# United States Patent

[11] 3,588,888


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[54] **ELECTROMAGNETIC INDICATING APPARATUS**
**39 Claims, 14 Drawing Figs.**


[52] **U.S. Cl.** ..... **340/378R,** 310/49R, 340/319
[51] **Int. Cl.** ..... **G08b 5/00**
[50] **Field of Search** ..... 340/324, 325, 378, 379, 319; 310/49



[56] **References Cited**

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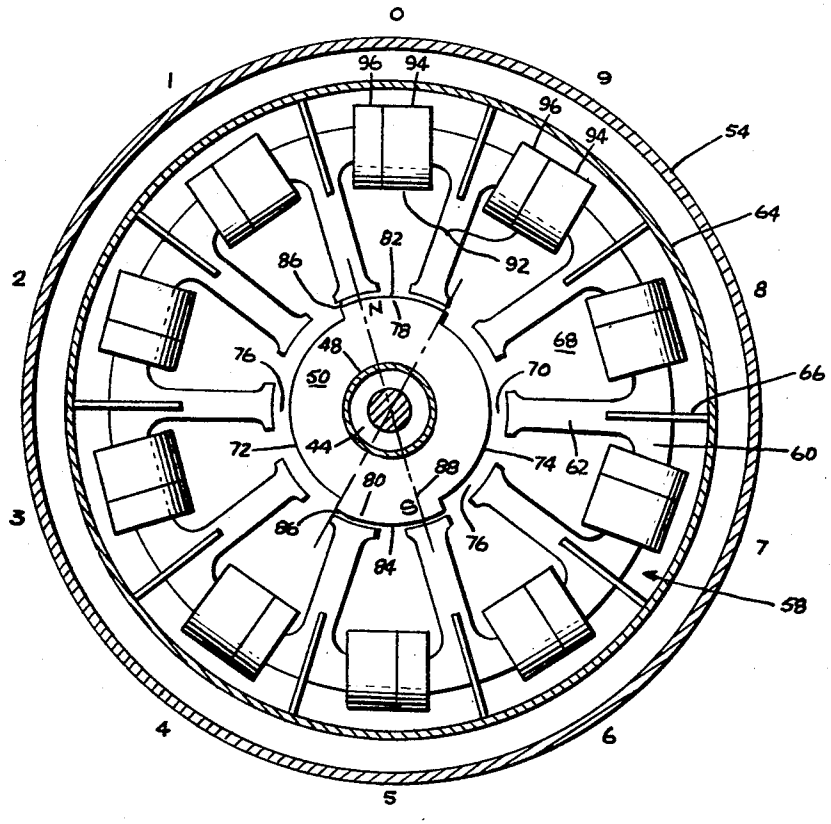
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**ABSTRACT:** Electromagnetic indicating apparatus for displaying a predetermined number of discrete indicia in response to the characters of a prearranged code and having a magnetic stator core structure and a radially polarized permanent magnet rotor member. The stator structure includes a plurality of polar projections or teeth which define a bore for receiving the rotor member, and a plurality of coils arranged selectively to energize one preselected adjacent pair of polar projections with one magnetic polarity and another preselected adjacent pair with the opposite magnetic polarity. The rotor member has peripheral surface portions which define first radial airgaps with the polar projections and a pair of spaced pole face portions which project radially outwardly from the surface portions and respectively define second radial airgaps with the stator polar projections and which are narrower than the first airgaps, the rotor pole face portions respectively having an angular extent generally corresponding to the angular extent of each adjacent pair of stator polar projections and being respectively generally aligned with the oppositely polarized adjacent pairs of stator polar projections in each position of the rotor member. The rotor member is polarized on a magnetic axis which extends through the pair of pole face portions and which is generally aligned with one stator polar projection respectively of the oppositely polarized adjacent pairs in each position of rotor member.

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SHEET 1 OF 7

FIG. 1

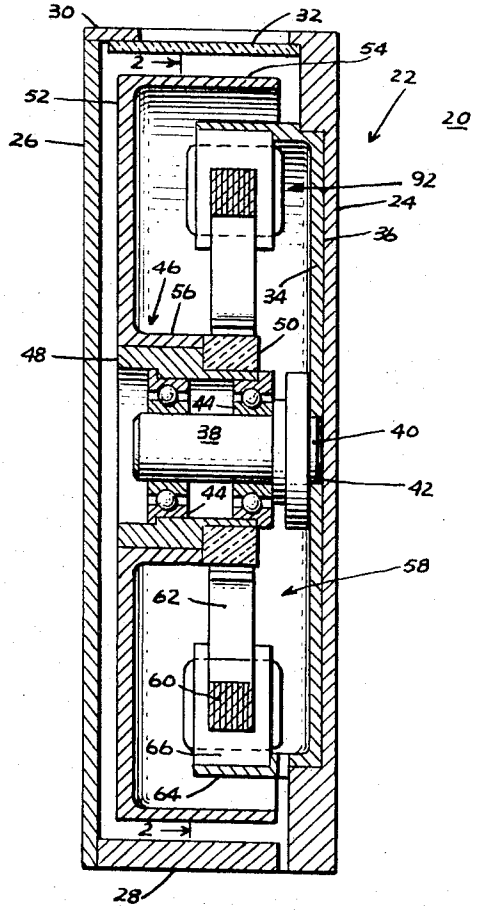
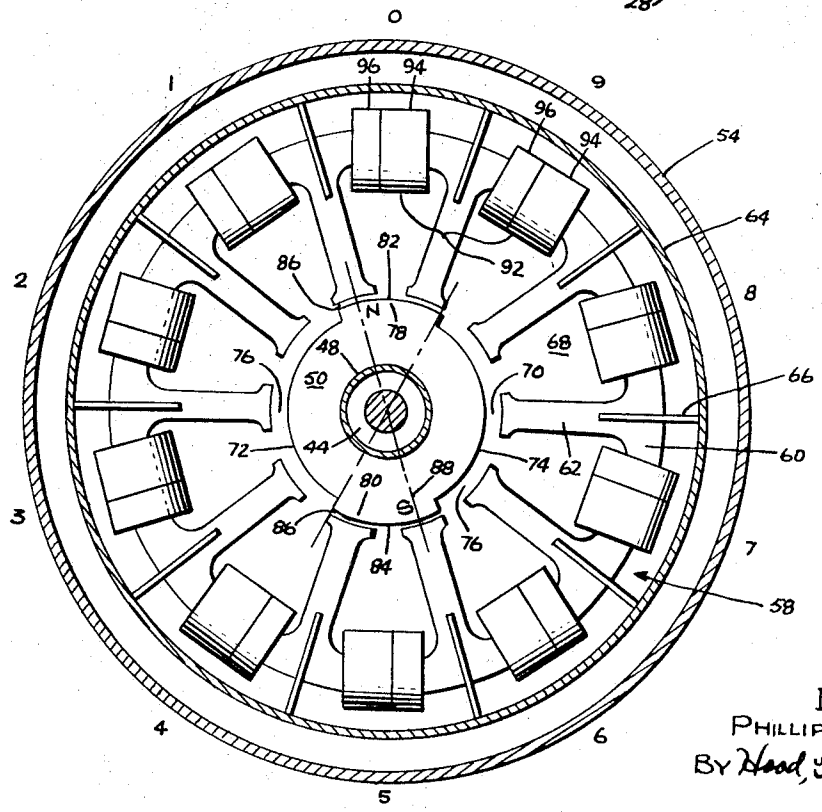



