

Oct. 19, 1965

Filed June 4, 1963

AKIRA NAKAI
VIBRATORY MOTOR AND CONTROLLED
CIRCUIT FOR A SMALL TIMEPIECE

3,212,252

5 Sheets-Sheet 1

FIG. 1.

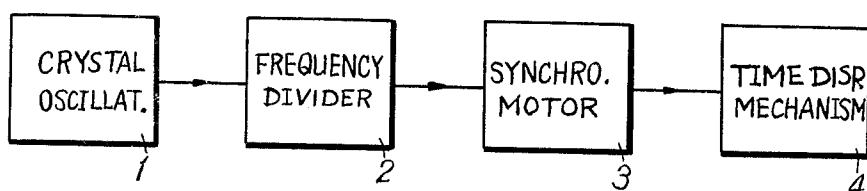


FIG. 2.

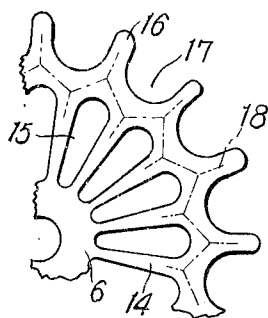
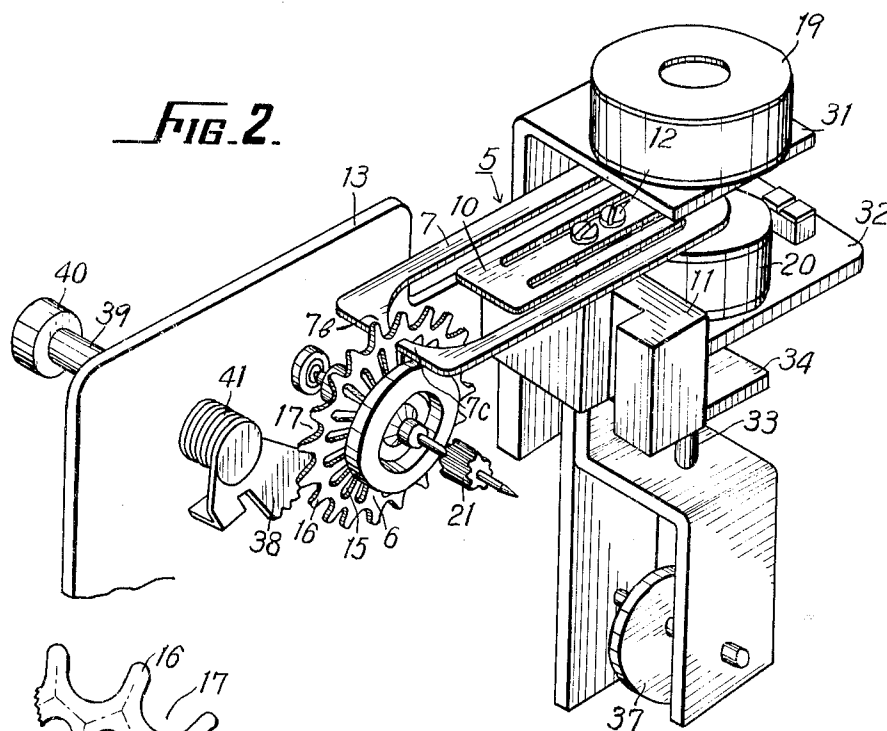


FIG. 10.

