Nov. 30, 1965 W. O. BENNETT ETAL 3,221,190

TRANSDUCER FOR ELECTRONICALLY-CONTROLLED TIMEPIECE

Original Filed Jan. 19, 1961

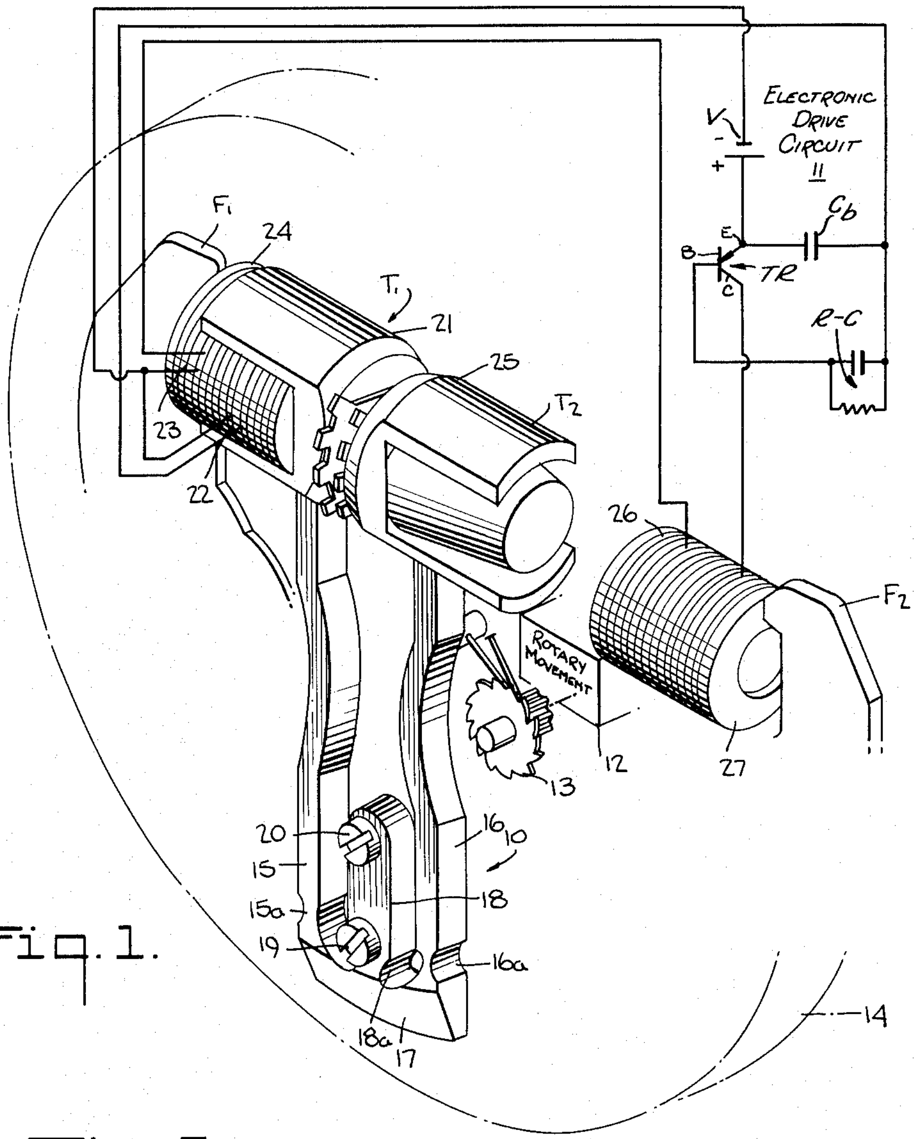


Fig. 1.

Fig. 2.

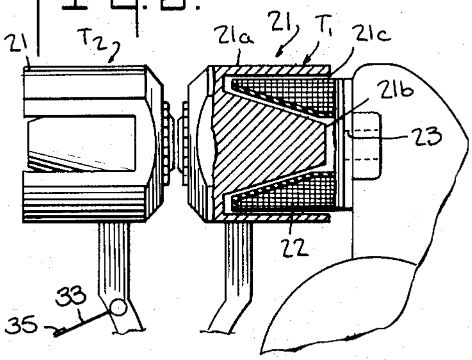
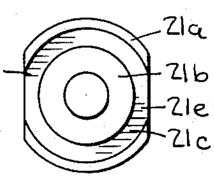


Fig. 3.



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United States Patent Office

3,221,190

Patented Nov. 30, 1965

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TRANSDUCER FOR ELECTRONICALLY-CONTROLLED TIMEPIECE

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Original application Jan. 19, 1961, Ser. No. 89,896. Divided and this application Aug. 19, 1963, Ser. No. 302,954

4 Claims. (Cl. 310—25)

This invention relates generally to electronically-controlled timepieces which incorporate electromagnetically-actuated tuning forks, and more particularly to improved transducer structures therefor. This application is a division of our copending application Serial No. 89,896, filed January 19, 1961, now abandoned.

