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Lundin

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[45] **June 11, 1974**

[54] **BISTABLE ELECTROMECHANICAL TRANSDUCER**

[75] Inventor: **Robert S. Lundin**, Thomaston, Conn.

[73] Assignee: **General Time Corporation,** Thomaston, Conn.

[22] Filed: **Mar. 29, 1973**

[21] Appl. No.: **346,092**

[52] **U.S. Cl.** .... **310/37,** 58/28 B, 58/28 R, 58/116 M

[51] **Int. Cl.** **H02k 33/16**

[58] **Field of Search** .... 310/36–39, 310/49; 58/116 M, 28 B, 28 R; 318/119

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Primary Examiner—Gerald Goldberg
Attorney, Agent, or Firm—Pennie & Edmonds

[57] **ABSTRACT**

A bistable electromechanical transducer is disclosed for converting low energy, low duty cycle electrical input pulses to mechanical motion. The transducer includes a stator which is formed of a core element having an energizing winding wound thereabout. The stator is separated at its ends to form a generally circular air gap with the ends of the stator forming a pair of pole faces. A rotor is positioned in the air gap and includes a permanent magnet sandwiched between two parallel discs of high permeability material. The discs each have a plurality of working rotor pole faces with one of the discs having an extra pole face designated the holding pole. The rotor holding pole, when in a central neutral position, extends into a channel formed by the separated ends of the stator core. As the rotor rotates toward either of its stable positions, the holding pole comes into increasing angular alignment with the respective portions of the stator core to which it is attracted, there being a substantially constant radial air gap separating the rotor holding pole and the stator. Because of the constant radial air gap, the holding pole is attracted toward either end of the stator core by a torque which is substantially constant as the rotor approaches either of its stable positions.

To prevent the rotor main poles from having any influence on the quiescent state of the rotor the total air gap permeance of the main poles is kept essentially constant over the entire stroke of the rotor. This is accomplished by extending the arc length of the rotor poles beyond the arc limit of the stator pole so that regardless of rotor position (within its design limits) the rate of change of fringing permeance of the "entering" pole is little different from that of the "leaving" pole except that it is opposite in sign.

These aforementioned features prevent the rotor from becoming locked in either bistable position or from becoming temporarily centered in an intermediate neutral position.