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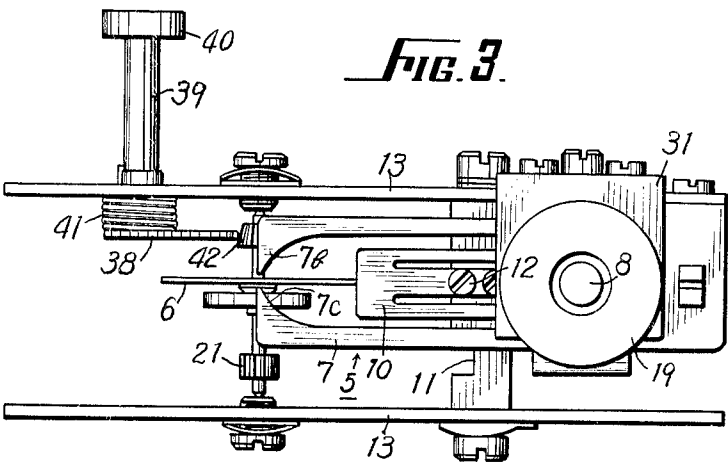
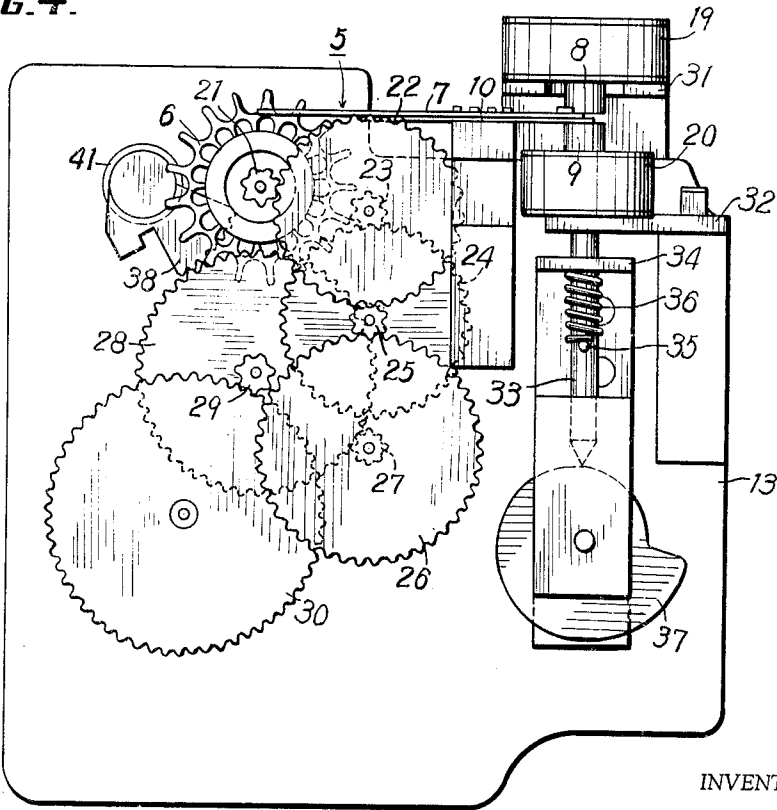


FIG. 4.



