June 30, 1970 TSUNETA KAWAKAMI ET AL 3,518,464

ELECTROMAGNETIC DRIVING MECHANISM

Filed Dec. 24, 1968 5 Sheets-Sheet 1

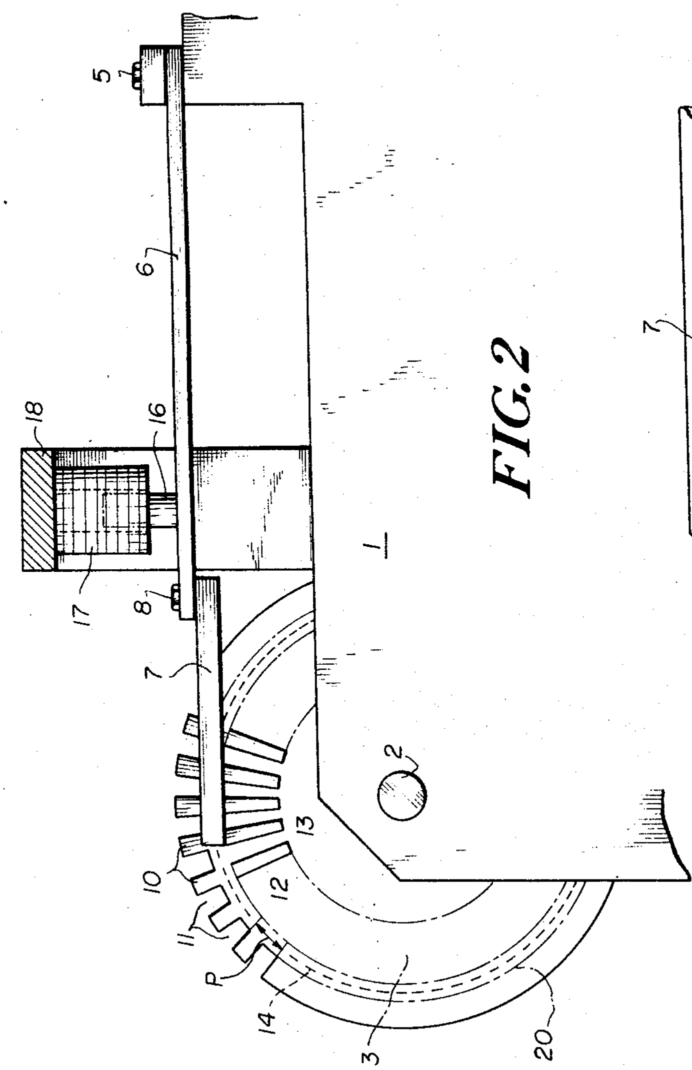


