1,186,065

PATENT SPECIFICATION

DRAWINGS ATTACHED

1,186,065

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COMPLETE SPECIFICATION

Electromagnetically Actuated Mechanical Oscillators particularly for use in Electronic Timepieces

We BULOVA WATCH COMPANY, INC., a corporation organized under the laws of the State of New York, one of the United States of America, of 630 Fifth Avenue, City and State of New York, United States of America, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to electromagnetically actuated oscillating structures.

In British Patent Specification Nos. 854196, 955559 and 981014 there are disclosed electronic timepieces including a self-sufficient timekeeping standard constituted by a tuning fork whose vibrations are sustained by two electromagnetic transducers operating in conjunction with a battery-energized transistor circuit. The vibratory action of the fork is converted into rotary motion to turn the dial pointers of the timepiece.

In timepieces made in accordance with the above-listed patents, each electromagnetic element attached to the end of the of the fork, the transducer including a magnetic element attached to the end of hte associated tine and vibrating therewoth. The magnetic element on one tine moves back and forth with respect to a first drive coil section occupying a fixed position, and that on the other tine moves back and forth both with respect to a second drive coil and a sensing coil, these coils also being fixed. The first and second drive coil sections are connected in series to the output circuit of the transistor, the sensing coil being connected to the input thereof, whereby alternating voltage induced in the sensing coil renders the transistor conductive to produce current pulses in the drive coil sections for magnetically actuating the tines.

The physical arrangement of timepieces made in accordance with the above-listed patents is necessarily such that the transducer coils are supported on the framework of the timepiece on either side of the fork, the transistor as well as the resistor and capacitor circuit elements associated therewith also being mounted on the framework, connections being made between the coils and the circuit elements. In designing a highly compact electronic watch using the tuning-fork principle, the space requirements for an arrangement of this type impose distinct limitations on the degree of compaction which is attainable.

When a battery-operated timepiece is to be confined within a small watch casing or in a miniature chamber of similar dimensions where space is at a premium, it is essential that the electrical and mechanical efficiency of the system be of an exceptionally high order. Otherwise any loss of energy, which in a large-scale device may be negligible, can give rise to serious drawbacks in a more compact structure. It is vital, therefore, that the transducer or transducers which actuate the fork operate at optimum efficiency, for in this way, even with a battery of small capacity, it is possible to sustain the vibratory action of the fork for a prolonged period.

According to the present invention there is provided a unitized electromagnetically actuated oscillating structure comprising a mechanical oscillator having a pair of oscillating members which oscillate in phase opposition, a magnetic element secured to one of the members and oscillating therewith, the element having an air gap across which extend magnetic lines of flux, and an electronic circuit assembly secured to

[Price 5s. 0d.]

the other of said members, the assembly including a drive coil and a sensing coil, both of the coils being disposed in or extending into the air gap, the circuit being arranged to generate current pulses in the drive coil to create a magnetic force imparting a first or forward momentum to the magnetic element and a second or backward momentum to the electronic circuit assembly.

Further, the mechanical oscillator may be, for example, a tuning fork, and the magnetic element provided with a permanent magnet structure having an air gap across which extend magnetic lines of flux, and secured to the end of one tine of the fork, the coil and electronic circuit assembly being secured to the end of the other tine, which assembly includes a drive coil and a sensing coil, the coils being disposed within said air gap, the sensing coil being connected to generate the input and the drive coil being connected to receive the output of said electronic circuit, whereby pulses induced in the sensing coil cause the electronic circuit to feed current pulses, derived from a battery external to the unitized structure, to the drive coil to create a magnetic force imparting a forward momentum to said magnetic element and an equal backward momentum on said drive coil to cause simultaneous deflection of the tines.

In the form shown in the accompanying drawings, the electronic circuit comprises an NPN silicon transistor, together with a capacitor and resistor constituting biasing means to maintain the transistor normally in a quiescent or cut-off condition save for that period, once each tuning fork cycle, when the bias is overcome by the effect of the voltage induced in the sensing coil, thereby rendering the transistor conductive and delivering a pulse of current to the drive coil to sustain fork vibration. It is to be understood, however, that the particular circuit configuration is by way of example only and that other means of excitation can be employed in conjunction with the transducer.