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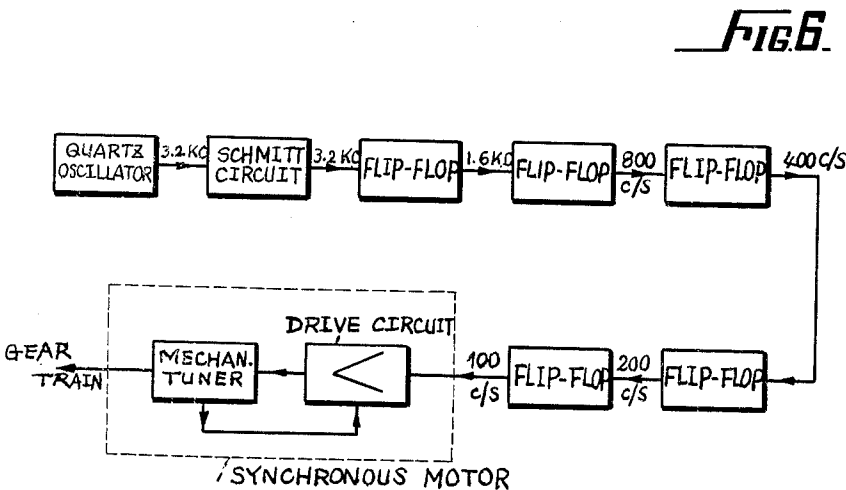
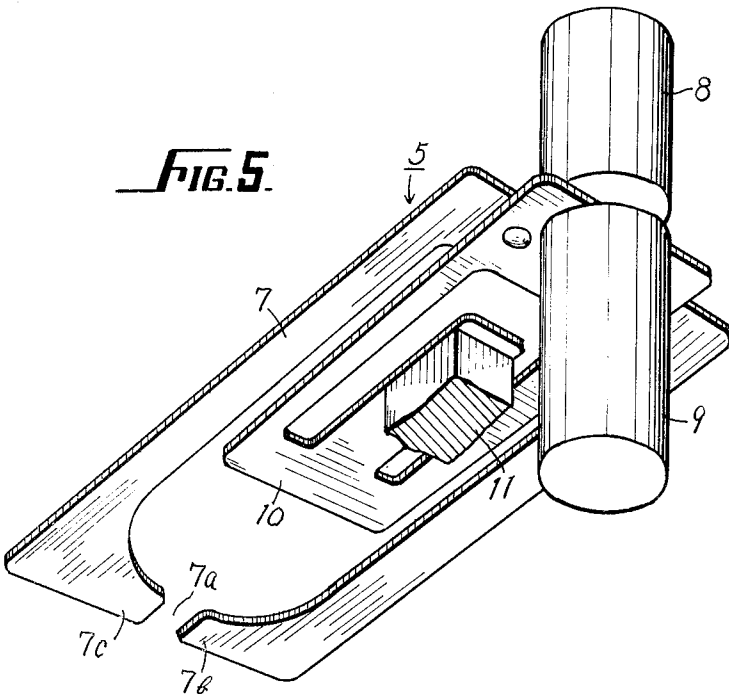
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FIG. 7.

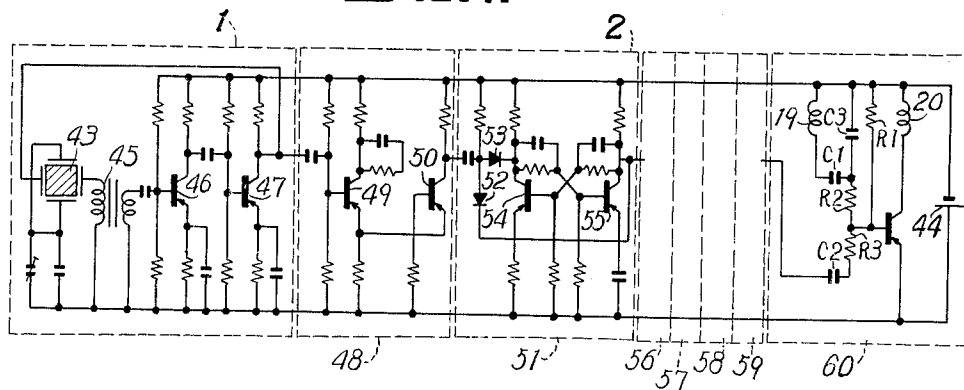
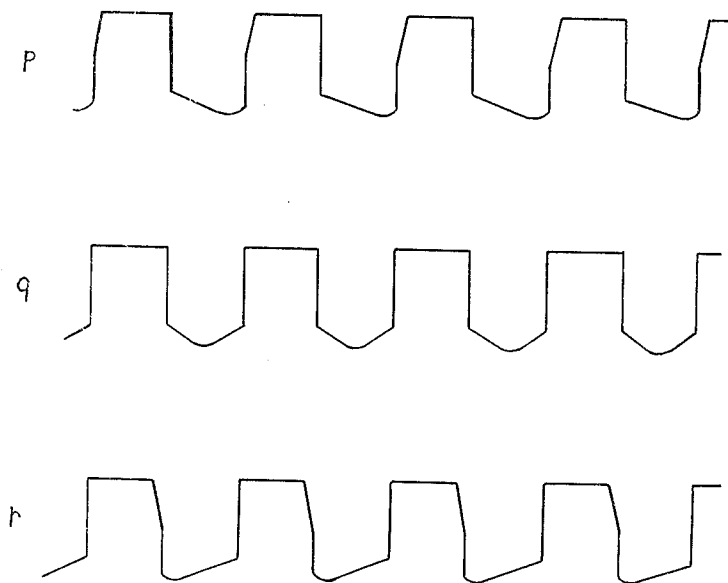


FIG. 8.