FIG. 2

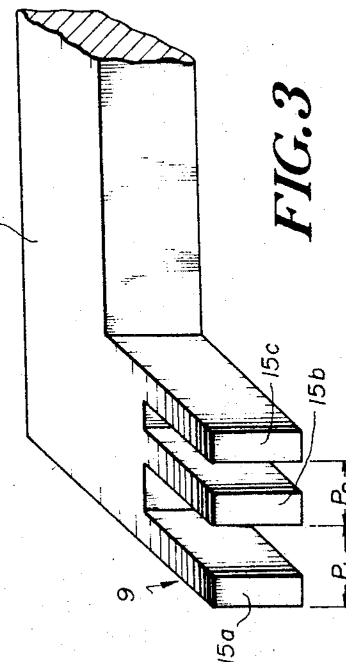


FIG. 3

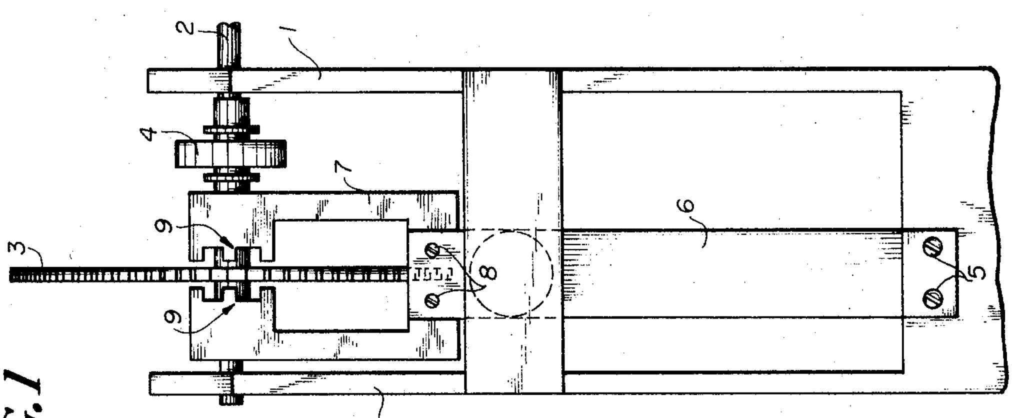


FIG. 1

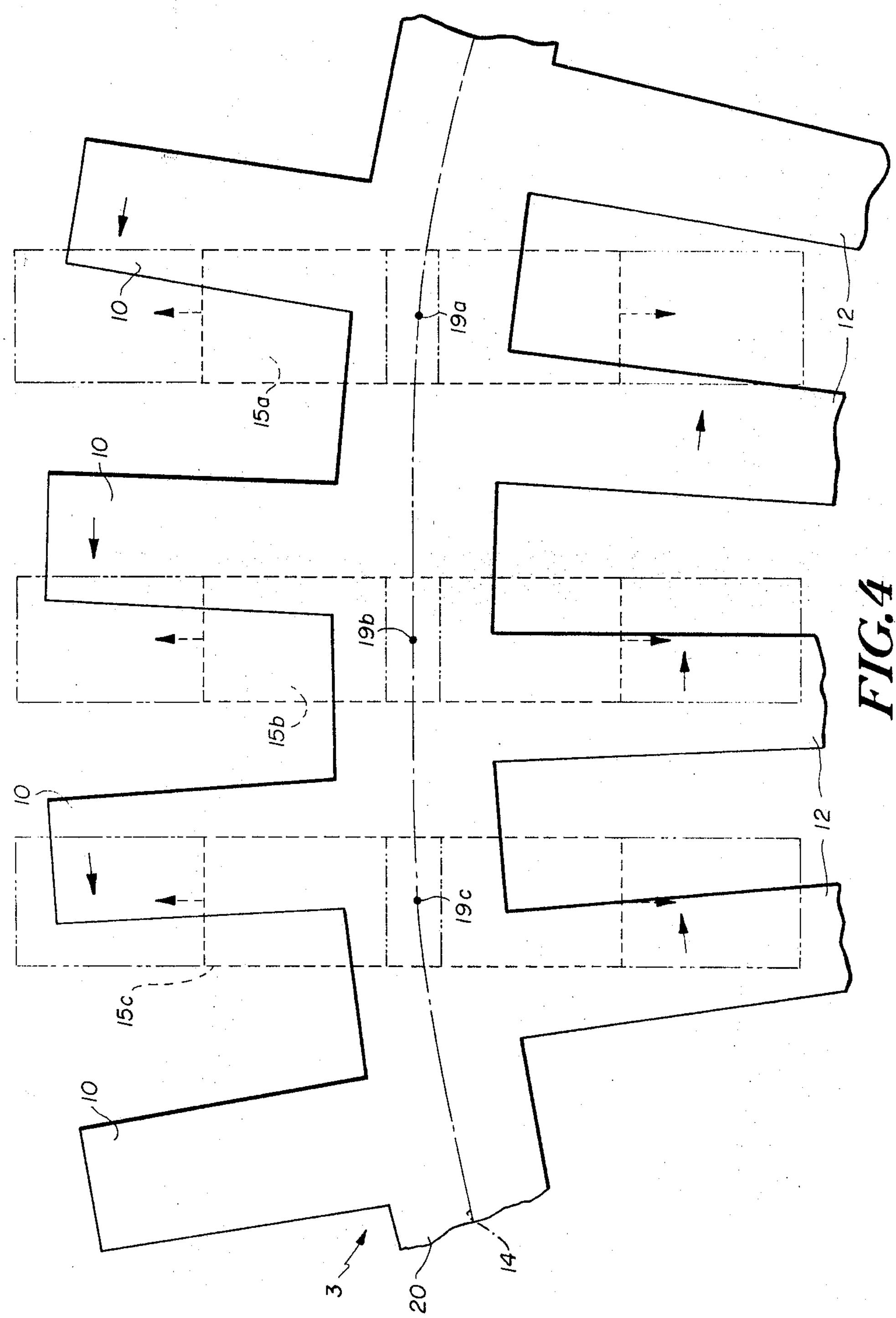


FIG.4