In ordinary electric watches, make-and-break contacts are mechanically operated by the swinging of the balance wheel. Each time these contacts close, battery current flows in a coil or coils to electro-magnetically impulse the balance wheel. This mechanically operated make-and-break contact system is subject to wear and also to deterioration and contamination of the delicate contact points which must open and close an electric circuit without fail 216,000 times a day. The slightest sparking will cause rapid deterioration of these contacts and early failure of the watch.

The present invention does away with a balance wheel and escapement as well as make-and-break contacts and makes use of a timekeeping tuning fork which is pulsed electromagnetically by means of a transistor circuit. It constitutes an improvement over timepieces of the type disclosed in the copending applications Serial No. 665,480, filed June 13, 1957, entitled "Electronically-Controlled Timepiece," issued February 14, 1961, as Patent No. 2,971,323, and in Serial No. 584,709, filed May 14, 1956, entitled "Electrical Timepiece," issued November 22, 1960, as Patent No. 2,960,817.

In said copending applications there are disclosed novel timepieces including a self-sufficient timekeeping standard formed by a tuning fork having a predetermined natural frequency and a battery-energized transistorized drive circuit to sustain the vibratory motion of the fork. This motion is transferred to a rotary movement including the usual gear train and dial pointers by means of a pawl attached to one tine of the fork, the pawl advancing a ratchet wheel which drives the gear train.

When the timepiece is to be confined within a watch casing or in a small chamber of similar dimensions, it is vitally important that the electrical and mechanical efficiency of the system be of an exceptionally high order. Otherwise, any loss of energy which in a larger scale device may be negligible, can give rise to serious drawbacks in the more compact structure.

It must be borne in mind that the sole source of energy for the timepiece is a single miniature battery cell. Thus any factor which dissipates energy or reduces efficiency not only cuts down the useful battery life but also creates operating difficulties. Also of importance is that maximum use be made of all available space and that the transducers which actuate the fork operate at optimum efficiency.

The main object of this invention is to provide a magnetic transducer of exceptional efficiency for actuating a tuning fork in an electronic watch of the above-described type. The construction of the magnetic element and of the coils constituting the transducer are such as to realize an optimum relationship between flux denstiy and the number of coil turns.

For a better understanding of the invention as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawings wherein like components in the several figures are identified by like reference numerals.

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In the drawings:

FIG. 1 is a schematic representation, in perspective, of the basic components of an electronic timepiece in accordance with the invention.

FIG. 2 is a separate view of the tuning fork structure showing the transducer partly in section.

FIG. 3 is a side view of the transducer.

Referring now to the drawings and more particularly to FIG. 1, the major components of a timepiece in accordance with the invention are a timekeeping standard constituted by a tuning fork **10** and an electronic drive circuit **11** therefor, a rotary movement of conventional design including a gear train **12** for turning the hands of the timepiece, and a motion transformer including an index wheel **13** operatively intercoupling the fork **10** and the rotary movement **12** and acting to convert the vibratory action of the fork into rotary motion. The tuning fork has no pivots or bearings and its timekeeping action is therefore independent of the effects of friction.

All of the electrical components of the drive circuit are mounted on the unitized sub-assembly units or modules F_1 and F_2 attached to a disc-shaped metallic pillar plate **14** which may be supported within a watch casing of standard design or within any other type of housing, depending on the use to which the timepiece is put. Electronic circuit **11** is constituted by a transistor TR having a base B, a collector C, and an emitter E, a resistance-capacitance biasing network R-C, and a by-pass capacitor C_b to prevent parasitic oscillations of the circuit. The electronic circuit **11** is energized by a voltage source in the form of a battery V.

Tuning fork **10** is provided with a pair of flexible tines **15** and **16** interconnected by a relatively inflexible base **17**, the base being provided with an upwardly extending stem **18** secured to the pillar plate by suitable screws **19** and **20**. The central area of the pillar plate is cut out to permit unobstructed vibration of the tines.

The tuning fork is actuated by means of a first transducer T_1 constituted by a magnetic element **21** secured to the free end of tine **15**, the element coacting with a drive coil **22**, and a phase sensing coil **23**. Drive coil **22** is wound on an open ended tubular carrier **24** affixed to a sub-assembly mounting form F_1 which is secured to pillar plate **14**. Coils **22** and **23** may be wound in juxtaposed relation on carrier **24** or the phase sensing coil **23** may be wound over drive coil **22**.

A second transducer T_2 is provided constituted by a magnetic element **25** secured to the free end of tine **16** and coacting with a drive coil **26** wound on a tubular carrier **27**.