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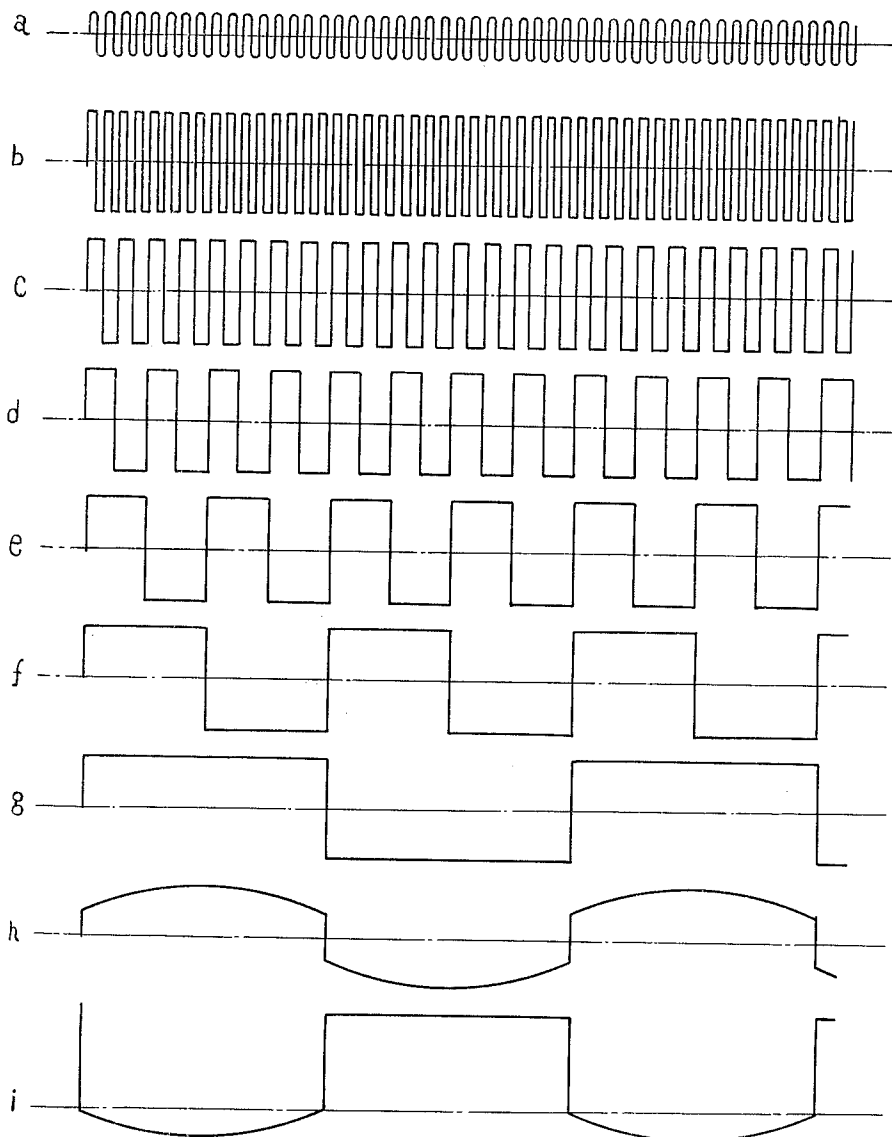
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FIG. 9.



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3,212,252
**VIBRATORY MOTOR AND CONTROLLED
CIRCUIT FOR A SMALL TIMEPIECE**
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Filed June 4, 1963, Ser. No. 285,348
3 Claims. (Cl. 58—23)

This invention relates to small timepieces having crystal oscillators for their time base. In this type of timepiece, generally speaking, electrical output from the crystal oscillator is supplied to a frequency divider and thence amplified by a power amplifier so as to energize a synchronous motor which drives a conventional time display mechanism.