6 Claims, 9 Drawing Figures

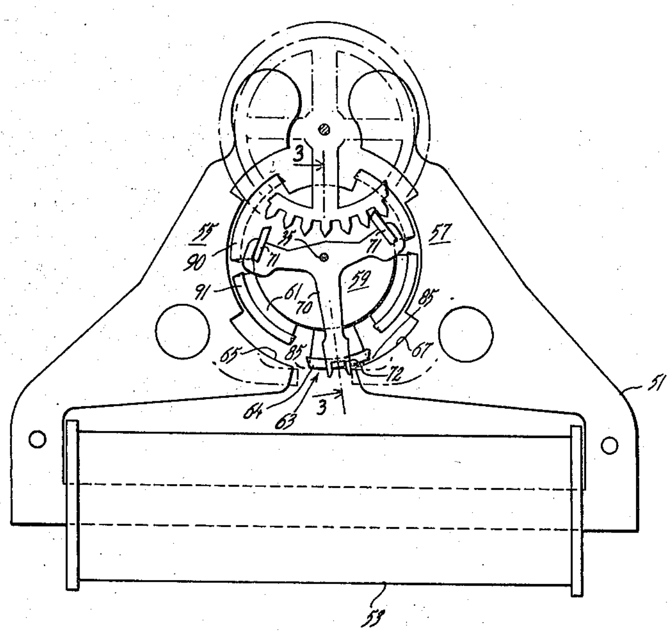


FIG. 1

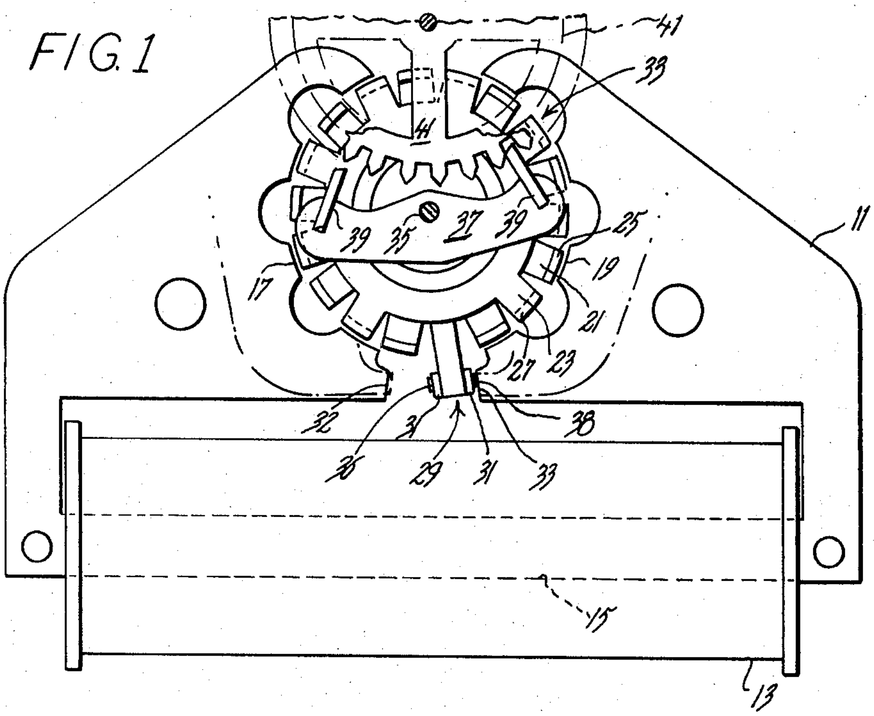


FIG. 2

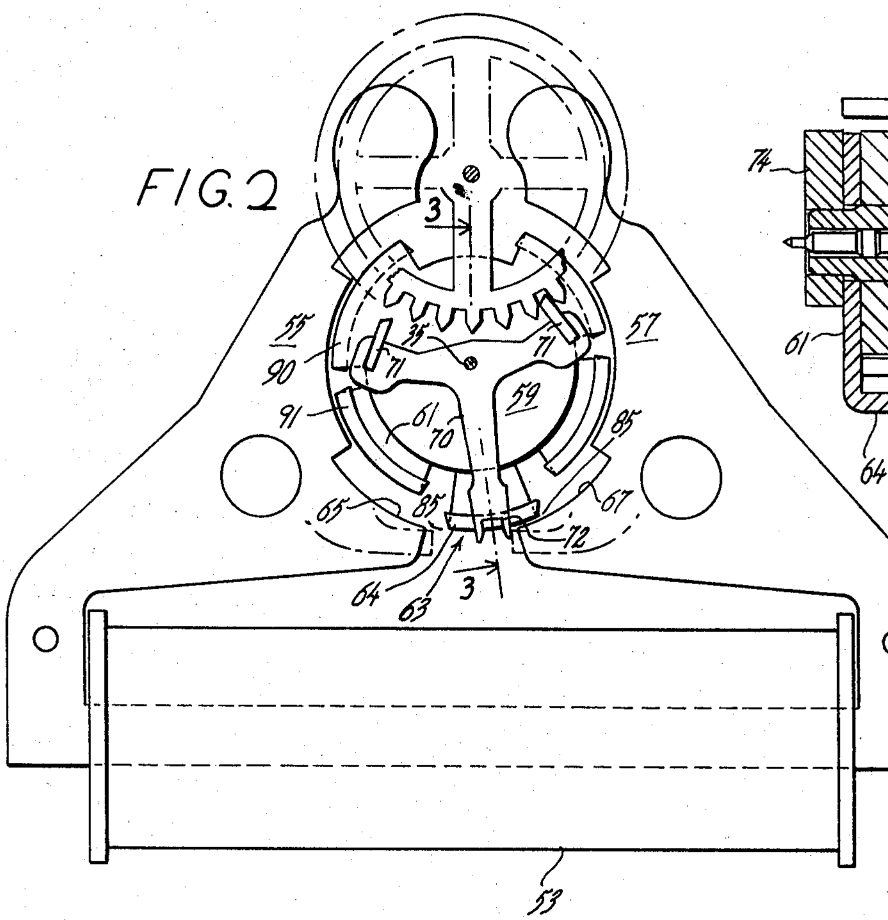


FIG. 3

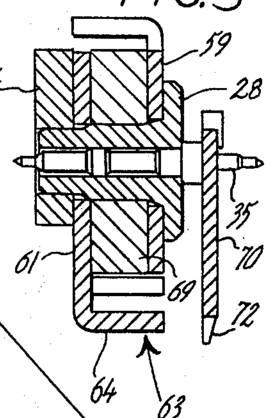


FIG. 4

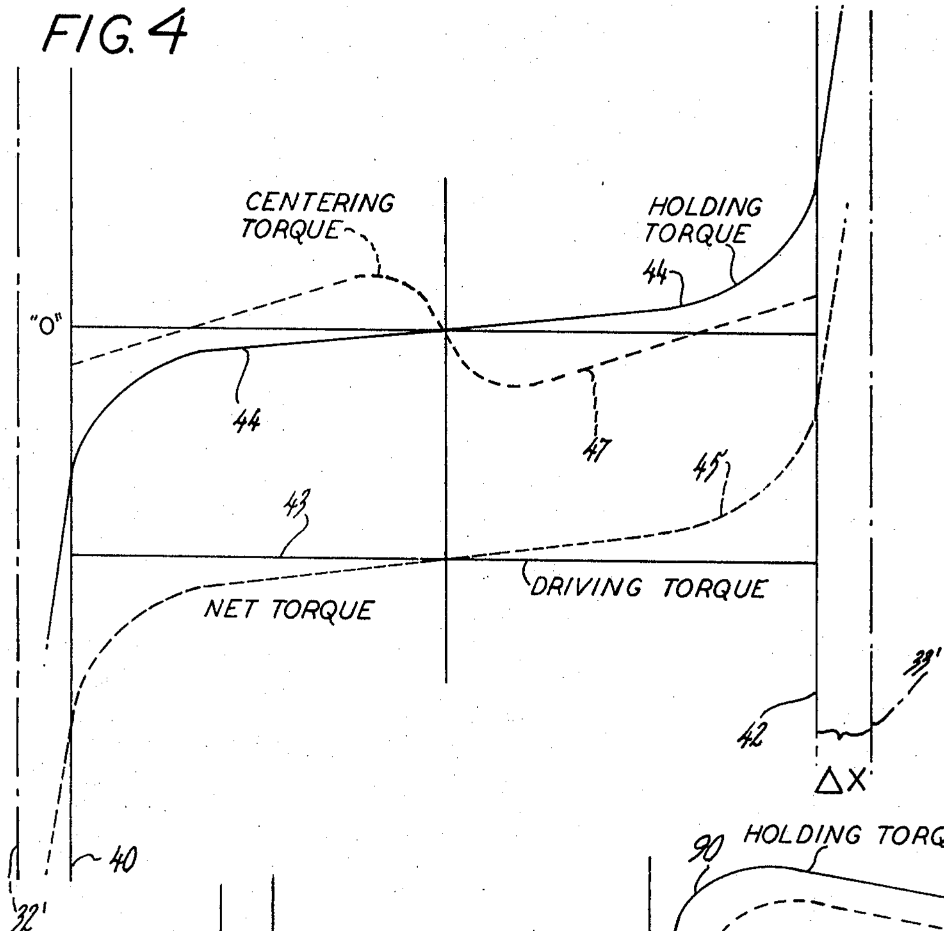

CENTERING TORQUE
HOLDING TORQUE
"O"
44
44
47
45
