils, the amplitude of oscillation and the amplitude of the voltage being interdependent upon each other. Thus, each coil together with its cooperating magnet forms an electro-mechanical transducer.

More particularly, the driving coil D together with its cooperating magnet **1106** forms an electro-mechanical driving means capable of converting electrical energy into mechanical energy, i.e., a voltage placed across the driving coil D will cause movement of the cooperating magnet and an alternating voltage will cause reciprocation of the magnet and consequently oscillation of tine **1104** and, by force, of tine **1103** since it is one of the basic characteristics of a tuning-fork type vibrator that its tines oscillate together. The amplitude of oscillation of the tines will depend upon the amplitude of the voltage placed across the driving coil.

Similarly, the sensing coil S*c* together with its cooperating magnet **1106** forms an electro-mechanical sensing means capable of converting mechanical energy into electrical energy, i.e., oscillation of the tine **1104** and reciprocation of the associated magnet **1106** will induce an alternating voltage across the sensing coil S*c*, the amplitude of this induced voltage being dependent upon the amplitude of oscillation of the tine **1104**.

The coils S and D are connected in circuit with the electrical energy supplying means. The latter is responsive to the signal or control voltage induced in the sensing coil and produces a driving voltage across the driving coil which is a function of the amplitude of the signal, the arrangement being such that the control voltage which, by virtue of the fact that the sensing coil has fewer turns than the driving coil, is smaller than the driving voltage, is amplified in such a manner as to maintain the driving voltage constant.

In the arrangement shown in Figs. 20 and 21, the electrical energy supplying means includes a transistor TR having base, emitter and collector electrodes respectively indicated at B, E and C, a battery or other suitable source of voltage B, a capacitor C and a resistor R. The transistor is preferably a germanium junction transistor and the battery is preferably one the terminal voltage of which, throughout substantially the entire useful life of the battery, remains substantially constant, with the voltage decreasing sharply only when the battery is almost completely discharged. For example, the battery may be of the mercury-cell type having a terminal voltage of approximately 1.3 v.

The capacitor C having a capacitance of the order of 2 microfarads and the resistor R having a resistance of the order of 2 megohms are connected in parallel with each other, and the parallel circuit is in series with the sensing coil S*c* so as to form a series circuit one terminal of which is connected to the transistor base and the other of which is connected to the positive terminal of the battery. The negative terminal of the battery is connected to one terminal of the driving coil D and forms another series circuit therewith, the terminals of which are constituted by the opposite terminal of the coil D and by the positive terminal of the battery, respectively. This last-mentioned terminal of the coil D is connected to the transistor collector, and the transistor emitter is connected to the positive terminal of the battery so as to complete the circuit, as shown in Figs. 20 and 21. Thus, the instant circuit differs from that illustrated in Fig. 7 in that the battery B is in the collector branch instead of the emitter branch, it being clear, however, that the mode of operation of either arrangement is almost the same. Circuit on Fig. 7 gives a better starting of the oscillation and a smaller variation of $I_1$ caused by amplitude variation. Also, the additional capacitor in parallel with the driving coil D is not necessary when D and S*c* coils are on separated magnets or if the electrical coupling between coils D and S*c* is so small that no wild oscillation will come up.

Alternatively, the battery may be interposed between the driving coil D and the collector, in which event one terminal of the driving coil D is connected to the positive terminal of the battery, the negative terminal thereof being connected to the collector. The emitter and the one terminal of the sensing coil-capacitor series circuit are connected to the free terminal of the driving coil.

The operation of the electrical means including the sensing means, the driving means and the electrical energy supplying means is as follows:

The instantaneous amplitude of oscillation of the tines may be represented

$$A = -A_0 \cos \omega t$$

where $A_0$ is the peak amplitude of the tine measured as the center of gravity of the respective permanent magnet **1106**, and the rate of travel or velocity of the magnet may then be expressed by

$$V=\frac{dA}{dt}=A_0\omega \sin \omega t$$

With $n_s$, $d_s$ and $B_s$ representing the number of turns and the diameter of the sensing coil Sc and the flux density of the magnet **1106** associated therewith, and with $n_d$, $d_d$ and $B_d$ representing the number of turns and the diameter of the driving coil D and the flux density of the magnet **1106** associated therewith, the voltages across these coils may be represented as follows:

$$V_S=n_s\pi d_s B_s v=n_s\pi d_s B_s A_0\omega \sin \omega t$$

$$V_D=n_d\pi d_d B_d v=n_d\pi d_d B_d A_0\omega \sin \omega t$$

so that it will be seen that oscillation of the tines is concomitant with the existence of a voltage across each of the coils, which voltages are proportional to the peak amplitude of oscillation of the tines.