Electrical circuits employed for this purpose make use of semiconductors, especially transistors, for the purpose of reducing overall size of the timepiece, as well as the power consumption of the circuit. With conventional techniques, however, the power consumption is still relatively high so that battery-powered small crystal timepieces have not yet been a commercial reality.

It is one of the objects of the present invention to provide an efficient small timepiece having as its time base a crystal oscillator and a synchronous motor driven therefrom.

It is another object of the invention to provide a small battery-powered crystal timepiece capable of operating for a long period of time on a small capacity battery.

It is still another object of the invention to provide a small battery-powered timepiece which provides a negligibly small position error and thus operates with a high accuracy.

It is a still further object of the invention to provide a small battery-powered crystal timepiece which is simple in its design and economic in its manufacture.

These and other objects of the invention will be more apparent to those skilled in the art from a consideration of the following detailed description when taken together with the accompanying drawings in which:

FIG. 1 represents a block diagram illustrating the timepiece according to this invention;

FIG. 2 represents a perspective view of essential parts of the timepiece mechanism of the aforementioned timepiece, with the electrical conductors and the conventional gear train omitted from the drawing for simplicity;

FIG. 3 represents an enlarged view of several parts of FIG. 2, illustrating more clearly the mechanical oscillator which is electromagnetically driven;

FIG. 4 represents a top plan view of the mechanism shown in FIG. 2;

FIG. 5 represents a perspective view of the mechanical oscillator;

FIG. 6 represents a block diagram showing the energy transmission in the novel mechanism by way of example;

FIG. 7 is a circuit diagram showing electronic constituents embodied in the invention by way of example;

FIG. 8, *p* to *r*, represents voltage curves of the driving energy of the mechanical tuner employed in this invention with the tuner operating at synchronized condition;

FIG. 9 represents voltage curves at various stages of the mechanism according to the invention, and;

FIG. 10 is an enlarged side view of a part of the rotor magnetically cooperating with the vibrator.

Referring now to the accompanying drawings, especially FIG. 1 thereof, the timepiece mechanism constructed according to the novel teachings of the invention comprises generally a crystal, preferably quartz oscillator 1, a frequency divider 2, a synchronous motor 3 having a

mechanical vibrator such as mechanical tuner, and a conventional time display mechanism 4.

The synchronous motor 3 comprises, as shown in FIGS. 2-5, a mechanical tuner or vibrator 5 and a rotor 6 magnetically coupled therewith for being driven therefrom. The vibrator comprises a resilient strip magnet 7 having a generally rectangular shape internally punched and provided with a front gap 7*a* providing a pair of oppositely arranged, inwardly directing pole formations 7*b* and 7*c* closely embracing the rotor 6 from its both sides. At the outboard or right-hand end of the magnet 7, a spring strip 10 is fixedly attached as by sticking, fusion welding, riveting or the like. As shown, the spring strip is shaped into a closed "E," the central lead of which is fixedly mounted on a bracket 11 by means of set screws 12. The thus provided spring-magnet assembly 5 is fixedly attached at its outboard end with a pair of oppositely arranged magnet pieces 8 and 9. These pieces are made preferably into short rigid cylinders as shown. The bracket is in turn fixedly mounted on framework 13 of the timepiece mechanism. As will be described more in detail hereinafter, the thus provided vibrator makes oscillatory movement about an imaginary axis X-Y passing through a point between set screws 12. The vibrator is so shaped and dimensioned that the center of gravity of the whole mass of the vibrator is substantially on the aforementioned axis.

The rotor 6 has spokes 14 having arched apertures 15. Radially in line with these arched apertures are outer tooth-like projections 16 which are separated by U-shaped recesses 17. As shown in FIG. 10 by dotted lines 18, a wavy track will be produced along the rim of the rotor which is rotatably supported on the framework 13 so as to magnetically cooperate with the aforementioned pole formations 7*b* and 7*c*. Rotor 6 is rotatably mounted in the framework 13 and drivingly connected with a conventional gear train 21-30 of the timepiece mechanism, the said gear train being shown, especially in FIG. 4.