ELECTROMAGNETIC DRIVING MECHANISM

Filed Dec. 24, 1968 5 Sheets-Sheet 3

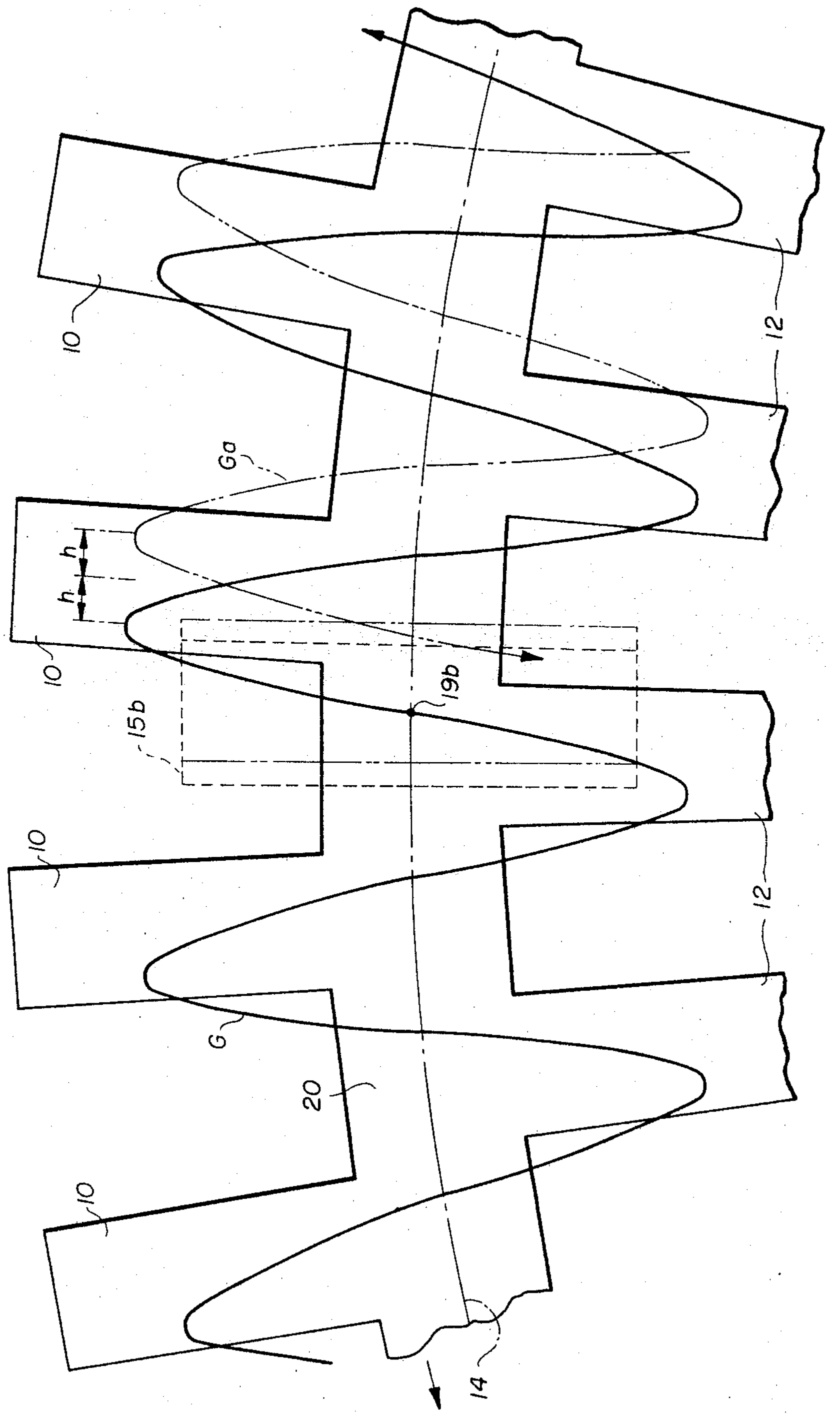
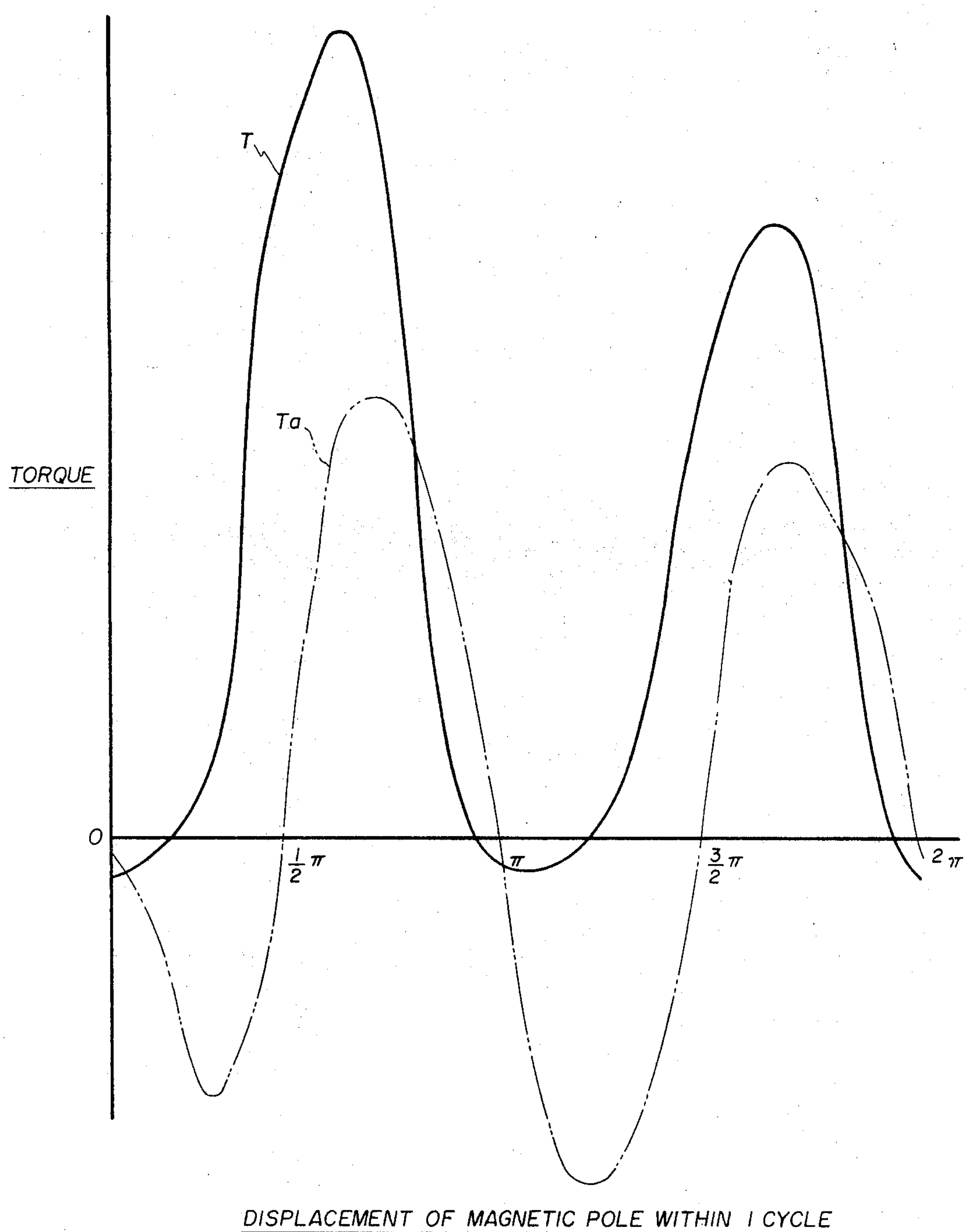