FIG. 2




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FIG. 3

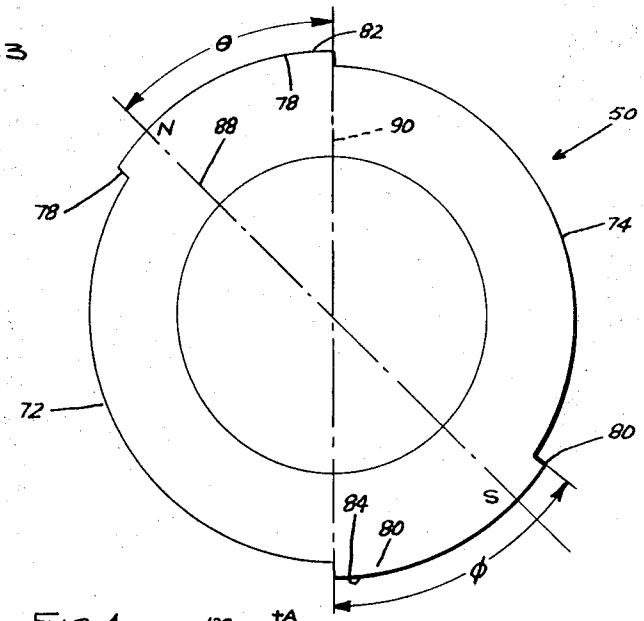
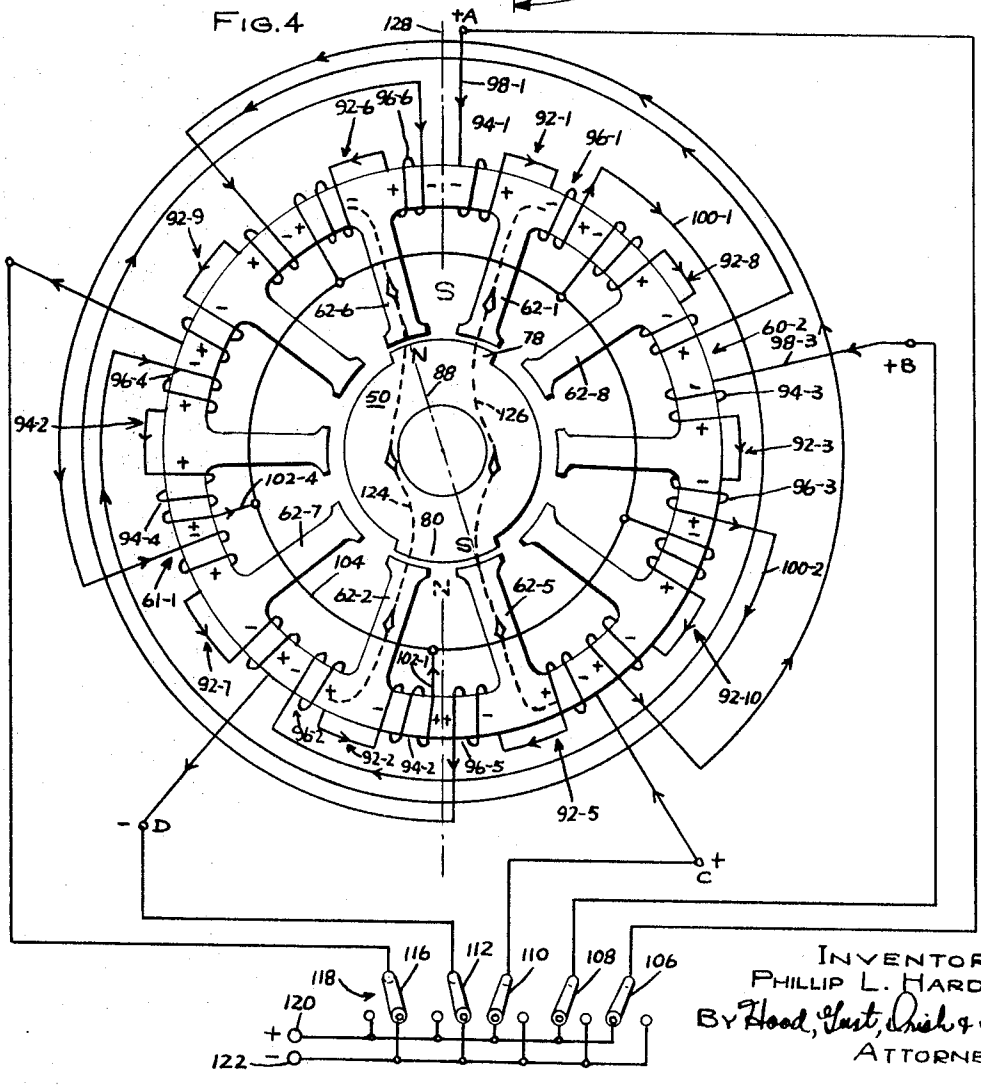



FIG. 4

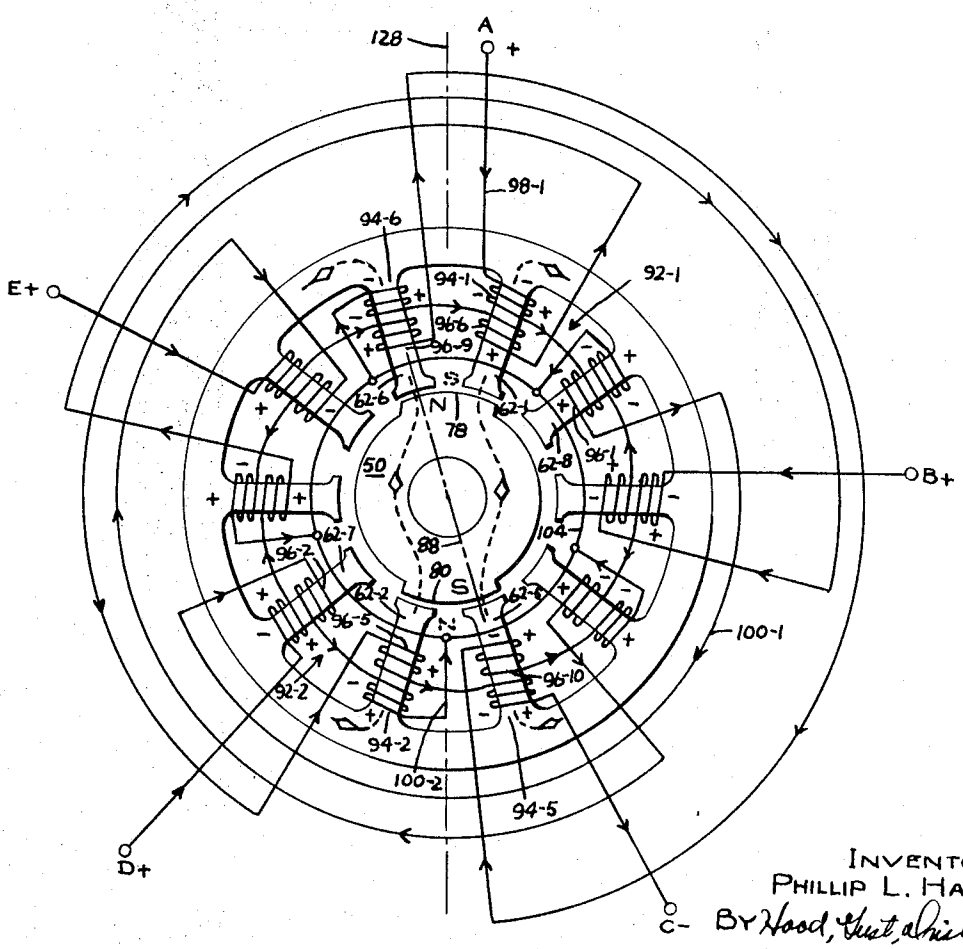



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FIG. 5.