A pair of sensing and drive coils 19 and 20 are mounted through proper supports 31 and 32 on framework 13. It will be seen especially from FIG. 4, magnet pieces 8 and 9 are concentrically arranged relative to these sensing and drive coils with small air gaps between them.

The coil 20 is rigidly mounted on a cantilevered support 32 fixedly attached to the framework. The fixing means are not shown. Through a bore of this support 32, as well as through a bore in the flange 34 of a bracket 35 fixedly mounted on framework 13, a pointed follower pin 33 passes without interference. The pin is provided with a stop 35 and a coil spring 36 inserted between flange 34 and stop 35 under compression so that pin 33 is urged to move downwards so as to keep pressure contact with a cam 37 which is rotatably mounted on bracket 35 and framework 13. Although not shown, cam 37 is provided with a knob so that by manipulating the latter the cam can be rotated in one direction or another to elevate or lower the follower pin 33 for the purpose of adjusting the magnetic performance of the drive magnet assembly. For this purpose, the pin 33 is provided at its top end with an auxiliary magnet piece which is arranged to cooperate magnetically with the main drive magnet piece 9, as will be described in detail hereinafter. In this way, the oscillating characteristics of the vibrator 5 can be adjusted to meet environmental requirements.

A manual starter of segmental gear type is provided. The segmental gear 38 is rotatably mounted on framework 13 and provided with a knob 40 fixed on the outboard end of the shaft 39 rigidly connected with the segment. Urging spring 41 is fitted to the segment and urges to rotate the segment in the disengaging direction from pinion 42 fixedly mounted on the shaft of rotor 6.

A more detailed block diagram of the timepiece according to this invention is shown in FIG. 6. FIG. 7 represents a circuit diagram showing a preferred combination of electrical parts employed.

Crystal oscillator 1 includes, by way of example as shown in FIG. 7, a conventional quartz oscillator 43 energized from a D.C. current source 44; a transformer 45; transistors 46 and 47; and a plurality of condensers and resistors. This crystal oscillator circuit is of rather conventional design and designed to deliver a 3.2 kc. output, the wave form of which is shown schematically at *a* in FIG. 9. This output is supplied to a conventional Schmitt circuit 48 comprising transistors 49 and 50 and transformed into a corresponding rectangular wave as shown at *b* in FIG. 9. The provision of this Schmitt circuit 48 serves effectively for obtaining an accurate and maintained rectangular wave even when the battery voltage should have been considerably reduced. The rectangular wave voltage thus produced is delivered to a first stage flip-flop circuit 51 including diodes 52-53, transistors 54-55, and the conventionally arranged resistors and condensers, whereby the frequency of the delivered voltage is reduced to 1.6 kc., or to half the input frequency, as shown at *c* in FIG. 9. The frequency divider circuit 2 comprises five such flip-flop stages 51, 56, 57, 58 and 59, for dividing the voltage frequency by two at each stage thereof, as shown *d-g* in FIG. 9. Thus, from the last flip-flop stage 59, a 100 cycle square wave is obtained and supplied to a drive circuit 60 of the synchronous motor 3. This circuit includes aforementioned two sensing and drive coils 19-20, condensers *c*1, *c*2 and *c*3, resistors *R*1, *R*2 and *R*3, transistor *Tr* and battery 44. The sensed and driving voltages in the both coils 19-20 are shown at *h* and *i* in FIG. 9, respectively, from which it will be seen that these voltages are in opposite phases to each other. Additionally, second and further flip-flops 56-59 are shown simply by dotted blocks for the simplicity of the drawing. Further, the natural frequency of the spring-magnet assembly is so selected that it is practically same as the frequency of the drive current for drive coil 20, that is 100 cycles per second in this preferred embodiment.