FIG.5

FIG. 6


T
Ta
TORQUE
O
$\frac{1}{2}\pi$
π
$\frac{3}{2}\pi$
2π
DISPLACEMENT OF MAGNETIC POLE WITHIN 1 CYCLE

ELECTROMAGNETIC DRIVING MECHANISM

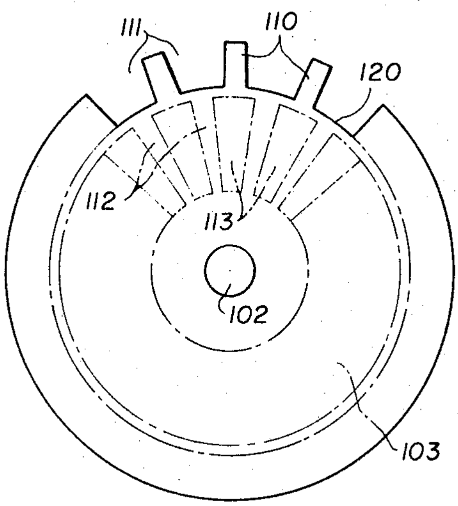


FIG. 7

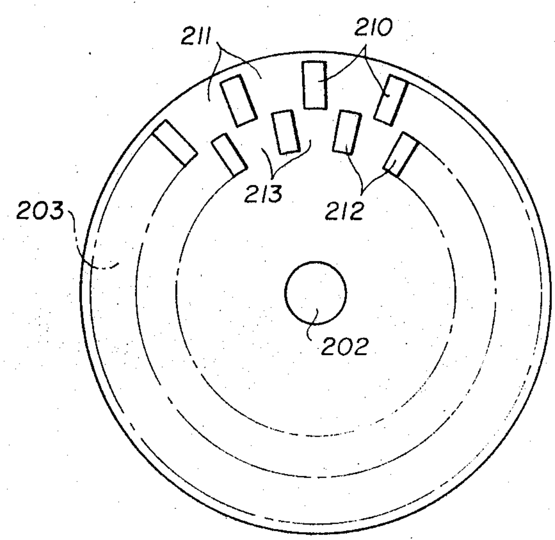


FIG. 8

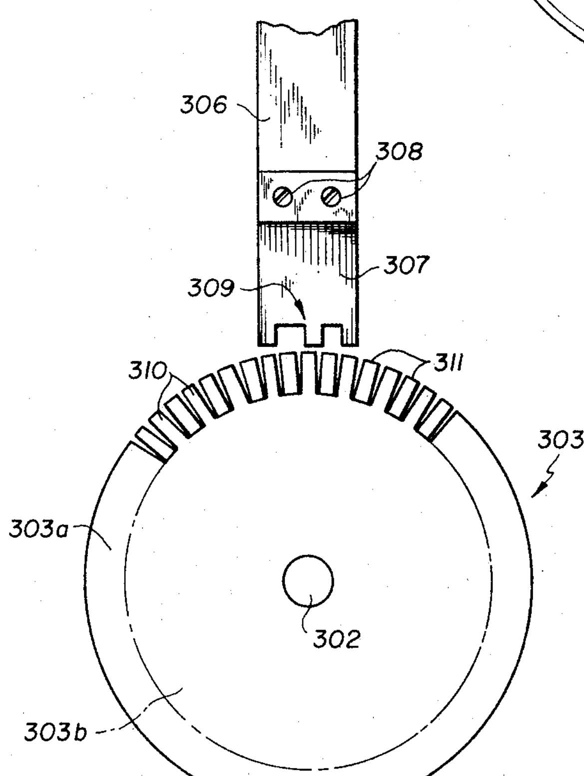


FIG. 9

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ELECTROMAGNETIC DRIVING MECHANISM

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Int. Cl. H02k 7/06
U.S. Cl. 310—22 11 Claims

ABSTRACT OF THE DISCLOSURE

Magnetic driving mechanism comprises a driven wheel, a magnetic pole unit having at least three spaced magnetic poles, and exciting means to oscillate said magnetic pole unit whereby said driven wheel is rotated unidirectionally in a self-starting manner.

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to magnetic driving mechanism of the self-starting type adapted to be generally used in clocks or watches.