| NUMERAL DISPLAYED | A | B | C | D | E |
|---|---|---|---|---|---|
| 0 | + | + | + | − | − |
| 1 | − | + | + | − | − |
| 2 | − | + | + | + | − |
| 3 | − | − | + | + | − |
| 4 | − | − | + | + | + |
| 5 | − | − | − | + | + |
| 6 | + | − | − | + | + |
| 7 | + | − | − | − | + |
| 8 | + | + | − | − | + |
| 9 | + | + | − | − | − |

FIG. 6




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FIG. 7

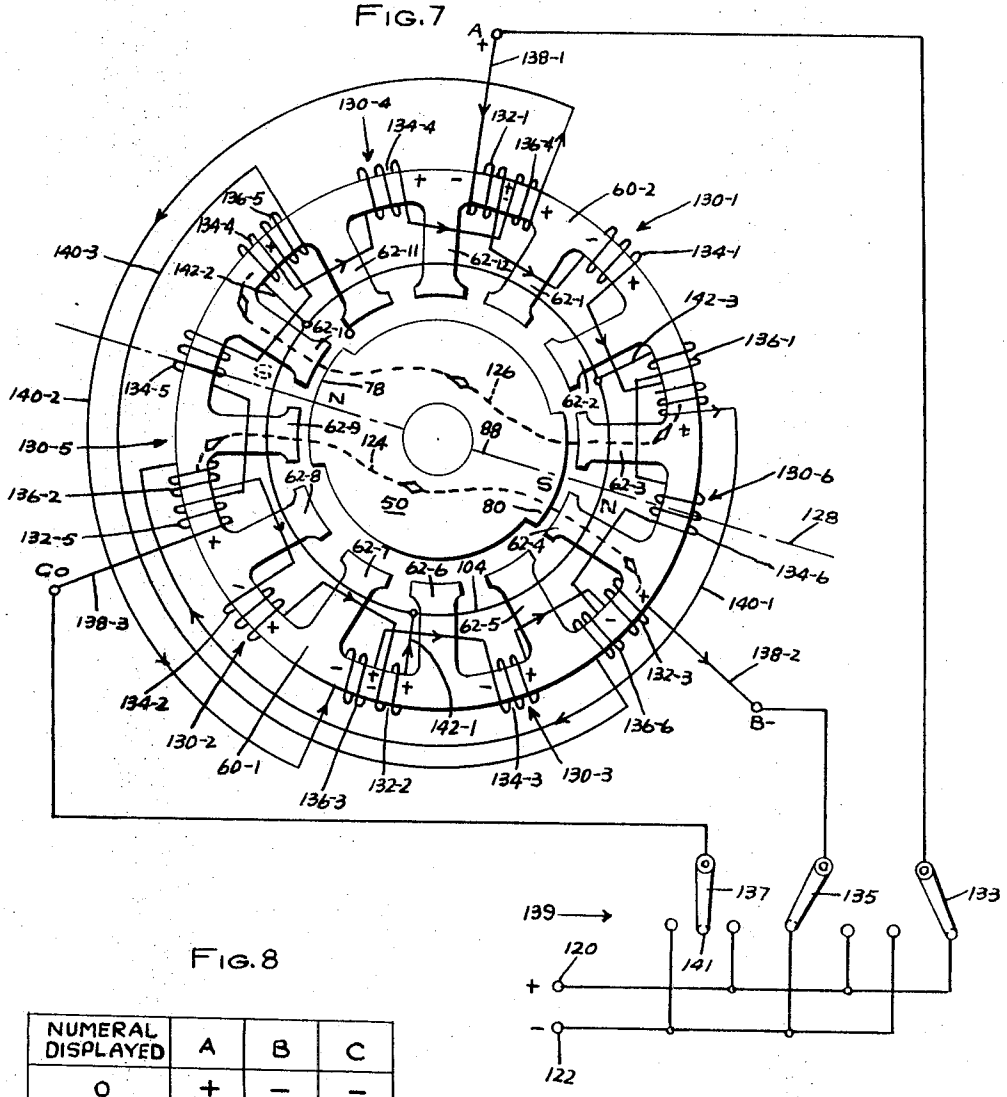
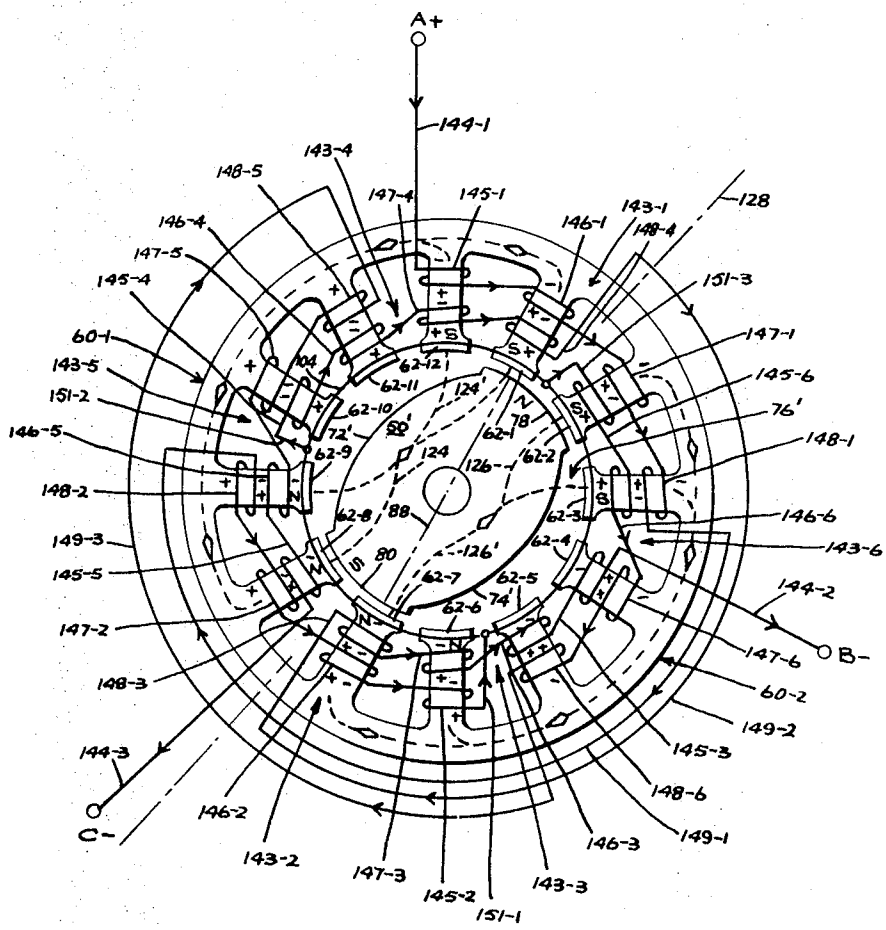



FIG. 8

| NUMERAL DISPLAYED | A | B | C |
|---|---|---|---|
| 0 | + | − | − |
| 1 | + | 0 | − |
| 2 | + | + | − |
| 3 | 0 | + | − |
| 4 | − | + | − |
| 5 | − | + | 0 |
| 6 | − | + | + |
| 7 | − | 0 | + |
| 8 | − | − | + |
| 9 | 0 | − | + |
| 10 | + | − | + |
| 11 | + | − | 0 |

