

[54] **WATCH TRANSDUCER**

[72] Inventor: James H. Reese, Manheim, Pa.

[73] Assignee: Hamilton Watch Company, Lancaster, Pa.

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[52] U.S. Cl. 58/28 B, 310/36, 318/130, 318/138

[51] Int. Cl. G04c 3/04, H02k 33/02

[58] Field of Search 310/36; 318/130, 138; 58/23, 58/28, 107; 74/1.5, 88

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Primary Examiner—Richard B. Wilkinson

Assistant Examiner—Edith C. Simmons

Attorney—LeBlanc & Shur

[57]

ABSTRACT

Disclosed is a crystal controlled watch having an improved transducer for converting the electrical impulses from a crystal oscillator and divider into unidirectional stepwise rotary motion suitable for driving watch hands. The transducer comprises a lightweight coil wholly mounted in the field of a permanent magnet having a natural frequency at least approximately equal to the frequency of the divider output so that the transducer coil is slaved to the crystal. An eccentric oscillates with the coil and drives the watch train through a lever pivoted to it and engaging an index wheel with magnetic attraction.

28 Claims, 23 Drawing Figures

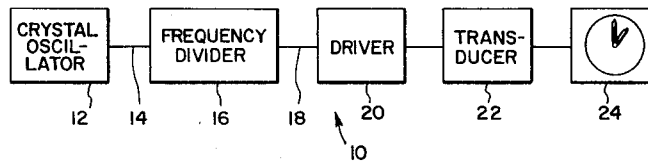


FIG. 1

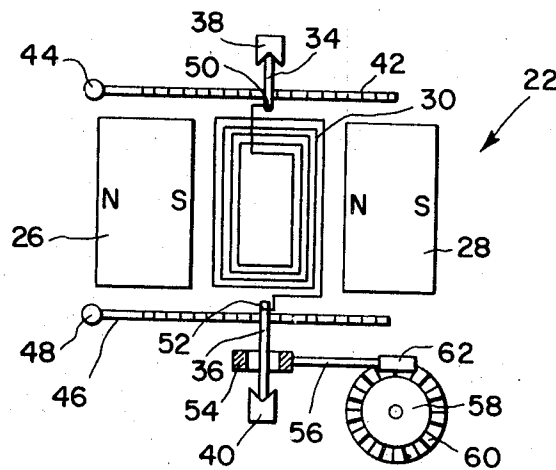
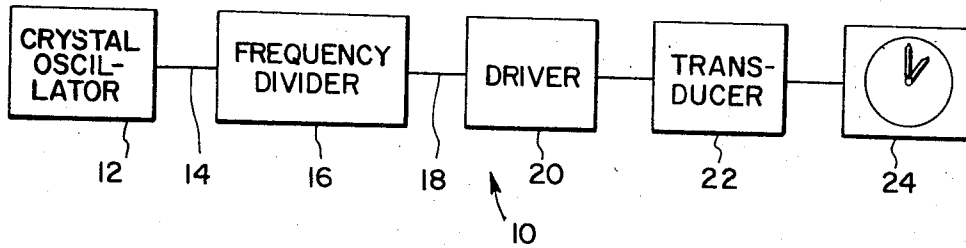