43
NET TORQUE
DRIVING TORQUE
33'
42
ΔX
40
32'

FIG. 5

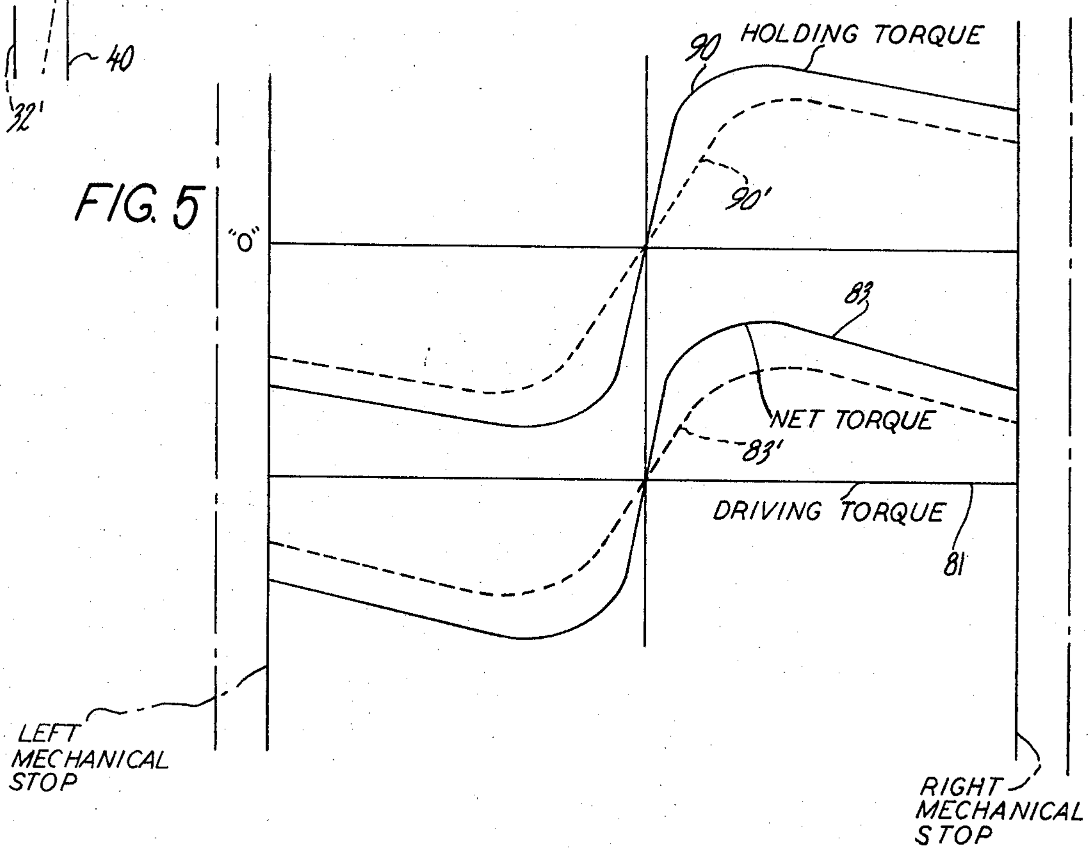

HOLDING TORQUE
90
90'
"O"
83
NET TORQUE
83'
DRIVING TORQUE
81
LEFT MECHANICAL STOP
RIGHT MECHANICAL STOP

FIG. 6(a)

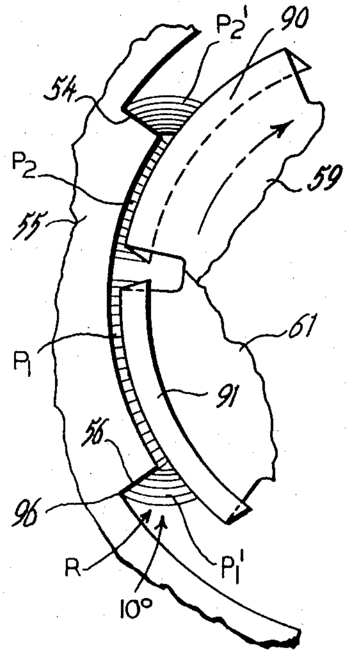


FIG. 6(b)

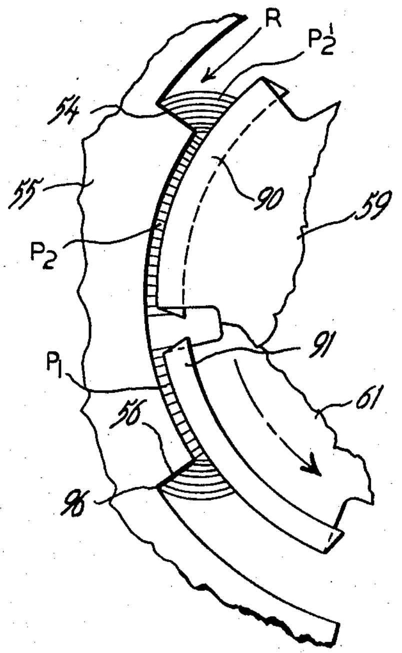


FIG. 7(a)