In a practical embodiment the two transducer coil structures are 0.15 inch long and 0.18 inch in diameter. Drive coil **26** of transducer T_2 has about 8000 turns of .0006 each wire, whereas in transducer T_1 drive coil **22** has about 6000 turns and phase sensing coil about 2000 turns of the same wire. Thus the two transducers bear the same number of turns.

The two transducers T_1 and T_2 are of like design except that an additional coil is provided in transducer T_1. The construction and behavior of the transducers are similar to that of a dynamic speaker of the permanent magnet type save that the moving element is the magnet and not the coil.

As shown for transducer T_1 in FIGS. 2 and 3, the magnetic element **21** is constituted by a cylindrical cup **21***a* of magnetic material, such as iron, and a permanent magnet rod **21***b* coaxially mounted therein. The magnet **21***b*, which may be made for example of Alnico, is supported on the end wall of the cup to provide a magnetic circuit in which the lines of magnetic flux extend across the annular air gap **21***c* defined by the inner magnet and the surrounding cylinder. The magnet **21***b* is tapered to assume a frustoconical shape, whereby the cross-sectional area of the air gap at the mouth of the cup is relatively large.

As best seen in FIG. 3, cylindrical cup **21***a* is cut out longitudinally along diametrically opposed planes to form slots **21***d* and **21***e*. This effects a substantial reduction in the transducer dimension with relatively little flux leakage. The cutouts act to reduce the space occupied by the cups in depth within the casing and make possible a more compact construction of the timepiece. The slots also prevent so-called "dash pot" effects resulting from air compression of the magnet and cup assembly. Such damping is avoided by the slot openings and also by the openings in the tubular carrier.

It will be seen that fixed carrier **23** for supporting the drive coil **22** is horn shaped and is dimensioned to complement the tapered magnet **21***b*. The carrier **23** and the drive coil supported thereon are received within the annular gap **21***c* and are spaced both from the magnet and the surrounding cylinder, whereby the magnetic element is free to reciprocate axially relative to the fixed coil.

It will also be noted that the coil **22** wound about carrier **23** is tapered in cross-section so that the greatest number of turns is concentrated at the mouth of the air gap **21***c*, the least number of turns being located well within the interior of the magnetic element. Since the magnetomotive force produced by the transducer at the fixed frequency and amplitude is the product of coil turns multiplied by flux density, optimum results are obtained by the structure shown herein, where the greatest number of turns is found at the point of maximum flux density.

In operation, an energizing pulse applied to the drive coils of the transducer will cause an axial thrust on the associated magnetic element in a direction determined by the polarity of the pulse in relation to the polarization of the permanent magnet and to an extent depending on the energy of the pulse. Since the magnetic element is attached to a tine of the tuning fork, the thrust on the element acts mechanically to excite the fork into vibration.

The vibratory action of the fork and the concomitant movement of the magnetic element induces a back E.M.F. in the drive coil, and in the case of the transducer T_1, in the phase-sensing coil as well. Since the magnetic element reciprocates in accordance with the vibratory action of the tuning fork, the back E.M.F. will take the form of an alternating voltage whose frequency corresponds to that of the fork.

Three functions are served by the transducers. They drive the tuning fork by converting pulses of current delivered to the coils to mechanical pulses. The control the amplitude of the tuning fork by sensing the alternating voltage induced during each cycle, and they control the instant during the cycle when the driving pulse is to be delivered to the coils.

While there has been shown a preferred embodiment of the invention, it will be manifest that many changes may be made therein without departing from the essential features of the invention as defined in the annexed claims.

What is claimed is:

1. A transducer comprising a magnetic element formed by a cylinder having a magnetic rod supported coaxially therein to define an air gap, and a multi-turn cylindrical coil received within the annular space between said rod and cylinder, said rod being tapered and said coil being similarly tapered to produce the greatest number of turns within said air gap at the position of maximum flux density, said magnet element being movable relative to said coil.

2. An electromagnetically-actuated vibrator comprising a tuning fork having a pair of tines, and means for actuating said fork including a transducer constituted by a magnetic element attached to one of said tines and formed by a cylinder having a magnetic rod supported coaxially therein to define an air gap, a fixedly supported multi-turn cylindrical coil received within the annular space between said and cylinder, said rod being tapered and said coil being similarly tapered to locate the greatest number of turns within said air gap at the position of maximum flux density.

3. An electromagnetically-actuated vibrator comprising a tuning fork having a pair of tines, and means for actuating said fork including a transducer constituted by a magnetic element attached to one of said tines and formed by a cylindrical cup having a magnetic rod supported coaxially therein to define an air gap at the mouth of said cup, a fixedly-supported multi-turn cylindrical coil received within the annular space between said rod and cylinder, said element vibrating axially relative to said coil, said rod being tapered and said coil being similarly tapered to produce the greatest number of turns within said air gap at the position of maximum flux density.

4. A vibrator as set forth in claim **3**, wherein said coil is wound about a tapered carrier which is telescoped within said annular space.

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