FIG. 2

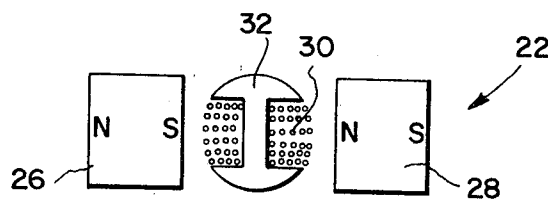


FIG. 3

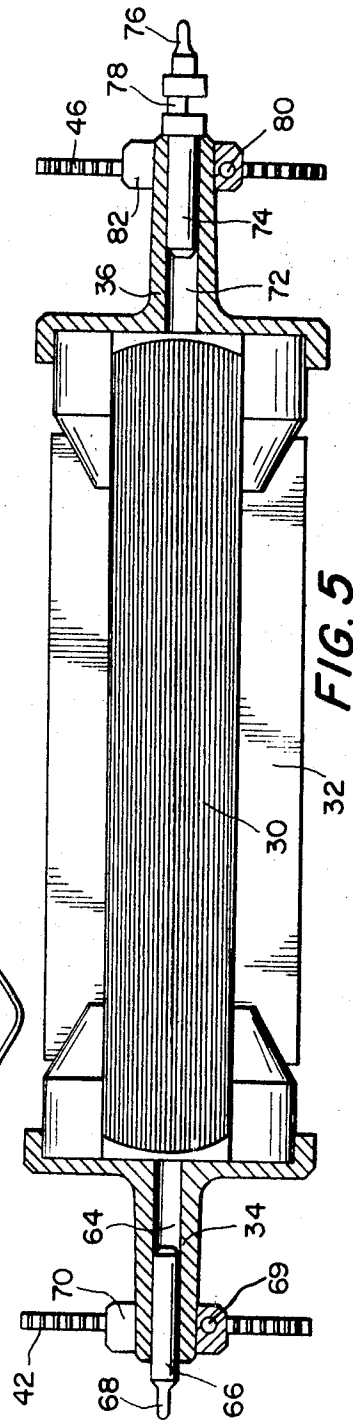
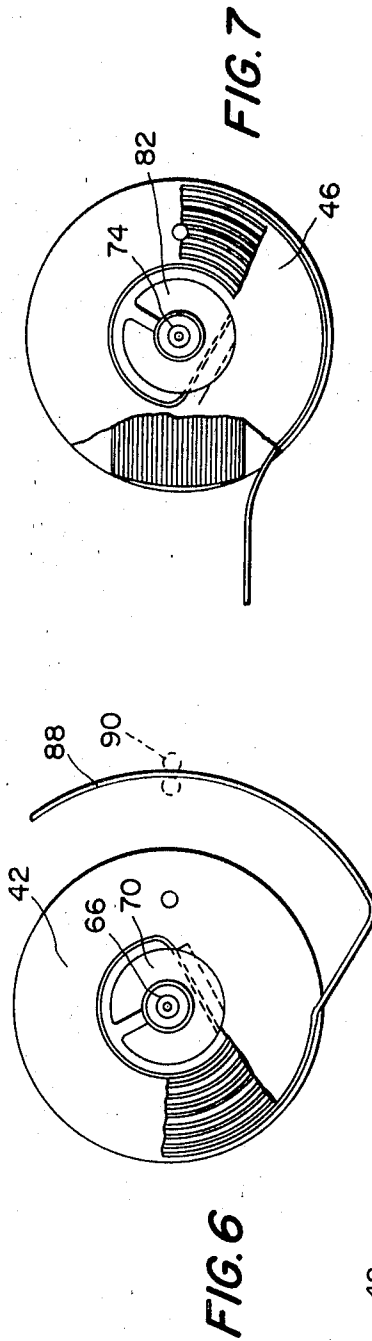
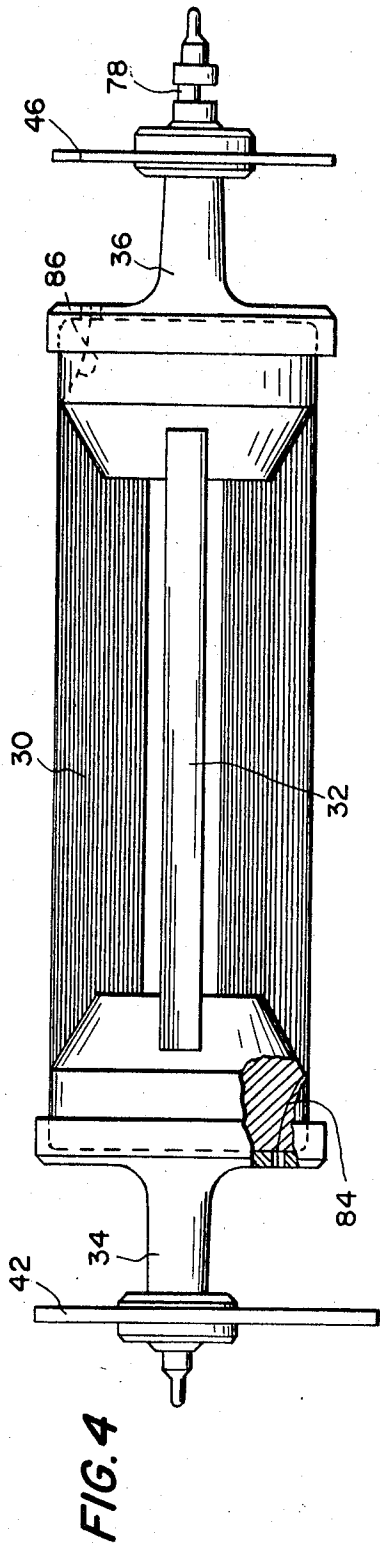
INVENTOR