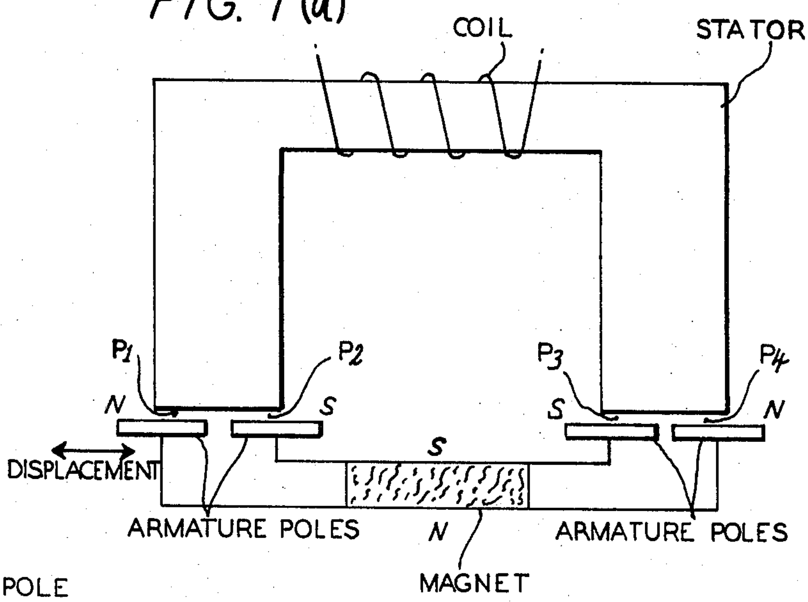
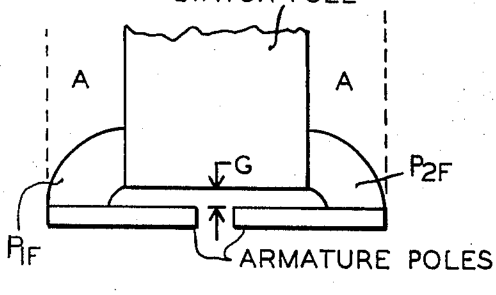


FIG. 7(b)



BISTABLE ELECTROMECHANICAL TRANSDUCER

BACKGROUND OF THE INVENTION

This invention relates to an efficient and reliable bistable electromechanical transducer.

In electrically operated timepieces, such as watches, a transducer is required to translate the electrical impulses derived from an input, such as a high-frequency oscillator, to mechanical motion. Such a transducer must have a very low average power consumption because of the low capacity of the small batteries which are typically mounted in watches. A number of transducers have appeared on the market, but these have been found to suffer serious drawbacks in reliability and efficiency in converting exceedingly low power, low duty cycle input pulses into mechanical motion.

Some of the particular deficiencies known to exist in prior art bistable electromechanical transducers are:

a. insufficient freedom from a third stable position somewhere near the center of the stroke,

b. high sensitivity to mechanical tolerances in relating the physical limits of rotor stroke to the magnetic center of the stroke making the stepper vulnerable to either:

1. High ratio of holding torque to driving torque thereby causing the rotor to lock in one of the two bistable positions;

2. Low ratio of holding torque to driving torque rendering the anticipated stable state insufficiently stable.

Either of these two conditions have a catastrophic effect on the performance of the transducer in a system in which the transducer is expected to faithfully reproduce mechanical motion in accordance with the number of pulses applied. This is essential for time-keeping accuracy in the caliber of watches in which such devices are used.

It, accordingly, is an object of this invention to provide a reliable bistable electromechanical transducer capable of being operated by a very low power source of electrical energy having:

a. a substantially constant ratio of driving torque to holding torque;

b. freedom from any stable position between the two stable positions at the ends of the stepping stroke.

SHORT STATEMENT OF THE INVENTION

Accordingly, this invention relates to an apparatus for converting lower power, low duty cycle electrical impulses to mechanical motion. The transducer includes a stator having a core with an energizing winding wound thereabout. The core is separated at its ends to form a generally circular air gap and at least two stator pole faces. A rotor is positioned in the air gap, the rotor including a permanent magnet positioned between a pair of parallel discs of high permeability. The rotor has a plurality of working pole faces, each of which has an arc length sufficiently great so that, regardless of the position of the rotor as it moves from one bistable position to the other, the fringing permeance rates of change for the entering and leaving poles are substantially equal in magnitude (though opposite in sign) over the working stroke of the rotor within its design limits.