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FIG. 9




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FIG. 10

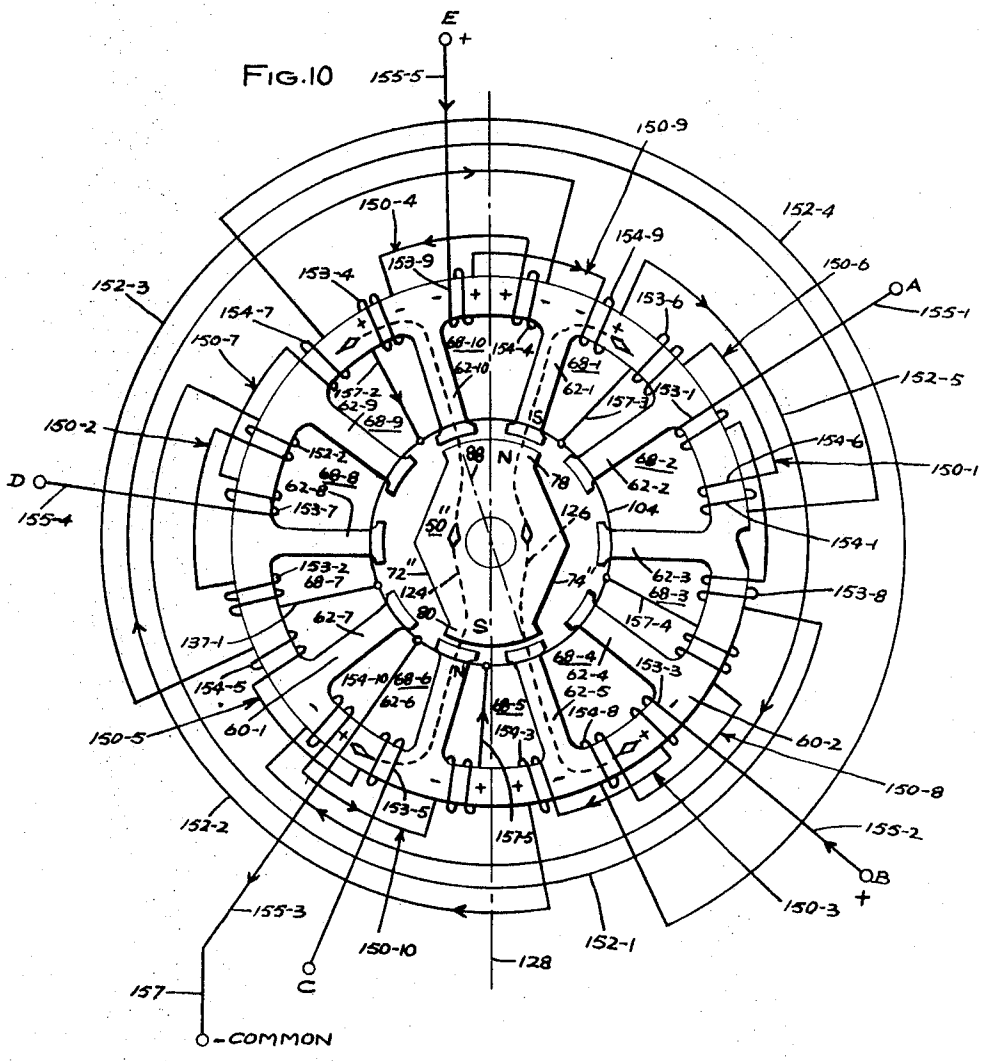



FIG. 11

| NUMERAL DISPLAYED | A | B | C | D | E | COMMON |
|---|---|---|---|---|---|---|
| 1 | | + | | | + | − |
| 2 | + | + | | | | − |
| 3 | + | | + | | | − |
| 4 | | + | + | | | − |
| 5 | | + | | + | | − |
| 6 | | | + | + | | − |
| 7 | | | + | | + | − |
| 8 | | | | + | + | − |
| 9 | + | | | + | | − |
| 10 | + | | | | + | − |

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FIG. 12

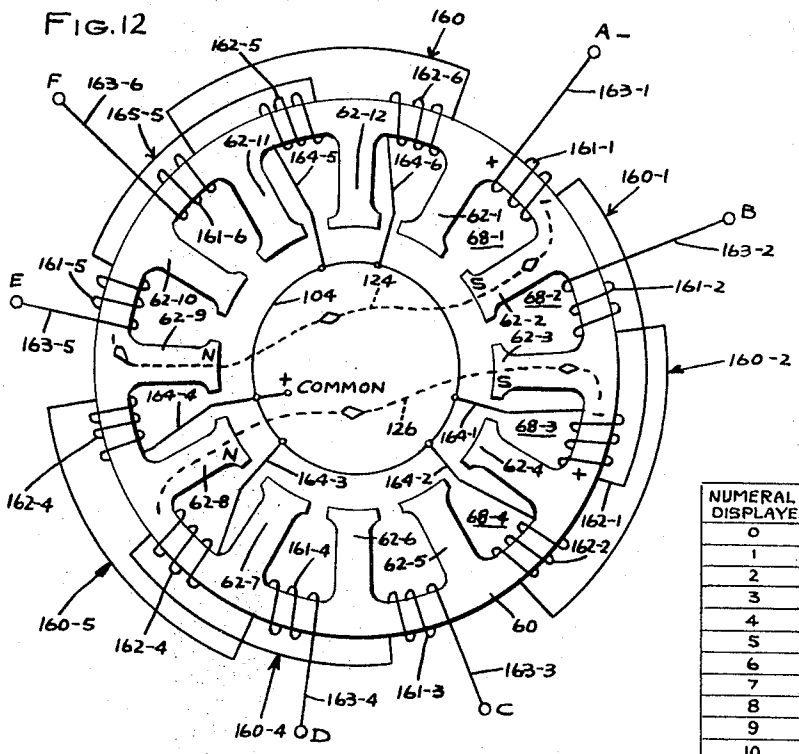
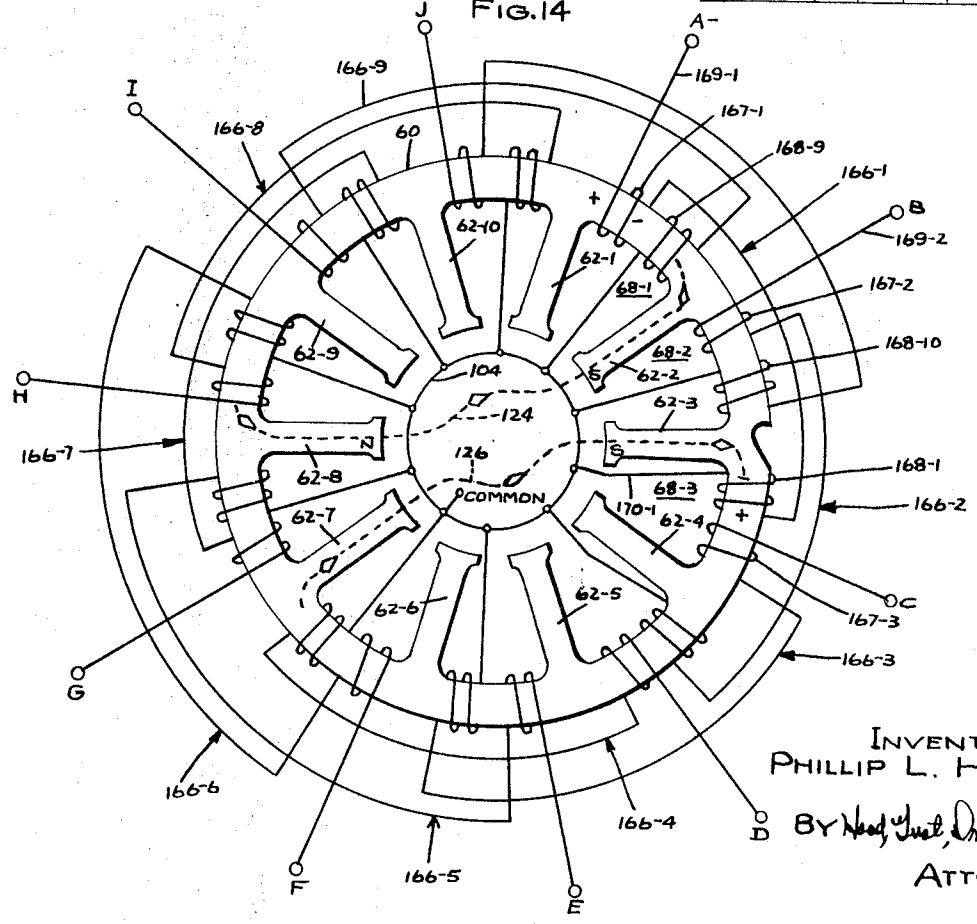