JAMES H. REESE

BY

LeBlanc & Shur

ATTORNEYS



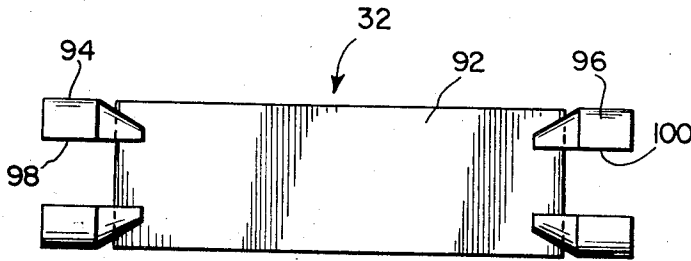


FIG. 8

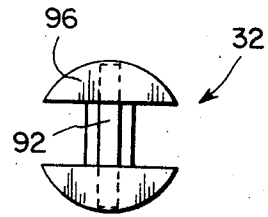


FIG. 10

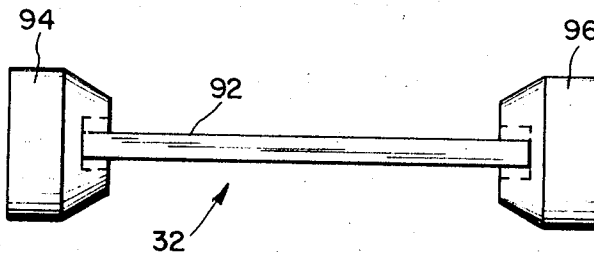


FIG. 9

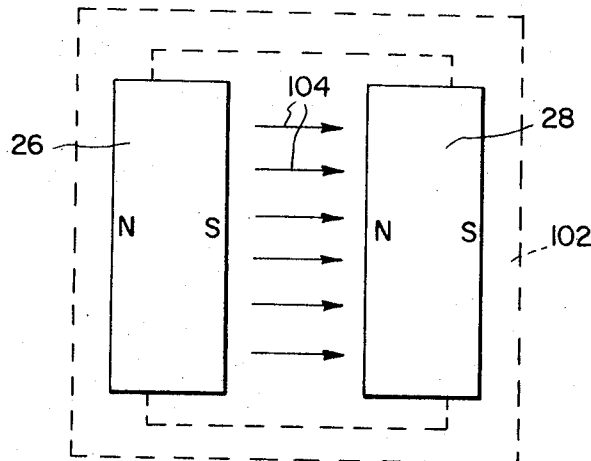


FIG. 11

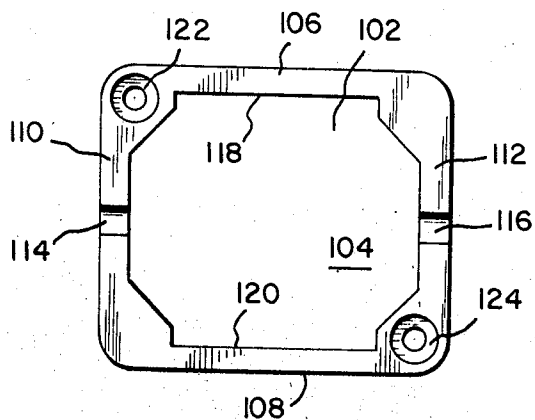


FIG. 12

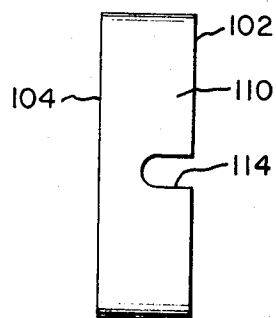


FIG. 13

FIG. 14

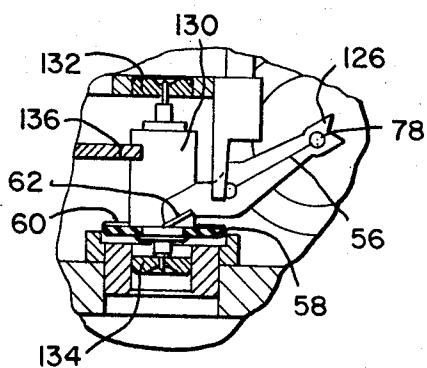
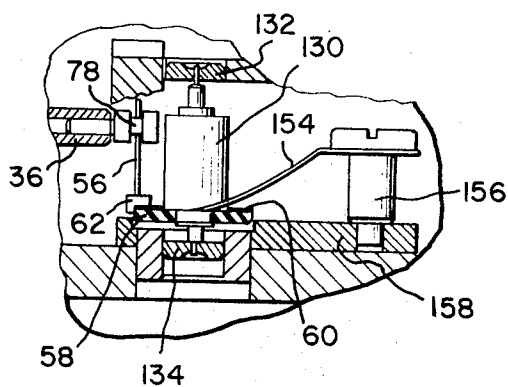


FIG. 19



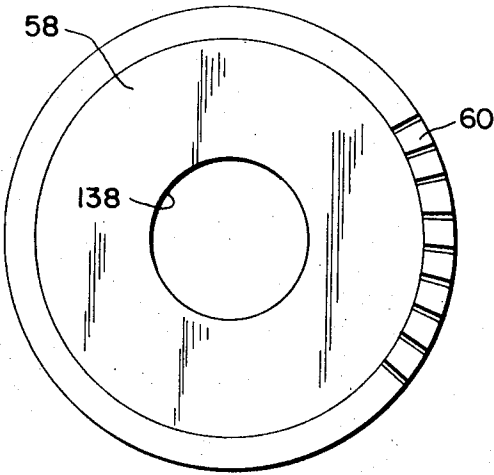


FIG. 15

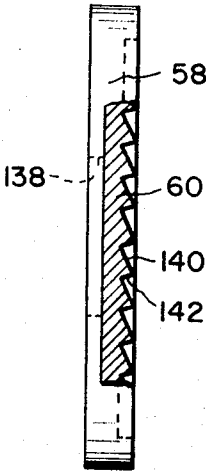


FIG. 16

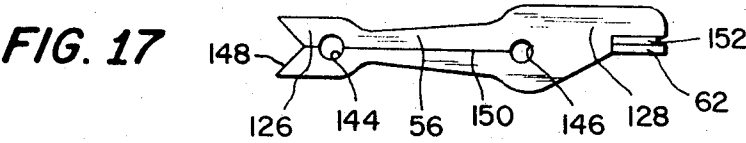


FIG. 18



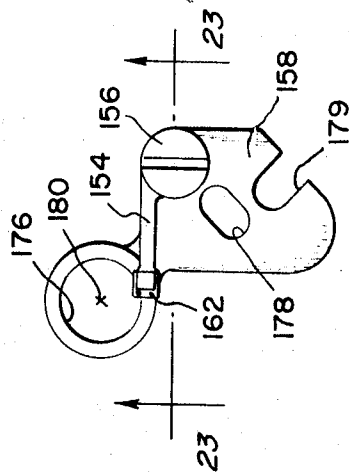


FIG. 22

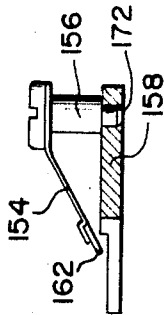


FIG. 23

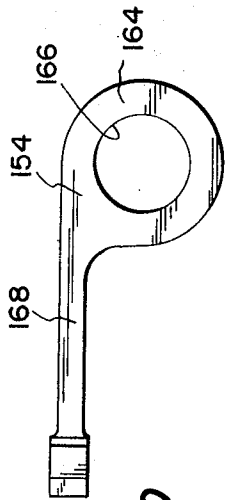


FIG. 20

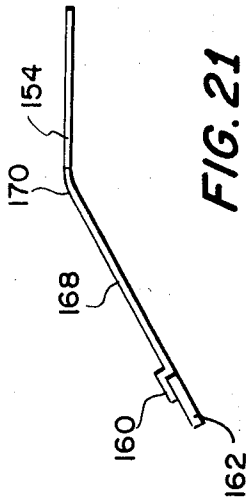


FIG. 21

WATCH TRANSDUCER

This invention relates to an electromechanical transducer for a watch and more particularly to an electromechanical transducer for converting the electrical pulses from a crystal controlled oscillator into mechanical movement suitable for driving a conventional watch train. The transducer is particularly adapted for use in an electronically regulated watch employing a crystal controlled master frequency standard of relatively high frequency and an electronic frequency divider to divide the high frequency of the crystal controlled oscillator of the frequency standard to a lower frequency suitable for driving the hands of a watch.