In order that the invention may be more clearly understood and readily carried into effect, the same will now be described more fully and by way of example with refernece to the accompanying drawings, in which:

Fig. 1 is a perspective view of one embodiment of a unitized electromagnetically actuated oscillating structure including a tuning fork;

Fig. 2 shows an arrangement diagram of electrical components supported on one tine of the fork;

Fig. 3 is a schematic circuit diagram of the transistor circuit associated with the transducer coils;

Fig. 4 is an exploded view of the electromagnetic transducer elements and electronic control circuit assembly borne by the tines of the fork;

Fig. 5 is a longitudinal section taken through the electromagnetic transducer and electronic control circuit assembly;

Fig. 6 is a sectional view showing another form of electromagnetic transducer;

Fig. 7 schematically shows another electromagnetic transducer arrangement;

Fig. 8 illustrates schematically still another transducer arrangement; and

Fig. 9 schematically shows yet another transducer arrangement;

Referring now to the drawing, and more particularly to Figs. 1 to 5, there are shown components of an electronic timepiece employing a unitized electromagnetically actuated oscillating structure as a timekeeping standard. It is to be understood that while the invention is illustrated in the context of time-keeping, similar structures are usable as frequency standards in optical modulators, tuned filters, and in various other applications requiring high "Q" electromagnetically-actuated tuning forks. It is also to be understood that the invention is applicable to other forms of oscillating devices which are constituted by two vibratory members oscillating in phase opposition. Such devices may take the form of a torsional fork, a pair of torsional pendulums or a pair of vibrating reeds.

The tuning-fork in this form comprises a U-shaped tuning fork having a pair of flexible tines 10 and 11 and a stem 12 projecting from the base of the fork. The fork is mounted by attaching stem 12 to the framework or pillar plate of the timepiece. The vibratory action of the fork is converted into rotary motion by a mechanical motion transformer constituted by an index finger 13 secured to and extending from a post on tine 10, the jeweled tip of the finger engaging the ratchet teeth on an index wheel 14 such that with each forward stroke of the finger the wheel is advanced one increment. Retrograde motion of the wheel is prevented by a pawl 15, one end of which is secured to a post mounted on the pillar plate, the jeweled tip thereof engaging the teeth of index wheel 14.

The rotation of index wheel 14 is at a rate determined by the operating frequency of the fork and the ratio of this frequency to the number of teeth on the wheel, this motion being transmitted to a suitable gear train for turning the dial pointers of the timepiece. The tuning fork has no pivots or bearings, and its timekeeping action is therefore independent of the effects of friction. While a mechanical motion transformer is shown, it will be appreciated that the fork structure may be combined with magnetic escapements or other means to convert the regulated vibratory action thereof into other forms of motion or energy.

A single transducer is employed to sustain the tuning fork in vibration at its natural frequency, the transducer being constituted by a magnetic element secured to the end of tine 10, and generally designated by numeral 16, and a coil and transistor circuit assembly secured to the other tine 11, and generally designated by numeral 17.

Magnetic element 16 is constituted by a generally cylindrical cup 18 of magnetic material, such as iron, and a permanent magnet rod 19 coaxially mounted therein, which may be made of Alnico or similar material. Rod 19 is supported from the end wall of cup 18 to provide a magnetic circuit in which lines of magnetic flux extend across the annular air gap defined by the inner rod and outer cup.

Cup 18 is slotted longitudinally along diametrically opposed planes to form openings 18*a* and 18*b* which effect a substantial reduction in the dimensions of the transducer with relatively little flux leakage. These cut-outs also act to reduce the space occupied by the cup as well as to prevent so-called "dashpot effects" resulting from air compression of the magnet and rod structure. It will be seen that the end of tine 10 is attached to the side of cup 18 at the midpoint thereof, whereby the axis of rod 19 is normal to the axis of the tine.

The coil and circuit assembly 17 is supported on tine 11, this being accomplished by means of a mounting ring 20 having a rectangular cross section. Ring 20 is attached at an upright position to the end of tine 11, the center axis of the ring being aligned with the axis of rod 19, the outer diameter of the ring being substantially the same as that of cup 18 of the magnetic element. Telescopically received within ring 20 and projecting into the annular air gap in magnetic element 16, is a tubular carrier 21 formed of a suitable non-conducting material such as plastic.

Carrier 21 has a relatively long forward section 21*a* whose outer diameter is slightly less than the inner diameter of ring 20, and a short rear section 21*b* whose outer diameter corresponds to the outer diameter of the ring, thus forming a shoulder 21*c* which rests against the flat end of the ring. Screws 22 passing through bores in rear section 21*b* and entering threaded bores in ring 20, serve to secure the carrier to the ring. Alternatively, the carrier may be cemented or riveted to the ring.