The working principle employed by the mechanical vibrator and rotor magnetically coupled therewith is already known as shown by U.S. Patent 2,841,986 granted July 8, 1958 to C. F. Clifford, which discloses mechanical oscillators designed for timepiece escapements. The prior art discloses that the vibrator is used for controlling the stepwise rotation of the rotor magnetically coupled therewith, which rotor is driven mechanically from a mechanical power source such as a conventional power spring embodied in a mechanical timepiece. A unique feature of the present invention is the elimination of the power spring and the employment of a synchronous motor comprising the spring-magnet assembly powered in the aforementioned way from a crystal oscillator which is in turn powered from a battery contained in the timepiece, on the one hand, and a rotor magnetically coupled with the vibrator assembly and having a wavy magnetic track as shown by dotted lines 18 in FIG. 10, on the other hand.

When it is desired to let the timepiece run, the vibrator assembly 5 is brought into actuation in the aforementioned way at a frequency of 100 cycles per second in this case. Next, knob 40 is manually turned against the action of spring 41 until segmental gear 38 is brought into engagement with pinion 42 which is fixedly attached on the shaft of rotor 6. When the knob is released, the spring 41 will release its accumulated power through the intermediary of gear segment 38 so as to turn the pinion 42 with its shaft and rotor 6 in a predetermined direction. The provision of this manual starter is for the purpose of an easy starting of the synchronous motor, on the one hand, and for the prevention of otherwise possible reverse rotation of the motor. As already mentioned, the natural frequency of the mechanical vibrator is selected to be

substantially equal to the frequency of the current fed to the vibrator, the motor will start running after a short time interval at a stable resonant frequency, more specifically at 100 cycles per second in this embodiment. Since the center of gravity of whole mass of the vibrator is placed substantially on the vibrating axis X-Y as already described, the vibrating system is well balanced so that the power consumption can be minimized as will be described hereinafter by a numerical example. Thanks to this arrangement, position errors of the timepiece can be also minimized.

If for some reason, the frequency of the vibrator becomes different from the design frequency thereof, cam 37 is manually turned by means of the knob (not shown) attached fixedly to the cam shaft so as to elevate or lower, as the case may be, the auxiliary magnet (not shown) attached to the top end of pin 33. If the auxiliary magnet has a magnetic polarity opposite to that of the drive magnet piece 9 and the former is brought nearer to the latter, the vibrator is somewhat accelerated, and vice versa. This adjusting means is principally employed for examination purpose while manufacturing a number of vibrators in a factory. Thus, practical timepieces can be dispensed with such means.

When the vibrator oscillates at a predetermined frequency, the rotor 6 is stepwise rotated in its predetermined advancing direction and thus rotation is transmitted therefrom through conventional gear train 21-30 mechanically connected to the conventional time display mechanism as at 4 which comprises a short hand, a long hand, a second hand and a timepiece dial carrying time symbols, all not shown.

It will thus be understood that when the quartz oscillator 43 is energized, the rotor 6 is rotated stepwise and the time is displayed by means of time indicator 4.

If necessary, Schmitt circuit 48 may be displaced by any conventional electronic circuit which is capable of converting a sinusoidal electric current into a corresponding rectangular one, although Schmitt circuit is highly recommended by reason of its high reliability and stable performance even with changes of the supplied voltage.

In this invention, a plurality of series-connected flip-flops 51, 56-59 are employed for the purpose of frequency division as described hereinbefore. This arrangement is highly recommendable for its high stability when subjected to possible gradual changes either or both in the ambient temperature of the atmosphere and the working voltage supplied from the source.

In practice, however, the series-connected flip-flops can be displaced by other conventional frequency dividers.

In the course of the operation of the timepiece in the above-mentioned way, an input current, at 100 c./s., is supplied from the last stage flip-flop 59 to drive circuit 60. The input side of transistor *Tr* in combination with resistors *R*1 and *R*2 constitutes an AND-circuit, so that the base of the transistor is supplied with the sum of the voltage induced in the sensing coil 19 by the vibratory movement of the vibrator 5, and a constant frequency voltage supplied from the last stage flip-flop 59. Thus, by adjusting resistors *R*1 and *R*2, the vibrator can be brought into a synchronous oscillation to the frequency of the drive current from the last stage flip-flop so that the vibrator may perform a stable oscillatory motion under resonant conditions. With use of this drive circuit, the frequency of the vibrator can be controlled at the input side of the transistor circuit by means of the signal output from the flip-flop assembly, which signal output may be of relatively small value. Thanks to this arrangement, a highly stable operation of the flip-flop assembly can be assured.