With the coil Sc being considered the driven or sensing coil, the above-mentioned voltage $V_S$ is induced thereacross during oscillation of the tines, and the base voltage $V_1$ may then be expressed as follows:

$$V_1=V_S-V_C=n_s\pi d_s B_s A_0\omega \sin \omega t-V_C$$

with $V_C$ being the voltage across the capacitor C, the latter constituting a D.C. voltage source which is capable of temporarily retaining a voltage generated by the coil S and the diode base-emitter of the transistor and of supplying this voltage as a negative bias for biasing the transistor in such a manner that the same is in class C operation. If desired, the capacitor C may be replaced by a battery or other voltage source for supplying the desired biasing voltage, but the oscillator will not start itself.

The alternating voltage $V_1$ causes the base current $I_1$ to vary in the manner shown in Fig. 22, and the changing base current, in turn, controls the collector current $I_2$ in such a manner that its configuration or wave shape may assume that shown in the same figure.

At the same time, the battery B will cause a collector current $I_2$ to flow through the driving coil D so that the same produces the driving voltage $V_D$ which is equal to

$$V_D=V_B-V_2$$

with $V_B$ representing the battery voltage and $V_2$ the collector voltage. The latter may be expressed as follows:

$$V_2=V_B-V_D=V_B-n_d\pi d_d B_d A_0\omega \sin \omega t$$

Then

$$V_{2min}=V_B-n_d\pi d_d B_d A_0\omega$$

with $V_{2min}$ being the collector voltage at the instant $I_2$ is greatest. The construction of the whole circuit is such that

$$0\geqq V_{2min}\geqq 0{,}3 \text{ v.}$$

so that, inasmuch as the transistor has characteristics analogous to that of a pentode in that the collector current $I_2$ is very strongly influenced when changes in the collector voltage $V_2$ occur within the range of 0 to 0.3 v., small changes in the collector voltage brought about by small changes in the voltage $V_D$ across the driving coil D produce relatively large changes in the collector current $I_2$, and that alone stabilizes the amplitude.

The entire electrical means are thus capable not only of driving the tines, but serve as an automatic regulator for oscillating the tines at a constant amplitude, the significance of which is described above. The variation of $V_s$ has no stabilizing effect, this voltage only determines the moment, when the current $I_1$ has to flow which current causes a $I_2$ current. But the volume of $I_2$ is determined by the voltage $V_2$ min. The amplitude stabilizing effect is limited at a current $I_2$ max. This $I_2$ max. will come up when for instance under the influence of increased friction in the timepiece mechanism the voltage $V_2$ min. will be greater than $0{,}3$ volts which is about the knee of the pentode characteristic of a junction transistor. Then for $V_2$ min. greater than $0{,}3$ volts the current $I_2$ max. is current amplification factor of the transistor multiplied by $I_1$ max. With capacitor-resistor biasing and these two connected on the negative pole of the battery as shown in Fig. 21 the current $I_1$ max. is almost independent on variations of $V_S$ caused by variations of the amplitude. This $I_1$ max. must be chosen by calculating the resistor which is parallel to the capacitor in such a manner that the greatest friction which may occur in the timepiece produces a current $I_2$, which is still smaller than $I_2$ min. as described above. Now the amplitude stabilizing effect, which works only in the region of 0 to $0{,}3$ volts for $V_2$ min. is regulating like this:

There may be a decrease in amplitude of oscillation caused by friction in the timepiece. The voltage $V_B$ will therefore decrease what makes increase the voltage $V_2$ min. and this causes a very big increasing of the current $I_1$ which current drives the tuning fork again to greater amplitude of oscillation, or with other words a very small variation in amplitude of oscillation in the described regulating area causes very big driving energy variations conducted to the tuning fork.