Forward section 21*a* of the carrier is received concentrically within the annular air gap between rod 19 and cup 18 of the magnetic element, a circumferential groove being formed on the forward section to accommodate a drive coil 23 and a sensing coil 24 wound thereabout. In practice, sensing coil 24 may be superposed above drive coil 23 on the carrier, or they may be wound in side-by-side relation. A bifilar arrangement of sensing and drive coils may also be used. Thus, it will be appreciated that to mount these coils on the same time eliminates a multiplicity of flexing electrical leads which would otherwise be required.

Housed within the hollow rear section 21*b* of the carrier are the components of the electronic control circuit associated with the coils. The components which are illustrated in block form in Fig. 2 and in schematic form in Fig. 3, are a silicon transistor 25 of the NPN type having an emitter *E*, a collector *C* and a base *B*, a capacitor 26 and a resistor 27, all of the components being cylindrical in form. The components include pigtail leads, and these are used to support the components within the carrier, the leads being connected to terminal posts 28 projecting from the annular end of carrier 21. In practice these components and the connections therebetween may be in printed-circuit or micro-module form.

Power for the electronic circuit is supplied by means of a battery cell 29, preferably of the mercury type (i.e., 1.3 volts), yielding a constant voltage for almost the full duration of its useable life. Battery 29 is placed at a suitable location within the chamber or casing housing the tuning-fork structure, and in the circuit shown, is connected between one end of drive coil 23 and collector *C* of the transistor.

Thus two connections are called for to complete the battery circuit. However, since in practice the tuning fork is made of conductive material and is secured to the framework of the timepiece or pillar plate by means of stem 12, one connection may be made without the use of a separate conductor, by attaching the contact 30 for the positive pole of the battery to the framework.

Contact 31 for the negative pole of battery 29 must, however, be connected to drive coil 23 supported on tine 11, and since the coil vibrates therewith, it is essential that this connection not interfere with the vibratory action of the fork. To this end, the connection is made by a slender U-shaped lead 32 of spring metal, one end of this conductor being connected to contact 31 engaging the battery, and the other, to coil 23. Conductor 32 is preferably made of a temperature-compensating alloy whose properties are the same as the alloy used in fabricating the tuning fork.

The spring characteristics of resilient conductor 32 are made such that its elastic force is slight as compared to that of tuning-fork tine 11. This fact, coupled with the fact that the temperature coefficient of the conductor matches that of the fork, minimizes the adverse influence of the spring on the "Q" or efficiency of the fork. For practical purposes, this influence is negligible. Alternatively, a hair of highly flexible wire could be used in lieu of the spring lead.

The operating frequency of the fork is determined not by the fork *per se*, but by the combined mass of the tines and the elements mounted thereon. For highest operating efficiency, it is essential that symmetry exist as between the centers of gravity of the two oscillating masses with respect to the axis of symmetry of the fork. In practice, therefore, magnetic element 16 on tine 10 is made such that its mass and center of gravity substantially match that of the coil and circuit assembly 17 on tine 11. To effect small corrections in operating frequency, the expedients described in the above-identified specifications may be used.

In the electircal circuit shown in Figs. 2 and 3, it will be seen that drive coil 23 is connected at one end to emitter *E* of the transistor, and at the other end through battery 29 to collector *C*. Collector *C* is connected through resistor 27 to base *B* of the transistor, the base being connected through capacitor 26 and sensing coil to emitter *E*.

In operation, when transistor 25 is rendered momentarily conductive, a current pulse derived from battery 29 flows through drive coil 23, the resultant magnetic field producing an axial thrust on magnetic element 16, this action producing an equal and opposite reaction in the coil and circuit assembly 17. Since magnetic element 16 is mounted on tine 10 and assembly 17 on tine 11, the tines are deflected in opposing directions.

The movement of magnetic element 16 and coil circuit assembly 17 relative to each other induces a back EMF in drive coil 23 and in sensing coil 24. Since this reciprocation is in accordance with fork motion, the back EMF assumes the form of an alternating voltage whose frequency corresponds to fork frequency. The voltage induced in sensing coil 24 is applied to the base *B* of the transistor and overcomes a bias imposed thereon by resistor 27 and capacitor 26 to control the instant or phase position in the course of each cycle when the drive pulse is to be delivered to the drive coil.