FIG. 13

| NUMERAL DISPLAYED | A | B | C | D | E | F | COM. |
|---|---|---|---|---|---|---|---|
| 0 | − | | | | | | + |
| 1 | | − | | | | | + |
| 2 | | | − | | | | + |
| 3 | | | | − | | | + |
| 4 | | | | | − | | + |
| 5 | | | | | | − | + |
| 6 | + | | | | | | − |
| 7 | | + | | | | | − |
| 8 | | | + | | | | − |
| 9 | | | | + | | | − |
| 10 | | | | | + | | − |
| 11 | | | | | | + | − |

FIG. 14




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# ELECTROMAGNETIC INDICATING APPARATUS

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to electromagnetic indicating apparatus of the rotary magnetic position indicating type for displaying discrete indicia in response to the characters of a prearranged code, and more particularly to electromagnetic indicating apparatus in which 180° rotation of the permanent magnet rotor member in a single step may be accomplished without an accompanying detent action.

2. Description of the Prior Art

A common type of electromagnetic indicating apparatus comprises a diametrically polarized permanent magnet rotor and a stator structure having a plurality of discrete poles with selectively energizable field windings thereon. Selective energization of the field windings causes the magnetic axis of the rotor to align itself with the respective poles of the field structure which are energized, thereby to provide the desired rotational indication. In some types of electromagnetic indicators, it is desired to rotate the rotor by 180° in one step, commonly accomplished by merely reversing the polarity of the voltage energizing the respective poles. However, the torque available for rotating the rotor is a function of the angular displacement of the magnetic axis of the rotor from the axis of energization of the field structure. Thus, while the rotor can be advanced by 180° in successive steps, i.e., from pole number one to pole number two, from pole number two to pole number three, et seq., since in each case there is an angular displacement between the magnetic axis of the rotor and the axis of energization, in the case of 180° rotation in a single step, there may be no such angular displacement and a form of "top dead-center" condition thus is provided.

A number of different types of electromagnetic rotary position indicator devices have been proposed which are capable of the desired 180° rotation of the rotor in a single step, those disclosed in U.S. Pat. No. 3,416,015 to Arthur R. Ordas, and assigned to the assignee of the present application; U.S. Pat. No. 3,311,911 to Leonard C. Pursiano et al.; U.S. Pat. No. 3,289,199 to John A. Watkins; U.S. Pat. No. 3,240,965 to Robert F. Casey; U.S. Pat. No. 3,218,625 to Aloysius E. Knotowicz; U.S. Pat. No. 3,118,138 to Raymond J. Milas et al.; and U.S. Pat. No 3,009,140 to Bernard M. Gordon, being typical. In each of these prior devices, the 180° rotation of the rotor member in a single step is accomplished by a magnetic detenting action in which the rotor is angularly displaced by a small amount upon deenergization of the field windings, thus providing the requisite angular displacement to eliminate the top dead-center condition. This detenting action, however, results in perceptible movement of the indicator drum between the energized and deenergized conditions. Thus, each numeral or indicia to be displayed, if in alignment with the viewing window in the energized condition, will be out of alignment in the deenergized condition, or vice versa.

It is desirable to provide an electromagnetic indicating device in which 180° rotation of the rotor member may be accomplished in a single step without the detenting action provided by such prior devices.

## SUMMARY OF THE INVENTION

The invention, in its broader aspects, provides electromagnetic indicating apparatus comprising a magnetic stator structure having means for forming a plurality of spaced, discrete pole face areas defining a bore. Winding means is provided on the stator structure for selectively energizing one preselected adjacent pair of the pole face areas with one magnetic polarity and another preselected adjacent pair with the opposite magnetic polarity. A permanent magnet rotor member is provided rotatably mounted in the bore and having a plurality of discrete rotational positions corresponding to the number of the pole face areas. The rotor member has peripheral surface portions which define a first plurality of radial airgaps with the pole face areas and means for forming a pair of spaced discrete pole face portions thereon which project radially outwardly from the surface portions and respectively define a second plurality of radial airgaps with the stator pole face areas which are narrower than the first plurality of airgaps. The rotor pole face portions respectively have an angular extent generally corresponding to the angular extent of each of the adjacent pair of stator pole face areas and are respectively aligned with the one and other adjacent pairs of oppositely polarized stator pole face areas in each position of the rotor member. The rotor member is polarized on a magnetic axis which extends through the pair of rotor pole face portions and which is generally aligned with one stator pole face area, respectively, of the one and other adjacent pairs of oppositely polarized stator pole face areas in each position of the rotor member.



It is accordingly an object of the invention to provide improved electromagnetic indicating apparatus.

Another object of the invention is to provide improved electromagnetic indicating apparatus capable of 180° rotation of the rotor member without a detenting action.

A further object of the invention is to provide an improved permanent magnet rotor member for electromagnetic indicating apparatus.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side cross-sectional view showing one embodiment of the invention;

FIG. 2 is a fragmentary cross-sectional view taken generally along the line 2–2 of FIG. 1;

FIG. 3 is an enlarged view of one configuration of the permanent magnet rotor member usable with the invention;

FIG. 4 is a schematic illustration of the embodiment of FIGS. 1 and 2 showing the connection of the stator windings together with the switching system therefor;

FIG. 5 is a chart showing a code which may be employed with the indicator system shown in FIG. 4;

FIG. 6 is a schematic illustration of a modification of the embodiment of FIG. 4 showing the windings position on the stator core teeth rather than upon the yoke portion;

FIG. 7 is a schematic illustration showing another embodiment of the invention which provides 12 discrete rotational positions with three external leads;

FIG. 8 is a chart showing a code which may be employed with the indicator system shown in FIG. 7;

FIG. 9 is a schematic illustration showing a modification of the embodiment of FIG. 7 in which the windings are positioned on the stator core teeth rather than upon the yoke portion;

FIG. 10 is a schematic illustration showing yet another embodiment;

FIG. 11 is a chart showing a code which may be employed with the embodiment of FIG. 10;

FIG. 12 is a schematic illustration showing a further embodiment in which only one winding is energized in each rotor position.

FIG. 13 is a chart showing a code which may be employed in the embodiment of FIG. 12; and

FIG. 14 is a schematic illustration showing an embodiment in which a separate lead is employed for each rotor position.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1 through 5, there is shown an electromagnetic indicator device, generally indicated at 20, for displaying 10 discrete indicia, such as the numerals zero through nine, in response to the characters of a prearranged code. Indicator 20 comprises housing 22 having spaced-apart

sidewalls 24, 26, bottom wall 28, and top wall 30 having window 32 therein for viewing the indicia which are displayed.