Description on prior art

Known magnetic driving mechanisms of the self-starting type generally comprises a rotating wheel made of a magnetic substance and provided with circumferentially spaced teeth each having a tooth profile asymmetric with respect to the radial direction of said rotating wheel, and an oscillating element provided with a magnetic pole acting magnetically on the teeth upon the oscillating element being excited, so as to rotate the rotating wheel in a self-starting manner. However, as the teeth of the rotating wheel involve an extremely complicated tooth profile and require high precision which cannot be obtained by usual press works, none has heretofore come into commercial use. Further, employment of such prior magnetic driving mechanism as an escapement mechanism has a tendency to adverse effects on the frequency of the oscillating element, caused by the asymmetric tooth profile. It will thus be apparent that an escapement mechanism of this type is lacking in isochronism.

TECHNICAL SUBJECT-MATTER OF THE INVENTION

It is an object of the present invention to eliminate the above-mentioned shortcomings in the prior magnetic driving mechanism and to provide a novel and improved magnetic driving mechanism.

In accordance with a feature of the present invention, there is provided magnetic driving mechanism comprising a driven wheel having at a peripheral part thereof a magnetically neutral circle, and magnetic driven parts arranged on opposite sides of said magnetically neutral circle in an alternately staggered relation to each other; at least one magnetic pole driving unit having at least three magnetic poles located in opposed relation to said magnetic driven parts; and exciting means to oscillate said magnetic pole driving unit in a direction across said magnetically neutral circle, the sum total of rotating energy exerted on said magnetic driven parts by magnetic attractive forces of said magnetic pole driving unit at the time when said magnetic pole driving unit is offset toward one of its alternative amplitude positions being larger in magnitude than the sum total of rotating energy exerted on said magnetic driven parts by magnetic attractive forces of said magnetic pole driving unit at the time when said magnetic pole driving unit is offset toward the other amplitude position, and further the former rotating energy and the latter rotating energy acting in opposite directions to each other at least at the time when said driven wheel starts to rotate. Thus, the magnetic pole units made an oscillatory movement under a condition in which the driven wheel is within a magnetically stable angular zone. In an initial stage when the oscillatory movement of the magnetic pole unit is still small in amplitude, the driven wheel will make a rotational displacement alternately in opposite directions. On the other hand, in a stage when the oscillatory movement of the magnetic pole unit becomes comparatively larger in amplitude, the driven wheel may be rotated into a new and adjoining magnetically stable zone by the larger rotating energy. The driven wheel is naturally subjected to external loads of various types and, therefore, the driven wheel upon its movement into a new stable zone may follow the magnetic poles with an inevitable phase lag with respect to the latter. As a result of such phase lag, the driven wheel, after having moved into said adjoining stable zone, is not kept in said zone but is rotated afresh in the same direction by the succeeding oscillation of the magnetic pole units so that the driven wheel may start to rotate in a fixed direction in a self-starting manner. Once the driven wheel starts rotating, it may continue its steady and unidirectional rotation due to said larger rotating energy which acts on the driven wheel in the rotating direction of the latter.

To obtain the effects in which the sum of rotating energy at the time when said magnetic pole unit is offset toward one of its alternative amplitude positions is larger in magnitude than the sum total of rotating energy at the time when said magnetic pole unit is offset toward the other amplitude position, and further the former rotating energy and the latter rotating energy act in opposite direction to each other, it may be preferred that at least one pitch provided between any adjacent two of at least three magnetic poles is somewhat larger than an integer times the pitch between any adjacent two parts of said driven parts, while another pitch provided between two adjacent magnetic poles is somewhat smaller than an integer times said pitch of said driven parts.

Preferably, the driven wheel may be made from either a disc in which the inner and outer driven parts, each being symmetrical with respect to the radial direction of the disc, are arranged in a continuously sinuous manner, or a modified disc in which the inner and outer driven parts are arranged in discontinuous manner.

Furthermore, another modification of the driven wheel comprises a disc of gear wheel type having therearound a plurality of circumferentially spaced first driven parts, and another disc of gear wheel type having therearound a plurality of circumferentially spaced second driven parts, the two discs being superposed one over another. The driven parts provided in the driven wheel of this invention can be easily fabricated by conventional press works.

An object of the present invention is the provision of magnetic driving mechanism to steadily rotate the driven wheel in a fixed direction, which is easy to fabricate and moderate in price.

Further features, advantages and objects of the present invention will become apparent from the following description with reference to the accompanying drawings.

BRIEF EXPLANATION OF THE DRAWING

FIG. 1 is a plan view illustrating a preferred embodiment of magnetic driving mechanism according to the present invention;

FIG. 2 is a side view, with a part thereof broken away, of the magnetic driving mechanism of FIG. 1;

FIG. 3 is an enlarged perspective view showing a magnetic pole unit;

FIG. 4 is an enlarged diagrammatic view illustrating a positional relationship between the driven parts and the magnetic poles in their stable positions;

FIG. 5 is a schematic illustrating sine wave forms which will assist in understanding the relative displacement of the magnetic poles to the driven wheel;

FIG. 6 is a graph illustrating variation of the rotating torque through a complete cycle of the relative displacement shown in FIG. 5;

FIG. 7 is a side view illustrating a modified embodiment of the driven wheel;

FIG. 8 is a side view showing another embodiment of the driven wheel; and

FIG. 9 is a side view illustrating still another embodiment of the driven wheel.