The back EMF developed in the drive coil is in series opposition to the voltage applied by battery 29 between emitter *E* and collector *C* of the transistor. Battery voltage has a constant value, whereas the back EMF is a function of tine amplitude. The operation of the transistor during its conductive periods is controlled in accordance with the algebraic sum of the battery and back EMF voltage applied thereto, and the amplitude of fork vibration is thereby regulated. The behavior of this and similar circuits is explained more fully in the U. S. patent specification 2,971,323.

It must be borne in mind that, at the same frequency and amplitude of vibration, the voltage induced in the single coil of the present arrangement is the same as the sum of the voltages induced in the two coils of prior arrangements, provided of course that like coils and magnets are employed for both systems. This is because there is twice as much relative motion between the coil and magnet, where both are vibrating in phase opposition.

The unitized oscillating structure, as above described, has three important advantages over prior arrangements. It requires less space and makes feasible highly compact timepieces. The fact that the mechanical driving impulses on the tines are exactly identical, optimizes tuning-fork performance, while the simplified design of the structure effects significant economies in production costs as well as affording greater operating reliability.

In the form shown in Fig. 6, a single transducer is again used to operate a tuning fork, the transducer including a magnetic element 33 and a coil and circuit assembly 34 attached to tines 10 and 11, respectively. However, in this instance, the magnetic element has a horseshoe configuration and inclues a polepiece *S* and a polepiece *N*, between which is an air gap, the polepieces extending in planes perpendicular to the axis of the tines.

Carrier 35 is reel-shaped, and includes a circumferential channel 35*a* and an inner well 35*b*. Drive coil 23 and phase-sensing coil 24 are wound about carrier 35 in channel 35*a*, the carrier being supported at the end of tine 11, whereby the coils are disposed within the air gap between magnetic polepieces *N* and *S*. The electrical components 25, 26 and 27 lie within well 35*b* and are connected to the coils in the manner described in connection with Figs. 2 and 3. This form has the same advantages as the form previously described.

In Fig. 6, only one portion of the coils 23 and 24 lies within the air gap of the horseshoe magnet. To increase the flux linkage, Fig. 7 shows an arrangement wherein the coils 23 and 24, mounted on tuning fork tine 11, operate within two magnetic air gaps, one being defined by a first horseshoe magnet 36 and the other by a second horseshoe magnet 37. The two magnets are supported on tine 10 by a non-magnetic yoke 38. The actual shape of these magnets may be circular, as shown, or rectangular, as in Fig. 6. The electronic circuit is supported within the coil form, very much as in Fig. 6.

Alternatively, the two air gaps may be formed, as shown in Fig. 8, by two bar magnets 39 and 40 in spaced parallel relation, held together by non-magnetic frame members 41 and 42, the curved poles of the bar magnets at either end defining the air gaps.

In the arrangement shown in Fig. 9, the two air gaps are formed from a single magnetic element 43 having slots cut therein at either end to define the air gaps within which the coils are received. The slots may be inclined or curved as necessary, to conform to the path of travel. Since the path of a vibrating tine is arcuate, the actual configuration of the air gaps in Figs. 7 and 8 will also be such as to suit the path of travel. The transducer arrangements in Figs. 7, 8 and 9 operate essentially in the same manner as those in the previous forms.

It will be apparent that the present electromagnetically operated oscillators may be constructed in other forms lying within the scope of the following claims.

WHAT WE CLAIM IS:—

1. A unitized electromagnetically actuated oscillating structure comprising a mechanical oscillator having a pair of oscillating members which oscillate in phase opposition, a magnetic element secured to one of the members and oscillating therewith, the element having an air gap across which extend magnetic lines of flux, and an electronic circuit assembly secured to the other of said members, the assembly including a drive coil and a sensing coil, both of the coils being disposed in or extending into the air gap, the circuit being arranged to generate current pulses in the drive coil to create a magnetic force imparting a first or forward momentum to the magnetic element and a second or backward momentum to the electronic circuit assembly.

2. A structure as set forth in claim 1, wherein the oscillator is a torsional fork.

3. A structure as set forth in claim 1, wherein the oscillator is constituted by a pair of torsional pendulums.

4. A unitized electromagnetically actuated oscillating structure having its parts constructed, arranged and adapted to operate substantially as hereinbefore described with reference to Figs. 2 and 3 and Figs. 1, 4 and 5 or Fig. 6 or Fig. 7 or Fig. 8 or Fig. 9 of the accompanying drawings.