Annular cup-shaped member 34 is seated in recess 36 formed in the inner surface of sidewall 24. Stationary shaft 38 is provided having end 40 seated in opening 42 formed in cup-shaped member 34 and secured thereto. Suitable antifriction bearings 44 are positioned on shaft 38 and rotatably support rotor assembly 46.

Rotor assembly 46 comprises annular sleeve member 48 mounted on bearings 44 and having annular permanent magnet rotor member 50 secured thereto. Indicator drum 52 is provided having outer cylindrical drum portion 54 and inner annular flange portion 56 mounted on sleeve member 48, permanent magnet 50, sleeve member 48 and indicator drum 52 thus rotating as a unit on bearings 44. The outer peripheral surface of cylindrical portion 54 carries indicia which are viewed through window 32.

Stator core structure 58 is provided which may be conventionally formed of a stacked plurality of relatively thin laminations of magnetic material, or which may be formed of sintered magnetic material. Stator core structure 58 comprises annular yoke portion 60 having a plurality of equally angularly spaced polar projections or teeth 62 extending radially inwardly therefrom. Stator core structure 58 is mounted in annular flange portion 64 of cup-shaped member 34 by a plurality of C-shaped supporting insulators 66 which respectively embrace yoke portion 60 and extend radially inwardly on opposite sides of teeth 62, as shown. Adjacent teeth 62 respectively define slots 68 therebetween and inner ends 70 of teeth 62 mutually define a bore for receiving permanent magnet rotor member 50.

In the illustrated embodiment, permanent magnet rotor member 50 has opposite cylindrical surface portions 72, 74 which respectively define a first plurality of radial airgaps 76 with inner ends 70 of certain of teeth 62. A pair of diametrically opposite projections 78, 80 are formed which project radially outwardly from the surface portions 72, 74 and respectively form pole face portions 82, 84 which define a second plurality airgaps 86 with tooth ends 70 which are narrower and thus have lower reluctance than airgaps 76. Projections 78, 80 each have an angular extent $\Phi$ generally equal to the angular extent of inner ends 70 of an adjacent pair of teeth 62. As will be hereinafter more fully described, and as seen in FIGS. 2 and 4, in each discrete rotational position of rotor member 50, projections 78, 80 and pole face portions 82, 84 are generally aligned, respectively, with diametrically opposite adjacent pairs of teeth 62. Intermediate surface portions 72, 74 need not be cylindrical thus forming uniform airgaps 76, but may be oval or of another configuration with some of the airgaps 76 then being wider than others; airgaps 86 must, however, be narrower than any of the airgaps 76.

Permanent magnet rotor member 50 is polarized on a magnetic axis 88 which extends through the pole face portions 82, 84, magnetic axis 88 in the illustrated embodiment being generally aligned with a diametrically opposite pair of teeth 62 in each rotational position of rotor member 50. In one embodiment of the invention, magnetic axis 88 of permanent magnet rotor member 50 is angularly displaced from grain axis 90 by the angle $\theta$, as shown in FIG. 3, however, the grain axis may be coincident with the magnetic axis. In a specific 10 pole embodiment of the invention, the angular extent of projections 78, 80 indicated as angle $\Phi$, was 57°, the angular extent of ends 70 of an adjacent pair of teeth 62 being 57°, and angle $\theta$ was 46°.

In the 10 pole, 10 position indicator of FIGS. 1 through 5, 10 field windings 92 are provided each comprising two coils 94, 96 connected in series, coils 94, 96 being respectively wound in toroidal fashion on yoke portion 60 and being disposed in adjacent slots 68 on opposite sides of respective tooth 62. Thus, there is a first coil 94 of one winding and a second coil 96 of an adjacent winding in each slot 68. Each of the coils 94, 96 of a winding 92 is arranged in aiding relationship.

In accordance with the embodiment of the invention illustrated in FIGS. 2 and 4, each winding 92 is serially connnected with a diametrically opposite winding 92, with the respective teeth 62 disposed between the respective coils 94, 96 thus being diametrically opposite. Thus, in the illustrated embodiment, end 98–1 of coil 94–1 of winding 92–1 is connected to exterminal A, end 100–1 of coil 96–1 is connected to diametrically opposite coil 96–2 of diametrically opposite winding 92–2, and end 102–1 of coil 94–2 diametrically opposite coil 94–1 is connected to common connection 104. Similarly, end 98–3 of coil 94–3 of winding 92–3 is connected to external terminal B, end 100–3 of coil 96–3 is connected to coil 96–4 of winding 92–4, and end 102–4 of coil 94–4 is connected to common connection 104. In like fashion, diametrically opposite windings 92–5 and 9–6 are serially connected between external terminal C and common connection 104, windings 92–7 and 92–8 are serially connected between external terminal D and common connection 104, and windings 92–9 and 92–10 are serially connected between external terminal E and common connection 104.

In the illustrated embodiment, external terminals A, B, C, D and E are respectively connected to double pole switches 106, 108, 110, 112 and 116 of switching system 118 for selectively connecting each of the serially connected pairs of diametrically opposite windings 92 to the positive polarity side 120 or the negative polarity side 122 of a source of direct current potential (not shown). It will be readily understood that a static switching system may be employed for the switching system schematically shown at 118.

Assuming now that external terminals A, B and C are coupled by switching system 118 to the positive polarity side 120 and that external terminals D and E are connected to the negative polarity side 122, as shown in FIG. 4, it will be seen that the coils of windings 92–6, 92–9, 92–4, 92–7 and 92–2 will all be in aiding relationship, the direction of current flow and the resulting mmfs. being such as to provide a magnetic flux path, as shown by the dashed line 124, through permanent magnet rotor member 50, tooth 62–6, yoke portion 60–1, and tooth 62–2, tooth 62–2 being polarized "North," and tooth 62–6 being polarized "South." Similarly, it will be seen that the coils of windings 92–1, 92–8, 92–3, 92–10 and 92–5 are in aiding relationship with the current flows and resulting mmfs. being such as to provide a flux path, as shown by the dashed line 126, through the permanent magnet rotor member 50, tooth 62–1, yoke portion 60–2, and tooth 62–5, tooth 62–5 likewise being polarized "North," and tooth 62–1 being polarized "South." It will thus be seen that with the external terminals connected to the polarities shown in FIG. 4, two parallel flux paths 124, 126 are provided which respectively polarize the diametrically opposite adjacent pairs of teeth 62–5, 62–2 "North," and 62–1, 62–6 "South," the two magnetic flux paths being on opposite sides of a polar axis shown by the dashed line 128. It will further be seen that the permanent magnet rotor member 50 will align itself with its "-North" projection 78 and pole face portion 82 aligned with the "South" teeth 62–1, 62–6, and with its "South" projection 80 and pole face portion 84 aligned with the "North" teeth 62–5 and 62–2, the magnetic axis 88 being aligned with the diametrically opposite teeth 62–5 and 62–6. It will be seen that the adjacent ends of the adjacent coils 94–1 and 96–6 provide mmfs. of the same polarity and likewise that the adjacent ends of the adjacent coils 94–2 and 96–5 provide mmfs. of the same polarity, thus establishing the polar axis 128 between the diametrically opposite pairs of adjacent, oppositely polarized teeth.