A holding pole is provided which is separated from the stator core by a substantially constant radial air gap as it passes into increasing angular alignment with the portions of the stator to which it is attracted. Accordingly, the force with which the holding pole is attracted to either end of the stator core remains substantially constant as the holding pole approaches one or the other of its bistable positions. Because of this feature resonable variances in the mechanical tolerances of the transducer will not cause the holding pole to become locked in one of the bistable states and, accordingly, a simple but reliable transducer is provided which can be readily manufactured on a mass production basis.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features, and advantages of the invention will become more fully appreciated from the following detailed description, appended claims, and accompanying drawings in which:

FIG. **1** is a plan view of a prior art electromechanical transducer;

FIG. **2** is a plan view of the electromechanical transducer of this invention;

FIG. **3** is a cross-sectional view of the rotor of this invention taken along lines **3**—**3** of FIG. **2**;

FIG. **4** is a graphical display of the torque curves associated with the prior art electromechanical transducer shown in FIG. **1**;

FIG. **5** is a graphical display of the torque curves associated with the electromechanical transducer illustrated in FIG. **2**;

FIG. **6**(*a*) is a partial cutaway plan view of the rotor and stator of this invention showing the rotor in a first bistable position;

FIG. **6**(*b*) is a partial plan view of the rotor and stator of this invention showing the rotor in the second bistable position;

FIG. **7**(*a*) is a linear representation of the circular system shown in FIGS. **2** and **6** in which the armature poles correspond to the rotor of this invention; and

FIG. **7**(*b*) is an illustrative representation particularly showing the fringe permeance relationship of one set of the stator and armature poles.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Refer now to FIG. **1** where there is shown a prior art embodiment of a bistable electromechanical transducer, which is fully disclosed in co-pending application Ser. No. 245,592 filed Apr. 19, 1972 for Quartz Crystal Controlled Stepper Motor and assigned to the common assignee herewith. Briefly, a stator **11** is shown having an energizing winding **13** wound about a leg portion **15** thereof. The stator is separated at its ends to form a generally circular air gap. The ends of the stator are notched to form a plurality of pole faces **17** and **19.** Positioned within the air gap is a circular rotor which includes a permanent magnet (not shown) positioned between a pair of discs **21** and **23.** Because of the permanent magnet, disc **21** has a south pole polarization and disc **23** has a north pole polarization. A plurality of teeth **25** and **27** are formed in the discs **21** and **23,** respectively. These teeth form a plurality of rotor pole faces which interact with the stator poles **17** and **19** to drive the rotor when winding **13** is energized.

A holding pole **29** extends from the south pole disc **21** into a channel formed between the ends of stator **11**. The pole has a pair of side surfaces **31** which form a pair of pole faces. This pole serves a dual function, namely, to hold the rotor in one of two bistable positions and to prevent continuous rotation of the rotor as in a rotary motor. Attached to the axle **35** of the rotor is a pallet arm **37** having a pair of pallet jewels **39** secured at each end thereof. The pallet jewels impart intermittent motion to an escapement wheel **41** by intermittently striking the gear teeth of the escapement wheel as the rotor oscillates about axle **35.** As is typical in watch movements, as the rotor becomes positioned in a central position with holding pole **29** positioned vertically, neigher of the jewels **39** will make contact with escapement wheel **41.** Accordingly, wheel **41** is free to rotate in either direction thereby rendering the possibility of timekeeping error possible if not probable. In some cases, such as when a calendar movement in the watch is driven by the escapement wheel **41,** the reverse torque generated by the calendar will cause the escapement wheel **41** to rotate rapidly in the reverse direction, thereby rendering the indicated time of the timepiece erroneous.

Refer now to FIG. **4** which is a graphical display of the torque curves associated with this prior art transducer. The vertical line **32'** on the left end of the diagram represents stator pole face **32** and the line **33'** on the right end of the diagram represents the pole face **33.** The distance between line **32'** and line **40** represents the thickness of the nonmagnetic gap separation element **36** shown in FIG. **1** on the holding pole **29.** The distance between line **33'** and line **42** represents the thickness of the nonmagnetic gap separation element **38** on the opposite side of the holding pole from element **36.** Using the convention that positive torque drives the rotor in a counterclockwise direction, i.e., drives the pole **29** to the right, it can be seen from curve **44** that the holding torque attracting pole **29** to stator pole face **33** increases rapidly as the pole approaches stator pole face **33.** The reason for this is that the magnetic permeance between the pole and the pole face **33** is inversely proportional to the distance between the side arm **31** of the pole and the pole face. Now, since the torque attracting the pole to the stator is proportional to the rate of change of permeance, it can be seen that the magnetic force attracting the holding arm is inversely proportional to the square of the distance between the holding pole face and the stator pole face.

A second quiescent torque is that due to the inequality in the magnitude of the rate of change of the fringing permeances of each "entering" pole, and its corresponding "leaving"pole. This torque has the effect of causing the rotor to find a stable state at or near the center of the stroke where this torque curve crosses the zero axis and has a negative slope. The reason for its existance has been alluded to as the difference in magnitude between the rate of change of fringing permeance of the entering pole, and that of the leaving pole. To understand this more fully attention is directed to the linear representation of a circular system in FIG. 7(*a*).

If we assume for simplicity that all air gaps are equal in length, then for displacement of the armature in either direction

$$P_1 + P_4 = P_2 + P_3$$

The magnetomotive force across the P_2 and P_3 air gaps is therefore equal to the m.m.f. across the P_1 and P_4 air gaps. It follows therefore that the m.m.f. across P_2 and P_3, as well as the m.m.f. across P_1 and P_4, is equal to one half of the total available m.m.f. from the magnet.