5. A unitized electromagnetically actuated oscillating structure as claimed in claim 1, wherein the mechanical oscillator consists of a tuning fork having a pair of vibratory tines, the magnetic element being secured to one of the tines and vibrating therewith, the coil and electronic circuit assembly being secured to the other tine and vibrating therewith, the electronic circuit having an input and an output, the input being generated in the sensing coil and the output being generated in the drive coil, whereby the a-c voltage induced in the sensing coil in the course of its vibration renders the electronic circuit conductive once each cycle to deliver a current pulse to the drive coil to create a magnetic field producing a mechanical action on the magnetic element and an equal and opposite reaction on the assembly, causing the tines to be simultaneously and identically impulsed in opposing directions.

6. A structure as claimed in claim 5, wherein the magnetic element has a horseshoe-shaped configuration and wherein the coils are disposed in the air gap defined by the poles of the magnetic element.

7. A structure as claimed in claim 5, wherein the magnetic element is formed by a cylindrical cup of magnetic material, and a permanent magnet rod coaxially disposed therein to form a magnetic circuit having an annular air gap.

8. A structure as claimed in claim 7, wherein the assembly includes a carrier which is tubular and is received concentrically within the annular gap, the drive coil and sensing coil being wound thereon.

9. A structure as claimed in any one of claims 5 to 8, wherein the mass of said magnetic element substantially matches the mass of said coil and electronic circuit assembly.

10. A structure as claimed in any one of claims 5 to 9, wherein the electronic circuit includes a resistor, a capacitor and a transistor, all of which are attached to a tubular carrier.

11. A timepiece including the structure as claimed in any one of claims 5 to 10, including means to convert the vibratory action of at least one of the tines into rotary motion for turning the dial pointers of the timepiece.

12. A timepiece as claimed in claim 11, wherein the converting means is a mechanical motion transformer including a finger attached to one of said tines and engaging a ratchet wheel.

13. A timepiece including the structure as claimed in any one of claims 5 to 10 or claims 11 or 12, further including a pillar plate, means mounting the fork structure on the plate, a battery for energizing the circuit borne on the other tine, one pole of the battery being connected to the circuit through the plate and the fork, and a flexible conductive lead connected between the other pole of the battery and the circuit whereby the other tine is free to vibrate.

14. A timepiece as claimed in claim 13, wherein the fork is fabricated of a tempera-

ture-compensating alloy and the conductive lead is formed of the same alloy.

15. A timepiece as claimed in claim 13 or 14, wherein the conductive lead has a resiliency characteristic which is slight in comparison to that of said other tine.

16. A timepiece having its parts constructed, arranged and adapted to operate substantially as hereinbefore described with reference to the accompanying drawings.

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1186065 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

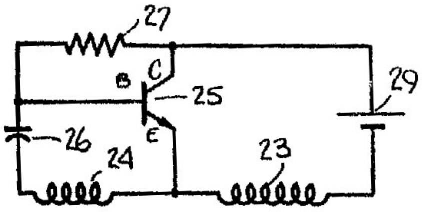


Fig.3.

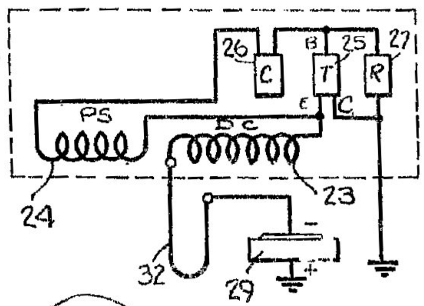


Fig.2.