In operation, when the flip-flop assembly is disconnected from the drive circuit 60, the vibrator will operate at its own natural frequency and thus inspection and adjustment of the natural frequency characteristic of the vibrator can be easily accomplished. Transistor *Tr* may prefer-

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ably be of the p-n-p junction type and resistor R3 acts as biasing means for it. C1 and C2 are coupling condensers and C3 is a condenser inserted in the circuit so as to suppress a possible high frequency oscillation caused by the electrical combination of sensing and drive coils 19-20.

Voltage curves of the fed current to the vibrator constructed according to the present invention are shown in FIG. 8, *p*, *q* and *r*, respectively. The curve at *p* is that will appear across the drive coil 20 when the natural frequency of the vibrator is somewhat lower than the frequency of the fed current, that is 100 c./s. in this case. The curve at *q* is obtained with the both frequencies precisely in coincidence with each other, while the curve shown at *r* applies to the case in which the natural frequency is somewhat higher than the frequency of the fed current.

With use of the aforementioned synchronous motor having a mechanical vibrator capable of operating at a resonant frequency, a higher electrical efficiency can be obtained. This, it will generally be about 30%, while that of a conventional comparative synchronous motor is about 10%.

Example

As drive coil, 3800 turns of insulated copper wire, 50 dia. were employed. The sensing coil had equally 3800 turns of 40 dia. insulated copper wire. Each of the magnet pieces was made from a magnetic alloy of Alnico-series "PFII" supplied by a Japanese firm, Nihon Jishaku Kabushiki Kaisha, Tokyo, Br: 12,500-13,000; Hc: 580-650. The vibrating magnet: "Vicalloy," 10 x 25 x .24 mm. The supporting spring: "Elinvar," 8.5 x 5.8 x .27 mm. The rotor: soft iron; O.D. 15 mm.; No. of teeth: 20.

Output of quartz oscillator: 3.2 kc. Output of Schmitt circuit: 3.2 kc. Outputs of first and last stage flip-flops: 800 and 100 c./s., respectively. Current source: 1.5 v.

With the above specifications of the constituent parts, the power consumption of the synchronous motor amounted to 0.5 ma. Power required for the electronic circuits including quartz oscillator, Schmitt circuit and five stages of flip-flop: 1.0 ma. Thus, overall power consumption of the timepiece mechanism: 1.5 ma.

The above mentioned novel timepiece mechanism operated satisfactorily under variable ambient temperature conditions ranging from -0 to +40° C.

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 inven-

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tion, and therefore, such adaptations should and are understood to be within the meaning and range of equivalents of the following claims.

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

1. In a timepiece, the combination comprising a crystal oscillator, a vibrating means for movement of time display elements of the timepiece with vibration thereof, an electromagnetic drive means for vibrating said vibrating means, first signalling means actuated by said crystal oscillator for providing rectangular wave form signals having a frequency substantially the same as the natural frequency of vibration of said vibrating means, second signalling means for detecting the vibrations of said vibrating means and providing signals indicative thereof, and electric circuit means for feeding the first-mentioned signals summed with the second-mentioned signals to the electromagnetic drive means whereby deviations from the resonant frequency of vibration of said vibrating means are immediately detected and corrected.

2. The timepiece of claim 1 wherein said vibrating means are magnetically coupled to a rotor having an irregular magnetic track which when acted upon by the vibrational forces of said vibrating means transmitted through the magnetic coupling causes said rotor to rotate.

3. The timepiece of claim 1 wherein said first signalling means includes frequency divider means interposed between the crystal oscillator and the electromagnetic drive means for reducing a higher frequency signal originated by the crystal oscillator to a lower frequency signal substantially the same as the natural frequency of vibration of said vibrating means.

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JOSEPH P. STRIZAK, *Examiner*.