Battery powered wristwatches and other small portable timekeeping devices of various types are well known and are commercially available. The first successful commercial electric watch is of the type shown and described in assignee's U.S. Re. Pat. No. 26,187, reissued Apr. 4, 1967, to John A. Van Horn et al., for ELECTRICAL WATCH. Electric watches of this type employ a balance wheel and a hairspring driven by the interaction of a current-carrying coil and a magnetic field produced by small permanent magnets. Other types of mechanically regulated battery operated wristwatches are also known.

Considerable effort has recently been directed toward the development of a high accuracy wristwatch which does not employ electromechanical oscillators as the master time reference. One approach which has been considered and has been subjected to substantial investigation is the use of completely electronic circuitry to generate a master drive signal. For example, it has been proposed to provide a low frequency oscillator or pulse generator operating at the desired timekeeping rate for a direct drive of the time display through an electromechanical energy converter. However, difficulties have been encountered in implementing this construction, including the difficulty in providing a low frequency oscillator having sufficient stability and realistic size and power dissipation for use in a wristwatch.

In order to overcome these and other difficulties, it has been proposed to use a high frequency oscillator as the frequency standard in conjunction with a quartz crystal for maintaining frequency stability and a divider for dividing down the frequency of the crystal controlled oscillator to produce an output at a suitable timekeeping rate. A structure of this type is disclosed, for example, in assignee's copending application, Ser. No. 568, filed Jan. 5, 1970.

The present invention is directed to a crystal controlled watch of the same general type as disclosed in the above-mentioned copending application, which is incorporated herein by reference, and more particularly to a transducer for converting the low frequency output pulses from the divider and transducer driver into mechanical motion suitable for driving the watch hands through a conventional watch gear train. In the present invention, the transducer takes the form of an electrical coil mounted on a balance staff and adapted to oscillate in a magnetic field established by a pair of permanent magnets mounted on opposite sides of the coil. Important features of the invention include the fact that the resonator structure, including the oscillating coil and its supporting components, are made relatively lightweight and low inertia to oscillate at a relatively high frequency, such as 16 or 32 Hz., and to provide quick response to impulses and minimum response to shock effects. Since the driving coil is always in the magnetic field established by the permanent magnets, it remains at all times responsive to impulses from the electrical control signals, even at times when it may get out of phase with the signals due to environmental shocks and accelerations. An additional important feature of the novel transducer of this invention includes the provision of an eccentric drive for converting the oscillating motion of the balance staff and coil resonator assembly into a unidirectional rotary motion suitable for driving conventional watch hands through a conventional gear train. The eccentric drive provides a sinusoidal acceleration to an index lever and an index wheel, thus

minimizing inertial effects and associated energy losses. The index lever is kept in engagement with the index wheel through magnetic attraction and the low mass of the index lever and the small eccentric diameter of the eccentric drive further contribute to the reduction in energy losses of the transducer system.

It is therefore one object of the present invention to provide an improved transducer for converting electrical impulses into unidirectional stepwise rotary motion.

Another object of the present invention is to provide an electromechanical transducer particularly adapted for use as the transducer element in a crystal controlled electric watch.

Another object of the present invention is to provide an electromechanical transducer in the form of a coil resonator which oscillates at an increased natural frequency.

Another object of the present invention is to provide an improved eccentric drive for coupling the oscillator of an electromechanical transducer to a watch drive train.

Another object of the present invention is to provide an improved electronic timepiece.

Another object of the present invention is to provide a crystal controlled watch having an improved electromechanical transducer for converting electrical time pulses into rotary motion for driving the hands of the watch.

Another object of the present invention is to provide an oscillating-coil-type electromechanical transducer in which the coil is at all times in the magnetic field of a permanent magnet.

These and further objects and advantages of the invention will be more apparent upon reference to the following specification, claims, and appended drawings, wherein:

FIG. 1 is a simplified overall block diagram of a crystal controlled wristwatch constructed in accordance with the present invention;

FIG. 2 is a partially schematic diagram of the novel transducer of the present invention forming a portion of the watch of FIG. 1;

FIG. 3 is a view taken at right angles to that of FIG. 2;

FIG. 4 is a more detailed view of the coil and balance staff assembly forming a part of the transducer of the present invention;

FIG. 5 is a view of the coil and balance staff assembly taken at right angles to the view in FIG. 4;

FIG. 6 is a plan view of the regulator hairspring for the oscillating coil of FIGS. 4 and 5;

FIG. 7 is a plan view of the other hairspring illustrated in FIGS. 4 and 5;

FIGS. 8, 9, and 10 are front, side, and end views, respectively, of the core and bobbin on which the transducer coil is wound;

FIG. 11 is a schematic diagram showing the magnetic circuit for the permanent magnets establishing the field in which the transducer coil oscillates;