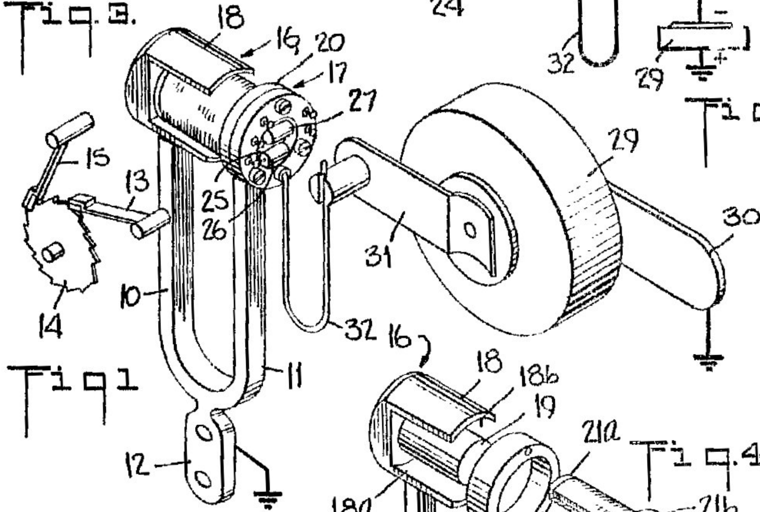


Fig.1

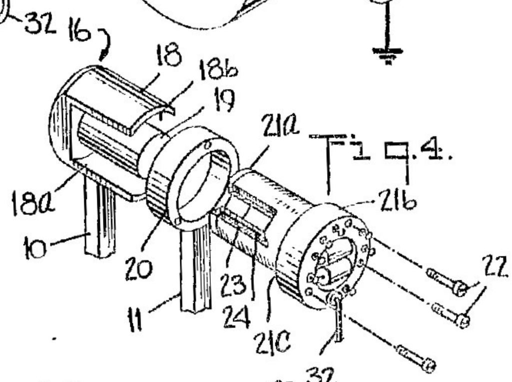
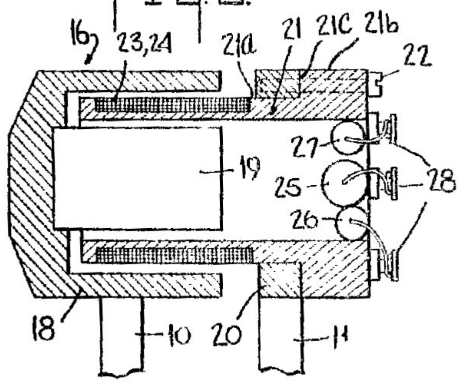


Fig.4.

Fig.5.



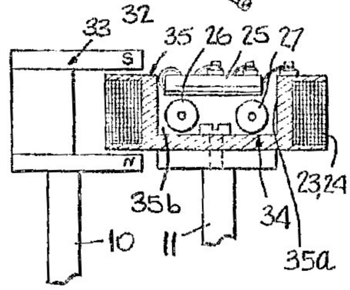


Fig.6.

Fig. 7.

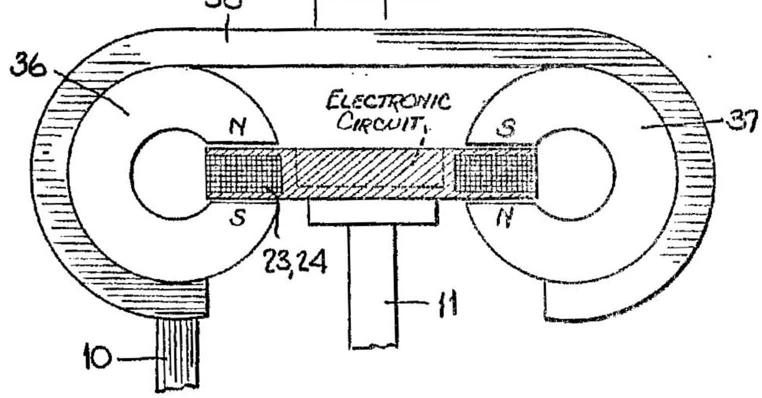


Fig. 8.

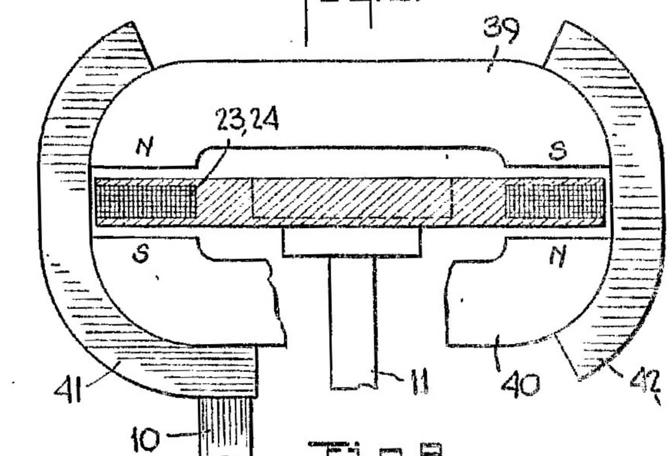


Fig. 9.