DETAILED EXPLANATION OF PREFERRED EMBODIMENTS

Reference will be now made to FIGS. 1 to 3 showing a preferred embodiment which is provided with magnetic pole units each having three magnetic poles. Oppositely spaced parallel base plates **1** support on their foremost extremities a traverse shaft **2** in a freely rotatable manner. Fixed on the shaft **2** is a driven wheel **3**. A damper disc **4** of brass is mounted for rotation on the shaft **2**. The base plates **1** are integral with each other at their rearmost ends through a connecting portion on which is mounted by screws **5** the rearmost end of an oscillating spring element **6** extending tangentially of the driven wheel **3**. Secured to the free or foremost end of the oscillating element **6** is a C-shaped permanent magnet **7** by means of screws **8**. The magnet **7** includes oppositely spaced arms the forward ends of which are formed with a pair of oppositely facing magnetic pole driving units **9**.

The driven wheel **3** comprises a disc, preferably made of magnetic substance such as Permalloy which has high magnetic permeability. The disc of the driven wheel **3** comprises a magnetically neutral portion **20** of annular configuration, magnetic outer driven parts **10** extending radially of the disc and arranged around the outer periphery of the neutral portion **20** at a fixed circumferential pitch and separated by notches **11** which are provided between adjacent outer driven parts, and magnetic inner driven parts **12** extending radially of the disc and arranged along the inner periphery of the neutral portion **20** at a fixed circumferential pitch with apertures **13** provided between adjacent inner driven parts. The outer and inner driven parts **10** and **12** are of rectangular contour symmetrical with respect to the radial direction of the driven wheel **3**. Furthermore, the inner driven parts **12** are located between adjacent outer driven parts **10**, that is to say, the inner driven parts **12** are located in a staggered relation to the outer driven parts **10**. A magnetically neutral circle **14** is positioned substantially halfway of the radial width of the annular neutral portion **20**, as shown by a dotted line in FIG. 2.

Referring now to FIG. 3, each of the magnetic pole driving units **9** comprises three magnetic poles **15*a***, **15*b*** and **15*c*** of a rectangular configuration, said magnetic poles being disposed in parallel and spaced relation to each other and also in opposed relation to said neutral circle **14** of the driven wheel **3**. The magnetic poles are, moreover, arranged in such a manner that a first pitch P_1 provided between a first pair of adjacent magnetic poles **15*a*** and **15*b*** is longer than a pitch P measured along the neutral circle **14** between any adjacent outer driven parts **10**, and that a second pitch P_2 provided between a second pair of adjacent magnetic poles **15*b*** and **15*c*** is shorter than the above-mentioned pitch P. As an example, assuming that the driven wheel has an outer diameter of 12 mm., a neutral circle diameter of 10.1 mm., the pitch P measured along the neutral circle between and adjacent outer driven parts **10** of 0.79 mm. and the number of outer driven parts is **40**, the first pitch P_1 of the magnetic pole unit may be 0.87 mm. and the second pitch P_2 may be 0.64 mm. It should be noted that the magnetic poles **15*a***, **15*b*** and **15*c*** are equal in width to the width of the outer driven parts **10**.

Driving means for actuating the oscillating element **6** may be of the conventional type which comprises a cylindrical magnet core **16** projecting upwardly from the upper surface of the forward end of said oscillating element **6**, and a hollow cylindrical coil **17** adapted to receive the magnet core **16**. The coil **17** is mounted on a holder **18** which is fixed to the base plates **1**.

Operation of the magnetic driving means constructed as described above will be hereinafter given in detail. In case where the oscillating element **6** is not yet actuated, the driven wheel **3** may be at a standstill in its magnetically stable position. Referring now to FIG. 4 showing one of the magnetically stable positions in which the driven wheel **3** may be at a standstill, the centers **19*a***, **19*b*** and **19*c*** of the magnetic poles **15*a***, **15*b*** and **15*c*** are all located on the neutral circle **14** so that the resultant of magnetic attractive forces of the three magnetic poles **15*a***, **15*b*** and **15*c***, applied to their associated three outer driven parts **10**, and the resultant of magnetic attractive forces, applied to their associated three inner driven parts **12**, are equal in magnitude but acting in opposite directions to each other. As a result, the driven wheel **3** is maintained at a standstill.

Secondly, suppose the oscillating element **6** starts to oscillate by means of the coil **17** periodically excited by electric current, the oscillating element **6** will commence oscillating the magnetic pole units **9** in a direction radially of the driven wheel **3** across the neutral circle **14** and also such oscillatory movement of the magnetic pole units **9** will gradually increase in amplitude. In an initial stage in which the oscillatory movement of the magnetic pole units is still small in amplitude, when the magnetic pole units are offset radially outwardly toward their first amplitude position, the resultant of magnetic attractive forces acting on the outer driven parts **10** is greater in magnitude than the resultant of magnetic attractive forces acting on the inner driven parts **11** with the result that the driven wheel **3** may rotate in a counterclockwise direction (as viewed in FIG. 4) through a limited angle. Subsequently, upon the magnetic pole units being offset radially inwardly toward their alternative amplitude position, the resultant of magnetic attractive forces acting on the outer driven parts **10** is less in magnitude than the resultant of magnetic attractive forces acting on the inner driven parts **12**, whereby the driven wheel **3** may conversely make a clockwise rotation through a limited angle. From the foregoing, it will be apparent that the driven wheel **3** is permitted to rotate alternatively forwards and backwards within a limited angle. Such alternative rotational displacement of the driven wheel **3** in opposite directions is defined within the angular range in which the driven wheel **3** may be restored to its original, magnetically stable position, that is to say, within a magnetically stable angular zone, and moreover the driven parts of the driven wheel **3** may follow the magnetic pole units with some phase lag with respect to the latter, because of loads due to inertia and bearing friction of the driven wheel or due to gear trains intermeshed with the driven wheel.