In the preferred embodiment of FIGS. 2 and 4, each of the windings 92 is identical, however, coils 94 have a greater number of turns than coils 96, such as a ratio of 2/3 to 1/3. Thus, with the connections shown in FIG. 4, the mmf. in tooth 62–6 will be slightly more negative than the mmf. in the adjacent tooth 62–1, i.e., the "South" polarization of tooth 62–6 is slightly stronger than the "South" polarization of 62–1. Likewise, the mmf. in tooth 62–5 will be slightly more positive

than the mmf. in tooth 62–2, i.e., the "North" polarization of tooth 62–5 will be slightly stronger than the "North" polarization of tooth 62–2, this slight magnetic unbalance serving to aid in the return of the permanent magnet rotor member 50 to the position shown in FIG. 4 following rotational advance of the rotor member clockwise to the next rotational position with projection 78 aligned with the adjacent pair of teeth 62–1, 62–8.

Assuming now that the digits zero to nine are displayed on the drum 54 with respect to the position of the permanent magnet rotor member 50 as shown in FIG. 2, selective energization of the external terminals A through E with positive or negative polarity in accordance with the code shown in FIG. 5 will result in selective positioning of the permanent magnet rotor member 50 at any one of 10 discrete rotational positions. Thus, with terminals A, D and E connected to the negative polarity side 122 and terminals B and C connected to the positive polarity side 120, inspection of FIG. 4 will reveal that the adjacent pair of teeth 62–1, 62–8 will be polarized "-South" and the diametrically opposite adjacent pair of teeth 62–2, 62–7 will be polarized "North." It will further be seen that the mmf. in tooth 62–1 will now be more negative than the mmf. in tooth 62–8, and likewise that the mmf. in tooth 62–2 will be more positive than the mmf. in tooth 62–7, and thus, the "North" projection 78 will be attracted toward alignment with the "South" adjacent pair of teeth 62–1, 62–8, and the "South" projection 80 will be attracted toward alignment with the adjacent pair of teeth 62–7, 62–2, magnetic axis 88 of permanent magnet rotor member 50 thus rotating into alignment with diametrically opposite teeth 62–1, 62–2 and thus moving the digit "one" clockwise for display in window 32.

It will now be observed that with magnetic axis 88 of permanent magnet rotor member 50 at all times in alignment with a respective diametrically opposite pair of teeth 62, no incremental rotation of the permanent magnet rotor member or detent action occurs when energization is removed from the windings 92. Thus, a respective numeral will be displayed in exactly the same position in the window 32 both when the windings 92 are energized and when they are deenergized.

Still referring to FIG. 4 and to the "zero" position of permanent magnet rotor member 50 shown with external terminals A, B and C connected to positive polarity side 120 and terminals D and E connected to negative polarity side 122, it will be assumed that the polarities are reversed so as to display the diametrically opposite numeral "five," i.e., terminals A, B and C are connected to the negative polarity side 122 and terminals D and E connected to the positive polarity side 120, as shown in FIG. 5. It will now be seen that with this connection, the adjacent teeth 62–1, 62–6 will be polarized "North" and the diametrically opposite adjacent pair of teeth 62–5, 62–2 will now be polarized "South." Further, it will be seen that the "North" tooth 62–1 and "South" tooth 62–2 are respectively angularly displaced from the "South" and "North" polar extremities of the magnetic axis 88 thus providing the requisite angular displacement to insure rotation of permanent magnet rotor member 50 by 180°.

It will be seen that in this embodiment all of the coils of all of the windings are energized in each rotational position of rotor member 50 thus providing 100 percent utilization of the windings. While an unbalance between the number of turns respectively provided for the two coils 94, 96 of each winding 92 is considered preferable, the two coils may have the same number of turns.

Referring now to FIG. 6 in which like elements are indicated by like reference numerals, there is shown a modification of the embodiment of FIGS. 2 and 4 in which the two coils 94, 96 comprising field windings 92 are positioned on the stator teeth 62 rather than upon the yoke 60. Thus, serially connected coils 94–1, 96–1 comprising winding 92–1 are respectively positioned on teeth 62–1, 62–8 with end 98–1 connected to external terminal A. The other end 100–1 of winding 92–1 is connected to one end of serially connected coils 96–2, 94–2 of winding 92–2 having its other end 100–2 connected to the common connection 104. Coils 96–2, 94–2 are respectively positioned on teeth 62–7, 62–2 respectively diametrically opposite teeth 62–8, 62–1. Each of the serially connected coils 94, 96 of a winding 92 is arranged to provide mmfs. of the same polarity in their respective teeth.

The serially connected coils 94, 96 of the remaining windings 92 are similarly positioned and connected respectively to the remaining external terminals B, C, D and E and to the common connection 104. It will thus be seen that each tooth 62 has coil 94 of one winding 92 and a coil 96 of an adjacent winding positioned thereon. Assuming now that the A, B, D and E terminals are connected to the positive side of the source and that the C terminal is connected to the negative side, it will be seen that the directions of current flow and the resulting mmfs. will be such that the coils 94–1, 96–6 on tooth 62–1 and 94–6, 96–9 on tooth 62–6 will be in aiding relationship thereby to polarize teeth 62–1, 62–6, "South," and likewise that coils 94–2, 96–5 on tooth 62–2, and 94–5, 96–10 on tooth 62–5 will be in aiding relationship to polarize teeth 62–2, 62–5 "North," thereby causing permanent magnet rotor member 50 to position itself with projections 78, 80 respectively aligned with the diametrically opposite "South" and "-North" adjacent pairs of teeth and with magnetic axis 88 aligned with teeth 62–6, 62–5. It will further be seen that the coils 94, 96 positioned on the remaining teeth intermediate the "South" teeth 62–1, 62–6, and the "North" teeth 62–5, 62–2 will be in bucking relationship.

Inspection of FIG. 6 will now reveal that by selectively connecting the external terminals A, B, C, D and E to positive and negative polarity sides of the source in accordance with a prearranged code, 10 discrete rotational positions for the permanent magnet rotor member 50 will be provided. In this embodiment, it is preferable that each of the coils 94, 96 of each of the field windings 92 has substantially the same number of turns.

It will be seen that the embodiments of FIGS. 2, 4 and 6 provide 10 discrete rotational positions for permanent magnet rotor member 50 with five external terminals. It will be readily apparent that a 12 pole, 12 position indicator employing six external terminals may readily be provided using either the toroidal winding configuration of FIG. 4 or the salient pole winding arrangement of FIG. 6, the only requirement being that the stator structure have an even number of equally spaced pole face areas with each such pole face area being diametrically opposite another pole face area.

Referring now to FIGS. 7 and 8, the nondetent indicator of the invention may be embodied in a 12 pole, 12 position device employing only three external terminals. Here, six field windings 130 are provided, each comprising three serially connected coils 132, 134, 136 respectively wound in toroidal fashion on yoke portions 60 in adjacent slots and arranged in aiding relationship. Thus, coils 132–1, 134–1, 136–1 of winding 130–1 are positioned in slots respectively on opposite sides of teeth 62–1, 62–2, end 138–1 of coil 132–1 being connected to external terminal A and end 140–1 of coil 136–1 being connected to coil 136–2 of diametrically opposite winding 130–2. Coils 136–2, 134–2 and 132–2 are respectively positioned in slots on opposite sides of teeth 62–8, 62–7 which are diametrically opposite teeth 62–1, 62–2. The other end 142–1 of coil 132–2 is connected to the common connection 104.