Considering the center position of the armature as the start position, motion in either direction should produce no net force (in the quiescent state) if there is to be no stable position due to the main working poles. Since the m.m.f. of each air gap is equal to one half the available magnet m.m.f. we can write the equation for force as a function of armature displacement as follows:

$$F = (Fm/2)^2\, dP_1/dx + (Fm/2)^2\, dP_2/dx + (Fm/2)^2\, dP_3/dx + (Fm/2)^2\, dP_4/dx$$

but $P_1 = P_3$ at any position
$P_2 = P_4$ at any position
furthermore:

$$dP_1/dx = -\, dP_2/dx$$

at any position

$$dP_3/dx = -\, dP_4/dx$$

at any position
since $P_1 = P_3$ and $P_2 = P_4$ it is clear that:

$$dP_1/dx = dP_3/dx \text{ and } dP_2/dx = dP_4/dx$$

we can then write the force displacement equation in terms of $dP_1/d\,x$

$$F = (Fm/2)^2\, dP_1/dx + (Fm/2)^2\, (-dP_1/dx) + Fm/2)^2\, dP_1/dx + (Fm/2)^2\, (-dP_1/dx)$$

from which it can be seen that F=O at all times. When the fringing permeances are taken into account the above equalities must be modified to account for the fringing permeances. If we designate the fringing permeances identified with each working permeance by the addition of a subscript "F" we can write the equation for net force as follows:

$$F = (Fm/2)^2\, [dP_1/dx + dP_2/dx + dP_3/dx + dP_4/dx + dP_{1F}/dx + dP_{2F}/dx + dP_{3F}/dx + dP_4/dx\ ]$$

The first four terms in the bracket have been shown already to add up to zero at all positions. We can also see, that by symetry,

$$dP_{1F}/dx = dP_{3F}/dx$$

And

$$dP_{2F}/dx = dP_{4F}/dx$$

and therefore

$$F = Fm/2^2\ [2(dP_{1F}/dx + dP_{2F}/dx)]$$

In order that the force F equals zero the sum of dP_{1F}/dx and dP_{2F}/dx must equal zero. FOr this to be true they must be equal in magnitude and opposite in sign for all conditions. They are indeed opposite in sign, but it is clear to those versed in the art that they are not equal in magnitude for various displacements of the armature.

With particular reference to FIG. 7*b*:

$$P_{1F}=\frac{2ul}{\pi}lu\left(\frac{A-X}{G}\right)\Big]_{X=0}^{X=A-G}$$

$$P_{2F}=\frac{2ul}{\pi}lu\left(\frac{A+X}{G}\right)\Big]_{X=0}^{X=A-G}$$

where

U = permeability of the air gap medium.

l = length along axis perpendicular to plane shown.

G = air gap length.

A = extension of armature pole length beyond limits of stator pole, with armature centered.

x = horizontal displacement of armature from center.

P = respective fringing permeances.

Differentiating each of these expressions with respect to X we obtain:

$$dP_{1F}/dx = -2Ul/\pi\ (A-x)$$

And

$$dP_{2F}/dx = 2\ Ul/\pi(A+x)$$

The sum of dP_{1F}/dx and dP_{2F}/dx then is

$$dP_{1F}/dx + dP_{2F}/dx = 2Ul/\pi[1/A+x - 1/A-x]$$

It is clear that this quantity can never equal zero except at the center position for which X = 0. By making "A" very large however with respect to the maximum displacement intended, the quantity can be kept very close to zero

Prior art designs failing to take this into account suffer from the torque resulting from the term:

$$1/A+x - 1/A-x$$

which causes the rotor to find a stable state at the center of the stroke. This torque is shown in FIG. 4 by curve **47.**

The presence of a relatively large pluralty of rotor and stator poles in known prior art designs made it impossible to take the above mentioned considerations into account.

This centering torque, though small in magnitude, can have a substantial influence because the input pulses to the energizing winding **13** in a watch movement is typically of exceedingly short time duration, i.e., of low duty cycle, compared to the frequency of the bistable transducer. Because of this, the drive torque may not be present during the entire transition period of the rotor from one bistable position to the other. Thus, if the pulse ceases before the rotor passes the center point, the rotor will become temporarily immobilized in a center position. As aforementioned, when this occurs the escapement wheel **41** is free to rotate in any direction thereby introducing error in the timekeeping mechanism.

Referring again to FIG. **4**, when the energizing winding receives a pulse for driving the rotor in a clock wise direction, a driving torque is generated by the stator and rotor which is graphically shown by curve **43.** Thus, when the winding is excited the net torque holding the pole **29** to the pole face **33** is illustrated by dotted curve **45** (neglecting the centering torque). Since the net torque is negative, the pole will transfer to pole face **32.** However, in practice, it has been found that, unless the non-magnetic spacers **36** and **38** are of precise dimensions, the distance Δx between lines **33'** and **42** will vary. It can be seen from the drawing that as Δx becomes smaller by an exceedingly small amount, the change in the net torque curve is substantial and may even become positive. When this occurs the driving torque will not be sufficient to unlock the pole **29** and cause the rotor to rotate to its other bistable position. Because of this tight tolerance requirement for the spacers **36** and **38,** it has been found that the design of FIG. **1** is not commercially practical.