FIGS. 12 and 13 are plan and side views, respectively, of the magnetic shunt forming a part of the magnetic circuit of FIG. 11;

FIG. 14 shows the eccentric drive arrangement for coupling the oscillating balance staff of the transducer to the index wheel of a watch train;

FIG. 15 is a plan view of the index wheel shown in FIG. 14;

FIG. 16 is a partial cross section through the index wheel showing the shape of the ratchet teeth formed on the wheel;

FIGS. 17 and 18 are plan and side views, respectively, of the index lever coupling the balance staff to the index wheel;

FIG. 19 is a view of the eccentric drive assembly taken at right angles to that of FIG. 14 showing the holding pawl for indexing the index wheel;

FIGS. 20 and 21 are plan and side views, respectively, of the pawl spring;

FIG. 22 is a plan view of the pawl bridge assembly; and

FIG. 23 is a cross section through the pawl bridge assembly taken along line 23—23 of FIG. 22.

Referring to the drawings, FIG. 1 is a simplified block diagram of an electronic watch construction generally indicated at 10. The watch comprises a frequency standard 12, preferably in the form of a crystal controlled oscillator or free-running multivibrator which produces output pulses at a frequency in the neighborhood of at least about 5 kHz., having the stability of the controlling crystal. The output from oscillator 12 is applied by way of lead 14 to a multistage frequency divider 16 where the frequency of the electrical signal is reduced to a value usable for driving the hands of a watch. For example, the output of frequency divider 16 appearing on lead 18 may have a frequency of 16 or 32 Hz. This output is applied to a driver 20 which acts as a pulse shaper to shape the pulses and apply them to a transducer 22. The transducer converts the electrical pulses into physical motion to actuate a watch display 24 which may typically be the watch hands rotating about the dial of a conventional watch face. It is understood that the connection from transducer 22 to display 24 is by way of a conventional watch gear train. Oscillator 12 and frequency divider 16 are also preferably made from integrated circuit components utilizing complementary MOSFET transistors as disclosed in assignee's copending application, Ser. No. 768,076, filed Oct. 6, 1968, and incorporated herein by reference.

The present invention is directed to a new and improved transducer 22 which takes the form generally illustrated in FIGS. 2 and 3. The transducer comprises a pair of permanent magnets 26 and 28 positioned on opposite sides of an electrical coil 30. Coil 30 is formed of many turns of wire, as illustrated in FIG. 3, and is mounted on a core 32 connected to a balance staff at its upper and lower ends and consisting of upper section 34 and lower balance staff section 36. The ends of the balance staff are received in bearings 38 and 40 so that the coil, core and balance staff are all mounted for oscillating movement in the magnetic field formed by permanent magnets 26 and 28. Attached to upper section 34 of the balance staff is the inner end of a regulating hairspring 42 having its outer end secured to a fixed portion of the watch, as indicated at 44. A lower hairspring 46 similarly has its inner end connected to the lower section 36 of the balance staff and its outer end 48 secured to a fixed portion of the watch. The upper end of coil 30 is connected to ground, as at 50, through section 34 to hairspring 42 and the lower end of the coil 30 is similarly electrically connected to driver circuit 20, as at 52, through lower section 36 to hairspring 46 and stud 48. Hairsprings 42 and 46 are electrically connected to opposite sides of a suitable power supply, such as a battery located in the watch case, through drive circuit 20 which controls electrical current flow from one side of the battery to the other through the coil by way of the hairsprings and the balance staff sections.

Power takeoff from the oscillating coil is by way of an eccentric, generally indicated at 54, mounted on the lower section 36 of the balance staff and by way of an index lever 56 to an index wheel 58, in turn connected through a conventional watch train to the watch hands. Index wheel 58 is provided with ratchet-shaped teeth 60 which are engaged by index jewel 62 on the outer end of lever 56 so that index wheel 58 rotates in accordance with the oscillating movement of the coil and balance staff.

FIGS. 4 and 5 are a more detailed showing of the coil and core assembly of FIGS. 2 and 3. The hairsprings are shown in FIGS. 6 and 7. In FIGS. 4 and 5, the upper balance staff section 34 takes the form of a bobbin endpiece having a hollow center, as indicated at 64 in FIG. 5, receiving a stub bearing 66 with a reduced end 68 adapted to be received in the bearing or end shake bearing 38 of FIG. 2. Hairspring 42 is connected at its inner end 69 to a collar 70 mounted for rotation with endpiece 34. The other end of the balance staff 36 similarly takes the form in FIGS. 4 and 5 of a bobbin endpiece having a central opening 72 receiving one end of eccentric bearing 74 having a reduced outer end 76 for reception in the bearing jewel or end shake bearing 40 of FIG. 2. Eccentric bearing 74 is pro-

vided with a reduced diameter section 78 offset from the centerline of the bearing to form an eccentric drive as more fully described below. Finally, the inner end of hairspring 46 is connected as at 80 to a collar 82 carried for rotation with endpiece 36.

In one embodiment constructed in accordance with the present invention, and adapted to operate at a natural frequency of 16 Hz., coil 30 was formed of 4,200 turns of No. 57 polyurethane insulated wire having a resistance of approximately 50 ohms per foot to give a total resistance of approximately 10,000 ohms for the coil. The core 32 was made of ceramic material and the bearings 66 and 74 were made of silicone-treated steel. End caps or endpieces 34 and 36 were made of gold-plated and age-hardened beryllium copper and the ends of the coil, as indicated by the end 84 in FIG. 4, were passed through a suitable aperture 86 in endpiece 34 and electrically connected to the endpiece by "Eccobond" conductive adhesive or welding the coil wire lead securely in the hole. It is understood that the other end of the coil, as indicated by dashed lines at 86, is similarly bonded and electrically connected to endpiece 36.