It will be seen, therefore, that the amplitude of oscillation of the tines is automatically maintained between certain minimum and maximum amplitudes so that the pawl means **1120**, **1120***a* are reciprocated with a stroke the length of which is maintained between certain minimum and maximum lengths. These minimum and maximum amplitudes are the extreme amplitudes of a very narrow range of amplitudes, so that for practical purposes the amplitude of oscillation of the tines is maintained constant at that amplitude at which the base and collector voltages and currents assume the values shown in Fig. 22. For the reasons set forth above, this amplitude corresponds to a reciprocation of the pawl means with a stroke the length of which is equal to approximately 1.5P.

As also set forth above, a separate battery may be substituted for the capacitor C. However, not only has it been found to be more practical to provide a capacitor-type bias source instead of a battery, but also, the capacitor serves to bring about a relatively small change in the base current during relatively large changes in the voltage $V_S$ due to the automatic bias action.

Also, the capacitor resistor-type bias voltage source serves to drive the base voltage positive during at least a portion of the cycle, despite the occurrence of a relatively sharp amplitude decrease. With a battery biasing in this case the oscillation would stop because $I_1$ would be 0. This condition is prevented by providing the biasing capacitor C and resistor R which at all times supplies a negative biasing of such magnitude as to drive the base current positive during a portion of the cycle. In this way, the tines will be returned to normal amplitude oscillation even after a sharp amplitude decrease.

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

While the invention has been illustrated and described as embodied in an electric timepiece incorporating a tuning-fork type vibrator, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

For example, the physical arrangement of the sensing and driving coils may differ from that shown in Fig. 1 wherein both coils are associated with a single magnet carried by one tine or in Fig. 20 wherein the coils are associated with different magnets carried by different tines. If desired, either the driving coil or the sensing coil or both may constituted by two separate coils which are serially connected to each other, with one of these separate coils being associated with the magnet carried by one of the tines and with the other being associated with the magnet carried by the other tine. Thus, the total space available for the sensing and driving coils—which, in a timepiece of the character described, may be extremely small—may be utilized to best advantage, i.e., the total physical space requirement of both the sensing and driving coils may be evenly divided between the two magnets.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

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

1. In a timepiece having a timepiece mechanism, in combination, a base; ratchet wheel means having ratchet teeth of predetermined pitch and being rotatably carried by said base, said ratchet wheel means being operatively associated with said timepiece mechanism for driving the same at a rate directly proportional to the speed of rotation of said ratchet wheel means; reciprocatable driving means cooperating with said ratchet wheel means for rotating the same when the length of the stroke of reciprocation of said driving means is between a predetermined minimum stroke length which is a function of the pitch of said ratchet teeth and a predetermined absolute maximum stroke length which is a function of twice the pitch of said ratchet teeth; a tuning-fork type vibrator carried by said base and having a pair of tines capable of oscillating at a constant frequency, one of said tines being connected to said driving means for reciprocating the same with a stroke the length of which is a function of the amplitude of oscillation of said tines, each oscillation of said one tine bringing about one ricprocation of said driving means; abutment means for limiting the amplitude of oscillation of said tines to an absolute maximum amplitude of oscillation at which the stroke length of said driving means equals said predetermined absolute maximum stroke length; and electrical means for normally oscillating said tines of said vibrator at said constant frequency and at a constant amplitude at which the stroke length of said driving means is between said predetermined minimum stroke length and a predetermined normal maximum stroke length which is less than said absolute maximum length so that said driving means, while being reciprocated by said one tine during normal oscillation thereof under the influence of said electrical means as well as while being reciprocated by said one tine during excessive oscillation thereof under the influence of extraneous vibrations, may rotate said ratchet wheel means at a constant speed so that said ratchet wheel means in turn may drive said timepiece mechanism at a constant rate, said constant speed of rotation of said ratchet wheel means and consequently the rate at which the same drives said timepiece mechanism being directly proportional to said constant frequency, whereby said timepiece mechanism is driven at said constant rate despite excessive oscillation imparted to said tines of said vibrator extraneously.

2. The combination defined in claim 1 wherein said abutment means include at least one abutment element arranged between said tines, carried by one of said tines adapted to engage the other of said tines.

3. The combination defined in claim 1 wherein said abutment means include a pair of abutment elements arranged between said tines and carried by said tines, respectively, said abutment elements being adapted to engage each other.

**References Cited** in the file of this patent

FOREIGN PATENTS

767,359 France ---------------- May 1, 1934