Refer now to FIG. **2** which is a plan view of the improved bistable transducer of this invention which transducer overcomes the problems associated with the aforementioned prior device. There is shown in the figure a stator **51** having an energizing winding **53** wound about the core portion thereof. The core is separated at its ends to form a generally circular air gap. A pair of pole faces **55** and **57** are formed at the ends of the stator having a predetermined arc length and depth. A rotor is shown having a permanent magnet **69,** as best illustrated in FIG. **3,** sandwiched between two parallel discs of high permeability material. Disc **59** is polarized because of the permanent magnet as a north pole and disc **61** has a south pole polarization. A holding pole **63** is formed in the south disc **61** with the pole having an arm portion **64** bent upward so as to form a pole face for interacting with the stator core surfaces **65** and **67.** The surface **64** of the holding pole has a constant radial displacement with respect to the stator core surfaces **65** and **67.** Because of the structure of the holding pole and its constant spaced relationship with respect to the stator surfaces **65** and **67,** the magnetic permeance between the stator and the holding pole increases substantially linearly as the holding pole moves into increasing angular alignment with either of stator surfaces **65** and **67.** Accordingly, it can be seen that since the torque pulling the holding pole toward, for example, stator surface **67** is proportional to the rate of change of permeance therebetween, (which is substantially constant as the rotor moves into increasing angular alignment with the stator), the torque attracting pole **63** toward stator core surface **67** is substantially constant as the pole approaches its bistable position. As will be explained hereinbelow, constancy of the torque holding the pole **63** to the stator core prevents the possibility of the rotor from becoming locked in one or the other of the two bistable positions. A pallet arm **70** is shown secured fast to axel **35.** Pallet arm **70** is non-magnetic and has a pair of jewels **71** at each end thereof for engaging and stepping an escapement wheel, as disclosed in more detail in co-pending application Ser. No. 245,592 referred is hereinbefore. Formed integrally with pallet arm **70** is a fork extension **72** which co-acts with a stationary member on the bridge of the movement (not shown) to serve as a positive stop in each oscillating direction of the rotor.

Illustrated in FIG. **3** is a cross-sectional view of the rotor showing the position of the permanent magnet **69** between discs **59** and **61.** As illustrated in the drawing, the teeth of the rotor are bent inward toward each other so as to form a plurality of interleaved pole faces for interacting with the pole faces of the stator core. A bushing **28** is inserted through a hole in each of the discs and through a hole in the permanent magnet positioned therebetween. This bushing is rigidly secured to the permanent magnet and to the discs by any suitable adhesive component known in the art. Holding pole **63** is shown extended upward so that it can interact with stator surfaces **65** and **67.** A counterweidht **74** is shown secured to bushing **28** for balancing or poising the rotor assembly.

Refer now to FIG. **5** which is a graphical display of the torque curves associated with the bistable transducer of this invention. The left-hand line designates the extreme clockwise rotative position of the rotor and the right-hand line designates the extreme counterclockwise position of the rotor. In the preferred embodiment, the rotor rotates through a total angle of 15° so that each line represents an angular displacement of 7½° from a center position. Using the convention that a positive torque drives the rotor in a counterclockwise direction, it can be seen from curve **90** that the holding torque generated by the permanent magnetic field passing through the holding pole **63** and the stator core increases rapidly as the holding pole rotates in the counterclockwise direction from center toward stator core surface **67.** After the surface of the holding pole **63** starts to move into angular aligment with surface **67,** the holding torque becomes substantially constant with further rotation of the rotor.

It will be observed in examination of the holding torque curve, that substantial variations in the physical stop position dows not materially change the magnitude of the holding torque. Since the driving torque developed by the main poles is substantially constant over the entire stroke (within its design limits), a substantially constant holding torque results in a net torque (driving torque minus holding torque) which is relatively insensitive to physical stop position tolerances. The ratio between holding torque and net driving torque can thus be readily established by the ratio of main pole air gaps to holding pole air gaps and once established in design it can be depended on to remain substantially constant in production without abnormal care to maintain precision accuracy. By comparison the subject matter of this invention can tolerate accumulation in tolerances resulting in a Δx in the order of magnitude ten times greater than the Δx resulting from accumulated tolerances in prior art designs.

When a driving torque is provided by passing a current through winding **53,** an essentially constant driving torque is generated by the stator **51** and the rotor. This driving torque is illustrated graphically by line **81** (FIG. **5**). Accordingly, the net torque acting on the rotor is the albegraic sum of the driving torque **81** and the holding torque and is illustrated by curve **83.** It can be seen that by modifying the maximum angle through which the rotor rotates by a relatively small amount, the holding torque at the respective bistable positions will be affected by only a slight amount. Accordingly, the transducer of this invention is free of the undesirable locking torques generated by the prior art devices, this being attributed to the fact that the holding pole **63** is attracted to the stator with a substantially constant torque.

It has been found that by limiting the arc length of the holding pole **63** to an arc length slightly less than the width of the channel **85,** shown in FIG. **2,** the rotor will be driven with greater force (curves **90** and **83,** FIG. **5**) toward one or the other of the stable positions than if the holding pole had an arc length equal to or greater than the width of the channel **85** (curves **90'** and **83'**, FIG. **5**). The reason for this is that as the rotor rotates from a center or neutral position toward one of the bistable positions, the magnetic permeance instead of initially decreasing (due to fringing) monotonically increases. This results in a strong positive torque pulling the holding pole to its bistable rest position.

It has already been shown herein that the unwanted quiescent torque resulting from the inequality in magnitude of the rates of change of the fringing permeances of each entering pole and its corresponding leaving pole can be minimized by making the ratio of the extension (dimension "A" shown in FIG. **7*b***) of the rotor pole arc length (beyond the limit of the stator pole) great with respect to the intended stroke of the rotor.

The practical embodiment of this principle is shown in FIGS. **6*a*** and **6*b*** which are partial cut-away views showing the two bistable positions of the rotor. Initially, as shown in FIG. **6**(*a*), north rotor pole **59** is positioned in its extreme clockwise bistable rest position. Lines of magnetic flux pass between the north rotor working pole **90** and the stator pole **55** as shown through the permeance P_2. A leakage flux passes from the rotor pole to the stator pole through permeance P_2', along the side **54** thereof extending from the main body of the stator to the face of the stator pole **55.** The south pole disc of the rotor also has a working pole **91** positioned opposite stator pole **55.** Flux lines are shown extending between the south rotor pole **91** and the stator pole **55** through the permeance P_1. In addition, leakage flux lines are shown extending between rotor ple **91** and the side surface **56** of the stator pole **55** through the permeance P_1'. When in this stable position the south rotor pole **91** has a sufficient arc length so that at least a protion thereof extends downward beyond the normal surface area in which the flux and leakage flux lines impinge.