In order to produce unidirectional rotational displacement of the driven wheel, an important consideration is that the sum total of rotating energy applied to the outer driven parts **10** at the time when the magnetic pole units are offset radially outwardly is larger in magnitude than the sum total of energy applied to the inner driven parts **12** at the time when the magnetic pole units are offset radially inwardly, whereby the rotational displacement of the driven wheel 3 at the time when the magnetic pole units are offset radially outwardly is larger in angular amount than when the magnetic pole units are offset radially inwardly. Thus, it will be apparent that the rotational displacement of the driven wheel will gradually increase in magnitude as the oscillatory movement of the magnetic pole units is gradually increased in amplitude, however, the rotational displacement of the driven wheel 3 beyond the above-mentioned magnetically stable angular zone will necessarily occur only when the magnetic pole units are offset radially outwardly. This forms the basis of the fact that the driven wheel 3 may always, and with certainty be made to rotate unidirectionally (the rotational movement being in a counterclockwise direction in FIG. 4).

The driven wheel 3, after having thus gotten away from a magnetically stable angular zone, will move into a new and adjoining stable position and at this time the driven parts of the driven wheel, rotated by virtue of the magnetic attractive forces of the magnetic poles, may follow the magnetic poles with somewhat of a phase lag with respect to the latter by the reason of the loads, as described above, applied to the driven wheel. Accordingly, such phase lag causes the driven wheel to rotate continuously and unidirectionally whereby the driven wheel 3 is made to rotate with a counter-clockwise rotational movement in a self-starting manner. The damper disc 4 has for its object to smooth out the rotational movement of the driven wheel.

Illustrated in FIG. 5, is a curve G showing the relative displacement of the center 19*b* of the intermediate magnetic pole 15*b* to the driven wheel 3 which makes a steady rotation in a counter-clockwise direction, including the above-mentioned phase lag *h*. It will be seen that the curve G is of substantially sine wave form. While the relative displacement in connection with the remaining magnetic poles 15*a* and 15*c* may be also shown by sine wave forms substantially similar to said curve G, these additional sine wave forms are omitted in FIG. 5.

FIG. 6 is a graph showing variation of the resultant of rotating torques exerted on the driven wheel 3 by the three magnetic poles 15*a*, 15*b* and 15*c* during a complete cycle period of the sine wave form G shown in FIG. 5. In FIG. 6, a torque curve T indicates that almost all of the rotating toruqes are applied to the driven wheel 3 in the forward or counter-clockwise direction, whereas the rotating torque exerted on the driven wheel 3 in the backward or clockwise direction is small in magnitude and also extremely short in period so that the driven wheel 3 may take a steady and unidirectional rotation.

The question will arise as to what additional rotating torques would be exerted on the driven wheel 3 by the magnetic poles in the event the driven wheel 3 is forcibly rotated in the backward or clockwise direction owing to external force. A since wave form G*a* in FIG. 5 shows the relative displacement of the center 19*b* of the magnetic pole 15*b* to the driven wheel 3 at a time when the driven wheel 3 is forcibly caused to rotate in the backward or clockwise direction with a phase lag *h*. Variation of rotating torques exerted on the driven wheel 3 under such backward rotation is shown by a torque curve T*a* in FIG. 6. It will be seen from this torque curve T*a* that the energy applied to the driven wheel 3 by the rotating torques in the backward or clockwise direction, even under the backward rotation of the driven wheel, is substantially equal in magnitude to the energy applied by the rotating torques in the normal or counterclockwise direction, and therefore the driven wheel 3 does not acquire a sufficient energy to continue the backward or clockwise rotation. As a result, if the external force is eliminated, the driven wheel 3 will be attenuated to a stop and will again start to make its normal, counterclockwise rotation.

Alternative details of magnetic driving mechanism in accordance with the invention will be hereinafter described by way of example. Assuming that the driven wheel has an outer diameter of 12 mm., a neutral circle diameter of 10.1 mm. and 40 outer driven parts spaced circumferentially of the neutral circle with a pitch P of 0.79 mm. measured along the neutral circle between any adjacent driven parts, a magnetic pole unit may be provided in which the first pitch P_1 is 0.94 mm. and the second pitch P_2 is 0.71 mm.

Further, taking into consideration a modified magnetic pole unit in which the first pitch P_1 exceeds twice the second pitch P_2, in case where the driven wheel has an outer diameter of 12 mm., a neutral circle diameter of 10.1 mm. and 40 outer magnetic driven parts spaced circumferentially of the neutral circle with a pitch P of 0.79 mm. measured along the neutral circle between any adjacent driven parts, a magnetic pole unit will be provided in which the first pitch P_1 is $0.79+0.94=1.73$ mm. and the second pitch P_2 is 0.71 mm.

FIG. 7 shows a modified driven wheel 103 which has a neutral portion reduced in its radial width as compared with that of FIG. 2. In this figure, components indicated at 102, 110, 111, 112 and 113 are substantially identical in their functions with the corresponding parts shown in FIG. 2.