The resonator assembly illustrated in FIGS. 4 and 5 is part of mass/spring/mass or more correctly an inertia/spring/inertia system in which the large mass and inertia is considered to be the total of all stationary movement parts and relatively infinite compared with the mass and inertia of the moving coil assembly. Thus, the combined strength of both the hairsprings 42 and 46 is related to the coil assembly inertia and its natural frequency by the equation:

$$G=4\pi^2 f I$$

where G is the spring constant in dyne cm. per radian; I is coil inertia in gram cm.²; and f is frequency in Hz. In the embodiment illustrated, the spring strength is divided in the ratio of 6 to 1 with the spring 42 having six times the strength of spring 46. The stronger spring, i.e., spring 42, is provided with an outer turn 88 which passes through a conventional regulator, indicated at 90. With the regulator controlling the stronger spring, the arc of regulation by the regulator pins is more effective in bringing the system into resonance with the accurate quartz crystal controlled pulse at a frequency f of 16 Hz. Embodiments operating at a frequency of 32 Hz., have also been constructed with the spring strengths modified accordingly. Any other division of spring strength may be made as long as it is chosen to agree with the accuracy of the regulation required. Springs 42 and 46 are preferably made of a suitable temperature resistant material, such as that sold under the trade name Stavar, with spring 42 having nine full turns to the neutral position of the regulator pins. The hairsprings are made of flat wire with the spring 42 having a width of approximately 0.005 inch and a thickness of approximately 0.00095 inch. The spring had a total length of $9\frac{1}{4}$ turns. In this case, spring 46, also made of Stavar, had a total length of $10\frac{1}{4}$ turns and was made of flat wire having a width of approximately 0.003 inch and a thickness of approximately 0.00065 inch. Spring 42 is of three laminate construction and spring 46 of four laminate construction to provide suitable breathing clearance.

FIGS. 8-10 show the construction of the core 32, which, as previously stated, is made of ceramic and is of three-piece construction comprising a flat rectangular plate 92 over the ends of which are received the bobbin caps 94 and 96. The caps are suitably slotted to receive the ends of plate 92 and are cut away, as at 98 and 100, to receive the turns of coil 30.

FIG. 11 shows the magnets 26 and 28 and illustrates in dashed lines a shunt 102 forming a complete magnetic circuit for the transducer. The magnets are of rectangular cross section having a height of 0.215 inch, a width (perpendicular to the plane of the paper) of 0.100 inch, and a depth of 0.080 inch. The magnets are spaced 0.100 inch apart to define a magnetic field indicated by the force lines 104 having a strength of from 2,500 to 3,000 gauss. The magnets are preferably formed from cobalt platinum or samarium cobalt in which the minimum requirements are $H_c > 4,000$ oersteds,

$B_H > 6,000$ gauss, and $B_H \mu_0 > 9 \times 10^6$ gauss oersteds. The return path for the magnetic flux is through the shunt 102.

Shunt 102 is preferably formed of soft iron and is shown in detail in FIGS. 12 and 13. The shunt comprises a back plate 104 joined to an integral rectangular flange forming sides 106 and 108 and ends 110 and 112. Ends 110 and 112 are slotted as at 114 and 116 to permit passage of endpieces 34 and 36 of FIGS. 4 and 5. Magnets 26 and 28 of FIG. 11 are inserted into the open side of the shunt and are mounted on the flat inner surfaces 118 and 120 of sides 106 and 108, respectively. A pair of countersunk apertures 122 and 124 pass through the shunt flange so that it may be mounted in the watch by suitable bolts. The purpose of the shunt is to increase the field intensity and reduce stray fields in the hairspring areas.

FIG. 14 shows the eccentric drive for converting the oscillating motion of the coil and balance staff into unidirectional stepwise rotary motion for driving the watch hands. In FIG. 14, the index lever 56 has its upper end 126 pivotally connected to the eccentric 78 of FIGS. 4 and 5. Jewel 62 on the other end 128 of the lever engages ratchet teeth 60 on the index wheel 58. Index wheel 58 is mounted on one end of an index pinion 130 supported for rotation at each end in jewel bearings 132 and 134. Index pinion 130 engages with and drives the teeth of the sixth wheel of the watch, a portion of which is indicated at 136, it being understood that this wheel drives the remainder of a conventional gear train to rotate the hands of the watch over a conventional watch dial. The index wheel 58 is shown in detail in FIGS. 15 and 16 and is provided with a central aperture 138 to permit passage of the bearing support for the index pinion 130 and with 48 annularly spaced teeth 60 extending completely around the periphery of the wheel and having the shape illustrated in FIG. 16. The teeth preferably have a depth from tip to root of approximately 0.0016 inch, a slanting face 140 forming an angle of approximately 64° with a plane perpendicular to the rotary plane of the wheel, and a more steep face 142 forming an angle of approximately 15° with the perpendicular plane. The index wheel is preferably formed of carbon steel having a minimum hardness of Rockwell C-50. The overall diameter of the index wheel from its rotational axis to the inside edge of the teeth is approximately 0.0545 inch and the overall outside diameter is approximately 0.0635 inch. The overall thickness of the index wheel is approximately 0.0067 inch.