Theoretically, as already shown, the extension of the rotor pole arc length beyond the limits of the stator pole should be as great as possible with respect to the intended displacement of the rotor. For practical purposes however, edges **54** and **56** of the stator pole do not extend an infinite distance back from the stator pole face, and thus the fringing permeances P_2' and P_1' are defined by a maximum outside radius R, equal to the sum of the radial air gap and the radial length of the stator pole edge **54** or **56**, respectively. Those versed in the art will recognize that the length of the pole edges **54** and **56** should be about ten times the radial air gap length to conform with good magnetic design practice. Since the outer limit of the fringing permeances P_2' and P_1' are defined by arcs having a radius equal to the radial length of the stator pole edge **54** (or **56**) plus the radial air gap, it follows then that the amount of rotor pole arc length extension required on the entering pole **91** (when in the bistable position) corresponding to that pole's entered position, FIG. **6**(*a*) should be equal to the radial air gap plus the radial length of the stator pole edge **54** (or **56**).

For a typical air gap of 0.05 mm and rotor radius of 2.5 mm this pole extension corresponds to approximately 7°. To allow for manufacturing variations this is increased in the preferred embodiment to 10°.

FIG. **6**(*b*) shows the rotor **59** as its extreme counterclockwise position. Here by parity of reasoning, rotor pole **90** is shown having an arc length great enough so that at least a 10° arc length thereof extends beyond the edge **54** of the stator pole.

When the rotor is rotated from the position shown in FIG. **6**(*a*) to the position shown in FIG. **6**(*b*), the fringing permeances P_1' and P_2' remain unchanged, inasmuch as the exterior boundary of P_1' and P_2' (radius "R") does not diminish as the rotor moves from one stable state to the other. This is accounted for by the fact that R is never greater than the length of pole edge **54** (or **56**) plus the rotor gap, and in all positions the rotor pole arc length extends beyond the intersection of R and the rotor pole surface. Thus: $dP_1'/d\theta$ and $dP_2'/d\theta$ are both substantially zero, and the unwanted quiescent centering torque is for all practical purposes eliminated.

It has been shown therefore that the design of the present bistable transducer eliminates centering torques and, in addition, desensitizes the operation of the transducer to slight variances in the mechanical tolerances of the rotor and stator structure. Accordingly, an exceedingly reliable transducer is provided which can be driven by a low duty cycle, low power input signal with substantial reliability.

While the invention has been described in connection with a preferred embodiment, it is not intended to limit the invention to the particular form set forth, but, on the contrary, it is intended to cover such alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A bistable electromechanical transducer comprising in combination a stator including a core and an energizing winding wound about said core, said core being separated at its ends to form a generally circular air gap, the periphery of said air gap including at least two stator pole faces; means for energizing said winding with low duty cycle input pulses; a rotor including a permanent magnet and a pair of discs of high permeability material secured to each end of said magnet in substantial parallel relationship to one another, each of said discs having a plurality of pole faces, means including at least one holding pole for maintaining the rotor in either of its stable positions during the period between said input pulses wherein the rate of change of the permeance of the air between said holding pole and said stator is substantially constant as said rotor approaches either of its stable positions.

2. The bistable electromechanical transducer of claim **1** capable of operation at very low electrical energy and wherein said means for maintaining the rotor in either of its stable positions comprises a holding pole being separated from the portions of the stator to which it is attracted by a substantially constant radial air gap, the rate of change of the permeance between said holding pole and said portions of said stator to which pole is attracted being substantially constant as said rotor approaches either of its stable positions, whereby said rotor is free of any stable position between said two stable positions.

3. The bistable electromechanical transducer of claim **2** further comprising means for preventing said rotor from becoming temporarily locked in a neutral center position between said bistable positions, said means including the arc length of said rotor pole faces being great enough so that the total permeance of the air gap between said rotor and said stator remains substantially constant as the rotor moves from one bistable position to the other.

4. The bistable electromechanical transducer of claim **3** wherein said means for preventing said rotor from becoming temporarily locked in a center position comprises rotor pole faces having an arc length such that regardless of the position of the rotor substantially all of the leakage flux from the stator pole faces impinges upon the rotor pole faces.

5. A bistable electromechanical transducer comprising a stator including a high permeability core and an energizing winding wound about said core, said core being separated at its ends to form an air gap, the periphery of said gap including two stator pole faces; means for energizing said winding with input pulses; a rotor including a permanent magnet and a pair of high permeability armatures secured to each end of said magnet in substantial parallel relationship to one another, each of said armatures having two of pole faces, and means including at least one holding pole for maintaining the rotor in either of its stable positions during the period between said input pulses wherein the rate of change of the magnetic permeance between said holding pole and said stator is substantially constant as said rotor approaches either of its stable positions.

6. The bistable electromechanical transducer of claim **5** wherein said holding pole has a predetermined arc length and oscillates from one stable position to the other adjacent a channel formed in said stator, said channel having an opening greater than the arc length of the holding pole, whereby the magnetic permeance between rotor and stator increases as the rotor rotates beyond the central or neutral position thereof toward one of said stable positions.

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