FIG. 8 shows a further modified driven wheel 203 which comprises a disc of synthetic resin on which are embedded outer and inner driven parts 210 and 212 with no neutral portion being provided therebetween, said outer and inner driven parts 210 and 212 being made of magnetic substance having high magnetic permeability. When the neutral portion is eliminated, the neutral circle is coincident with the inner portions of the outer driven parts 210 and the outer portions of the inner driven parts 212.

On the neutral portion being completely eliminated or substantially reduced in radial width as in the modifications described just above, the magnetic attractive forces exerted by the magnetic poles on the driven wheel is increased in magnitude with the result that the self-starting performance of the driven wheel may be improved.

Referring now to FIG. 9, there is shown another modified driven wheel 303 comprising a disc 303*a* of gear wheel type having therearound a plurality of circumferentially spaced first driven parts 310, and a disc 303*b* of gear wheel type having therearound a plurality of circumferentially spaced second driven parts 311, said discs 303*a* and 303*b* being equal in diameter and superposed one on the other in such a manner that the first driven parts 310 are staggered in relation to the second driven parts 311. The discs 303*a* and 303*b* are spaced or not depending on whether a neutral portion is desired between the two sets of driven parts. In either event the neutral circle is between the discs. A magnetic pole unit 309 used in cooperation with this driven wheel 303 is caused to oscillate in the axial direction of the traverse shaft 302 on which discs 303*a* and 303*b* are fixed. Components indicated at 306, 307 and 308 in FIG. 9 are substantially identical in their functions with the counter parts shown in FIGS. 1 and 2.

In a magnetic pole unit having four or five magnetic poles, the magnetic poles should be arranged in such a manner that at least one pitch among pitches provided between any adjacent magnetic poles is somewhat larger than an integer times the pitch P provided between the driven parts while at least one other pitch between adjacent magnetic poles is somewhat smaller than an integer times said pitch P.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made.

What we claim and desire to secure by Letters Patent is:

1. Magnetic driving mechanism comprising a driven wheel having at its periphery a first set and a second set

of magnetic driven parts disposed respectively on opposite sides of a magnetically neutral circle, the magnetic driven parts of each said set being spaced circumferentially from one another and the magnetic driven parts of said second set being staggered relative to the magnetic driven parts of said first set, at least one magnetic pole driving unit having at least three magnetic poles located in opposed relation to said magnetic driven parts, and exciting means for oscillating said magnetic pole driving units in a direction across said magnetically neutral circle to apply rotating energy alternately to said two sets of magnetic driven parts, one pitch between two of the poles of said driving units being greater than an integer times the pitch of said driven parts measured along said neutral circle and another pitch between two of the poles of said driving unit being less than an integer times said pitch of said driven parts, the sum total of rotating energy exerted on said magnetic driven parts by said magnetic pole driving unit at a time when said driving unit is at one of its amplitude positions being larger than the sum total of rotating energy exerted on said magnetic driven parts by said magnetic pole driving unit at a time when said driving unit is at its opposite amplitude position, whereby said driven wheel is self starting and rotates unidirectionally.

2. Magnetic driving mechanism according to claim **1**, in which said two sets of magnetic parts comprise an outer set of said magnetic parts at the periphery of said driven wheel and an inner set of said magnetic parts disposed radially inwardly of said outer set, said driving unit oscillating radially of said wheel.

3. Magnetic driving mechanism according to claim **2**, in which there are two said magnetic pole driving units disposed on opposite sides of said wheel and facing each other.

4. Magnetic driving mechanism according to claim **2**, in which said driven wheel comprises a disc of magnetically permeable material, said magnetic parts of said outer set being spaced by notches in the periphery of said disc and said magnetic parts of said second set being spaced by apertures in said disc.

5. Magnetic driving mechanism according to claim **2**, in which said driven wheel comprises a disc of non-magnetic material and said magnetic driven parts comprise spaced portions of magnetically permeable material set in said disc.

6. Magnetic driving mechanism according to claim **5**, in which said disc is formed of synthetic resin material.

7. Magnetic driving mechanism according to claim **1**, in which said driven wheel comprises two discs fixed on a common shaft, sad first set of magnetic driven parts comprising spaced teeth on one said disc and said second set of magnetic driven parts comprising spaced teeth on the other said disc, said magnetic poled driving unit being oscillated in a direction parallel to the axis of said discs.

8. Magnetic driving mechanism according to claim **1**, in which one said pitch of the poles of said magnetic pole driving unit is from 1.1 to 1.2 times said pitch of said driven parts and another said pitch of said magnetic pole driving unit is from 0.8 to 0.9 times said pitch of said driven parts.

9. Magnetic driving mechanism according to claim **1**, further comprising damper means connected with said driven wheel to smooth the rotation of said wheel.

10. Magnetic driving mechanism according to claim **1**, in which said means for oscillating said magnetic pole driving unit comprises a solenoid and means for periodically exciting said solenoid.

11. Magnetic driving mechanism according to claim **1**, in which each of said magnetic driven parts is symmetrical with respect to a radius of said driven wheel bisecting said driven part.

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DONOVAN F. DUGGAN, Primary Examiner

U.S. Cl. X.R.

310—37; 74—1.5, 142; 58—23