FIGS. 17 and 18 show the details of the index lever 56. The index lever is formed from a flat plate of full hard beryllium copper gold plated with a gold layer of approximately 0.000050 inch to give an overall thickness to the index lever of approximately 0.0015 inch. The lever is provided with a 0.0075 inch diameter aperture 144 adapted to receive for pivotal movement the eccentric 78. A second aperture 146 is also provided through the index lever as indicated and the index lever is slit from its tail 148 along solid line 150 in FIG. 17 through to aperture 146 so that it may be readily slipped over and secured to the balance staff eccentric. Secured by Scotch weld or the like to the forward end of the index lever is a flat rectangular permanent magnet 152 and overlying and similarly secured to this magnet is the flat rectangular indexing jewel 62 adapted to engage the teeth 60 of the index wheel. The index jewel is preferably made of ruby material and is preferably formed of flat rectangular construction having an overall length of 0.015 inch, a width of 0.012 inch, and a thickness of 0.002 inch. The leading edge of the jewel 62 is preferably tapered and angled approximately 12° so that its lower end in FIG. 17 projects outwardly slightly beyond its upper end. Magnet 152 is preferably constructed of cobalt-platinum and is a flat rectangular plate having a length of 0.012 inch, a width of 0.010 inch, and a thickness of 0.004 inch. The magnet is polarized in FIG. 17 so that its upper surface forms a north pole and its lower surface in FIG. 17 forms a south pole such that the lines of magnetic force extend vertically and parallel with the plane of the paper in FIG. 17. This polarity is such as to cause the magnet to be attracted to the index wheel so that the jewel 62 at all times rides on the index wheel teeth.

FIG. 19 is a view of the index wheel taken at right angles to that of FIG. 14 showing the holding pawl 154 which indexes wheel 58. This pawl is in the form of a leafspring which engages the teeth 60 on index wheel 58 to hold the wheel between impulses from the indexing lever 56. The pawl is supported from a post 156 mounted in a pawl bridge 158.

Holding pawl 154 is shown in detail in FIGS. 20 and 21 and is made of a flat sheet of resilient metal of a thickness of approximately 0.0010 inch. The pawl is offset at one end 160 in FIG. 21 and secured to this offset is a pawl jewel 162 adapted to engage the teeth 60 of the index wheel to hold the wheel between impulses from the indexing lever. Pawl 154 is originally made from a flat sheet of material, annular as at one end 164 having the central aperture 166 and with an elongated narrow arm 168 terminating in offset 160. Arm 168 is bent down as at 170 in FIG. 21 to form an angle of approximately 30° with the horizontal.

FIGS. 22 and 23 show the pawl bridge assembly used to support the holding pawl 154. As illustrated in those Figures, the aperture 166 in FIG. 20 is frictionally received over the body of post 156, in turn friction fit in a suitable aperture 172 in pawl bridge 158. Bridge 158 is itself provided with an annular extension 174 having a central aperture 176 surrounding the bushing of jewel 134 for the index wheel 58 as best seen in FIG. 19. Bridge 158 is provided with an elongated oval-shaped slot 178 through which a screw may pass to attach the pawl bridge to the stationary structure of the watch. The oval slot leaves sufficient clearance so that the entire bridge 158 may be rotated by an eccentric stud passing through slot 179 about the axis of rotation 180 of the index wheel to zero the indexing stroke of an index lever 56.

It is apparent from the above that the present invention provides an improved transducer particularly suited for converting the pulses from the crystallized controlled oscillator of a watch into rotary motion suitable for driving watch hands. While described in conjunction with a wristwatch, it is understood that the transducer of the present invention may be used in all types of timepieces and other timekeeping apparatus where small size and low power dissipation are required. The construction is of extremely lightweight and low inertia so as to provide quick response to impulses and minimize shock effects. In the preferred embodiment specifically described, the mass of the overall resonator structure is less than 120 mg. with an inertia of less than 10^{-3} g. cm². The oscillating drive coil is always wholly within the magnetic field so that it is responsive at all times to impulses from the electrical control signals, even at such times as when it may get slightly out of phase with the control signals due to environmental shocks and accelerations. The watch incorporates as a power unit a 3.1 v. battery so that there is sufficient generated voltage relative to the power supply in the electromagnetic transducer to achieve good electromechanical efficiency, i.e., 1.5 to 2.2 volts back e.m.f. at 16 Hz. as compared with the 3.1 volt supply. High strength magnets are used with a relatively small gap to resist influence from external magnetic fields and the field between the magnets is greater than 2,500 gauss. The resonator uses temperature compensated springs to keep the unit properly tuned for best response in the usual environmental temperatures.

Also incorporated in the device is an eccentric drive which provides a sinusoidal acceleration to the index lever and index wheel which minimizes inertial effects and associated energy losses. The index lever has a minimal mass, i.e., 0.38×10^{-3} g., and inertia also contributing to low energy loss. A very small eccentric diameter is used to reduce energy loss by reducing the torque arm. The eccentric drive provides increased reliability in indexing and avoids double indexing. Many indexing systems heretofore proposed associated with resonant transducers, such as tuning forks and cantilevers, are susceptible to double indexing due to large amplitudes induced by shocks. Eccentric 78 preferably has a diameter of approximately 0.0070 inch and has its center offset from the center of rotation of the balance staff by a distance of approximately 0.0025 inch. Since the index lever is gold plated, the eccentric bearing

uses gold as the solid lubricant. The low forces encountered allow the gold to be transferred back and forth between the eccentric crank and the index lever with no wear evidenced. Because of these features, the indexing system can be run at relatively high frequency with low power loss—less than 1 microwatt at 16 Hz.

The unique low inertia right-angle drive is used to convert the harmonic motion of the index lever and resonator into discrete indexing of the time train. The lever is kept in engagement with the index wheel through magnetic attraction of the permanent magnet 152. This insures dependable operation and the added friction loss from drag on the back stroke is minimal. The centering device provided by the pawl bridge assembly makes it possible to zero the indexing stroke on both sides of the rest position by pivoting the pawl bridge about the index pivot axis. This permits the resonator to remain isochronous, even when heavily loaded near the stall torque.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. An electromechanical transducer for converting electrical impulses into mechanical motion comprising a coil mounted for oscillating movement, means coupled to said coil for establishing electrical connection to it, means adjacent said coil for establishing a magnetic field in which said coil is located in all positions during a cycle of oscillation, an index wheel, and means mechanically coupling said coil to said index wheel.

2. A transducer according to claim 1 wherein said magnetic field means comprises permanent magnets positioned on opposite sides of said coil.

3. A transducer according to claim 2 including a magnetic shunt surrounding said coil on three sides, said shunt being connected to said magnets on their sides remote from said coil.

4. A transducer according to claim 1 wherein said electrical connection means comprises a balance staff connected to said coil, and a pair of hairsprings connected to opposite ends of said balance staff.

5. A transducer according to claim 4 wherein said hairsprings are of unequal strength.

6. A transducer according to claim 5 including a regulator coupled to the stronger of said hairsprings.

7. A transducer according to claim 1 wherein said mechanical coupling means comprises an index lever pivoted to said eccentric.

8. A transducer according to claim 7 wherein said index lever is provided with a jewel for engaging said index wheel.

9. A transducer according to claim 7 wherein said index lever carries a permanent magnet for maintaining it in contact with said index wheel.

10. An electromechanical transducer for a timepiece comprising a coil, means mounting said coil for oscillations about an axis parallel to the planes of the coil turns, a permanent magnet on each side of said coil and establishing a permanent magnetic field in which said coil is wholly contained in all of its positions, a pair of hairsprings mechanically coupled to said coil to sustain its oscillations, means establishing electrical connection to the opposite ends of said coils through said hairsprings, and means coupled to said coil for deriving a unidirectional mechanical motion from its oscillations.

11. A transducer according to claim 10 in which the inertia of said coil and mounting means and the strength of said hairsprings are proportioned to provide a natural frequency for said transducer of at least 16 Hz.

12. A transducer according to claim 11 in which the natural

frequency of said transducer is 16 Hz.

13. A transducer according to claim 11 in which the natural frequency of said transducer is about 32 Hz.

14. An electromechanical transducer for a wristwatch comprising a pair of electrical input terminals, a coil, a balance staff having first and second sections connected to respective ends of said coil, said balance staff being pivotally mounted for oscillating movement with said coil, the turns of said coil lying in planes parallel to the oscillation axis of said balance staff, a permanent magnet on each side of said coil and establishing a permanent magnetic field in which said coil is wholly contained in all of its positions, a first hairspring connected to the first section of said balance staff and electrically coupling one of said input terminals to one end of said coil, a second hairspring connected to the second section of said balance staff and electrically coupling the other of said input terminals to the other end of said coil, an index wheel, an eccentric on one of said balance staff sections, and an index lever pivoted to said eccentric for unidirectionally driving said index wheel in response to the oscillations of said balance staff.

15. A transducer according to claim 14 wherein said first hairspring is stronger than said second hairspring.

16. A transducer according to claim 15 including a rate regulator coupled to said first hairspring.

17. A transducer according to claim 16 wherein the inertia of said coil, balance staff and index lever and the strength of said hairsprings are proportioned to provide a natural frequency for said transducer of about 16 Hz., said first hairspring being about six times stronger than said second hairspring.

18. A transducer according to claim 16 wherein said eccentric is on said second section of said balance staff.

19. A transducer according to claim 14 wherein the mass of the oscillating parts of said transducer including said coil, balance staff and index lever is less than 120 milligrams.

20. A transducer according to claim 14 wherein the inertia of the oscillating parts of said transducer including said coil, balance staff and index lever is less than 10^{-3} gram centimeters squared.

21. A transducer according to claim 14 wherein said index lever is gold plated to reduce wear.

22. A transducer according to claim 14 including an index pawl engaging said index wheel, and means for adjusting the position of said pawl about the rotational axis of said index wheel.

23. A transducer according to claim 22 including an index bridge supporting said pawl, said index bridge having a portion pivotal about the rotational axis of said index wheel.

24. An electric wristwatch comprising a crystal controlled oscillator for producing a series of timing impulses, a divider coupled to the output of said oscillator for dividing down the frequency of the timing pulses, a transducer coupled to the output of said divider, said transducer including a coil mounted for oscillations about an axis parallel to the planes of its turns, a pair of permanent magnets adjacent said coil and establishing a permanent magnetic field in which said coil is wholly contained in all positions, a gear train including an index wheel, an eccentric carried for oscillation with said coil, a lever pivoted to said eccentric and engaging said index wheel to drive said index wheel with the oscillations of said coil, and a display including a pair of watch hands driven by said index wheel.

25. A watch according to claim 24 in which the natural frequency of oscillation of said coil is at least approximately equal to the frequency of the timing impulses from said divider.

26. A watch according to claim 25 in which the divider output is at a frequency of about 16 Hz.

27. A watch according to claim 25 in which the divider output is at a frequency of about 32 Hz.

28. A watch according to claim 25 including a pulse shaper and driver coupling said divider to said coil.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,641,761 Dated February 15, 1972

Inventor(s) James H. Reese

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 2, line 71, "an" should read --and--.

In Column 6, line 64, " $0.38 + 10^{-3}$ g.," should read
-- 0.38×10^{-3} g.,--.

Signed and sealed this 1st day of August 1972.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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