In like fashion, winding 130–3 has its three coils 132–3, 134–3 and 136–3 respectively positioned in slots on opposite sides of teeth 62–5, 62–6, end 138–2 of coil 132–3 being connected to external terminal B and end 140–2 of coil 136–3 being connected to coil 136–4 of diametrically opposite winding 130–4. Coils 132–4, 134–4 and 136–4 of winding 130–4 are respectively positioned in the slots on opposite sides of teeth 62–11, 62–12, end 142–2 of coil 132–4 being connected to the common connection 104. It will now be seen that coils 132–1 of winding 130–1 and 136–4 of winding 130–4 share the same slot and likewise that coils 132–2 of winding 130–2 and 136–3 of winding 130–3 share the same slot.

Finally, end 138–3 of coil 132–5 of winding 130–5 is connected to external terminal C, coils 132–5, 134–5 and 136–5 of winding 130–5 being respectively positioned in slots on opposite sides of teeth 62–9, 62–10. The other end 140–3 of coil 136–5 is connected to coil 136–6 of the diametrically opposite winding 130–6 which has its coils 132–6, 134–6 and 136–6 respectively positioned in the slots on opposite sides of teeth 62–3, 62–4, end 142–3 of coil 132–6 being connected to the common connection 104. Again it will be observed that coil 132–6 shares the same slot with coil 136–1, coil 136–6 shares the same slot with coil 132–3, coil 136–5 shares the same slot with coil 132–4, and coil 132–5 shares the same slot with coil 136–2.

External terminals A, B and C are respectively connected to the three-pole switches 133, 135, 137 of switching system 139, each of the switches being adapted to connect its respective external terminal to positive side 120 or negative side 122 of the source, or to a neutral deenergized position 141.

Assuming now that terminal A is connected to the positive polarity side 120, terminal B is connected to the negative polarity side 122, and the terminal C is connected to neither side (designated "zero"), inspection of FIG. 7 will reveal that the directions of current flow and the resulting mmfs. are such that coils 132–4, 134–4, 132–1, 136–4, 134–1 and 136–1 are in aiding relationship thereby to provide magnetic flux path 126 traversing permanent magnet rotor member 50, tooth 62–10, yoke portion 60–2 and tooth 62–3, polarizing tooth 62–10 "South" and tooth 62–3 "North." Likewise, coils 132–3, 130–3, 132–2, 136–3, 130–2 and 136–2 are in aiding relationship to provide magnetic flux path 124 traversing rotor 50, tooth 62–9, yoke portion 60–1 and tooth 62–4 polarizing tooth 62–9 "South" and tooth 62–4 "North." It is thus seen that again, two parallel flux paths are provided on either side of polar axis 128, the adjacent pair of teeth 62–10 and 62–9 being polarized "South" and the adjacent pair 62–3, 62–4 being polarized "North" thereby to position the permanent magnet rotor member 50 with its "North" projection 78 in alignment with teeth 62–10, 62–9 and with its "South" projection 80 in alignment with teeth 62–3, 62–4, magnetic axis 88 being aligned with teeth 62–3, 62–9.

Inspection of FIGS. 7 and 8 will reveal that by selective connection of the external terminals A, B and C to positive, negative and "zero" polarities in accordance with the code shown in FIG. 8, 12 discrete rotational positions for rotor member 50 are provided.

Referring now to FIG. 9 of the drawing, six field windings 143 are provided, each comprising four serially connected coils 145, 146, 147 and 148 respectively positioned on four adjacent teeth 62 and arranged to provide mmfs. of the same polarity in their respective teeth. Thus, coils 145–1, 146–1, 147–1 and 148–1 of winding 143–1 are positioned on teeth 62–12, 62–1, 62–2 and 62–3, end 144–1 of coil 145–1 being connected to external terminal A, and end 149–1 of coil 148–1 being connected to coil 148–2 of diametrically opposite winding 143–2. Coils 148–2, 147–2, 146–2 and 145–2 are respectively positioned on teeth 62–9, 62–8, 62–7 and 62–6 which are respectively diametrically opposite teeth 62–3, 62–2, 62–1 and 62–12. The other end 151–1 of coil 145–2 is connected to the common connection 104.

In like fashion, winding 143–3 has its four coils 145–3, 146–3, 147–3 and 148–3 respectively positioned on teeth 62–4, 62–5, 62–6 and 62–7, end 144–2 of coil 145–3 being connected to external terminal B, and end 149–2 of coil 148–3 being connected to coil 148–4 of diametrically opposite winding 143–4. Coils 148–4, 147–4, 146–4 and 145–4 of winding 143–4 are respectively positioned on teeth 62–1, 62–12, 62–11 and 62–10, end 151–2 of coil 145–4 being connected to the common connection 104. It will now be seen that coils 145–1 and 146–1 of winding 143–1, and coils 147–4 and 148–4 of winding 143–4 share the same teeth 62–12 and 62–1, respectively, and that coils 145–2 and 146–2 of winding 143–2, and coils 147–3 and 148–3 of winding 143–3 share the same teeth 62–6 and 62–7, respectively.

Finally, end 144–3 of coil 145–5 of winding 143–5 is connected to external terminal C, coils 145–5, 146–5, 147–5 and 148–5 of winding 143–5 being respectively positioned on teeth 62–8, 62–9, 62–10 and 62–11. The other end 149–3 of coil 148–5 is connected to coil 148–6 of the diametrically opposite winding 143–6 which has its coils 148–6, 147–6, and 145–6 respectively positioned on teeth 62–5, 62–4, 62–3 and 62–2, end 151–3 of coil 145–6 being connected to common connection 104.

It will now be observed that two of the coils of each winding share the same teeth with two coils of one of the other two windings, and the other two coils of each winding share the same teeth with two coils of the other two windings each tooth thus having two coils thereon, all of the coils having substantially the same number of turns and preferably being wound in the same sense. External terminals A, B and C may again be respectively connected to the three-pole switches 133, 135 and 137 of switching system 139 of the embodiment of FIG. 7.

In this embodiment, intermediate surface portions 72', 74' of permanent magnet rotor member 50' are shown as being oval and in configuration, rather than cylindrical as in the previous embodiments.

Assuming now that terminal A is connected to the positive polarity side 120 and that terminals B and C are connected to the negative polarity side 122 (FIG. 7), inspection of FIG. 9 will reveal that the directions of current flow and resulting mmfs. are such that coils 145–1 and 147–4 on tooth 62–12, coils 146–1 and 148–4 on tooth 62–1, coils 147–1 and 145–6 on tooth 62–2, and coils 148–1 and 146–6 on tooth 62–3 are respectively in aiding relationship, thereby polarizing those teeth "South;" and such that coils 145–2 and 147–3 on tooth 62–6, coils 146–2 and 148–3 on tooth 62–7, coils 147–2 and 145–5 on tooth 62–8, and 148–3 on tooth 62–7, coils 147–2 and 145–5 on tooth 62–8, and coils 148–2 and 146–5 on tooth 62–9 are likewise respectively in aiding relationship, thereby polarizing those teeth "North;" coils 148–6 and 146–3 on tooth 62–5, 147–6 and 145–3 on tooth 62–4, 148–5 and 146–4 on tooth 62–11, and 147–5 and 145–4 on tooth 62–10 being respectively in bucking relationship, thereby rendering these teeth magnetically neutral.

It will now be seen that once again two parallel magnetic flux paths, 124, 126 are established, flux path 124 traversing tooth 62–8, rotor member 50, tooth 62–1 and yoke portion 60–1, and flux path 126 traversing tooth 62–7, rotor member 50', tooth 62–2 and yoke portion 60–2, thereby positioning permanent magnet rotor member 50' with its "North" projection 78 in alignment with teeth 62–1 and 62–2 and with its "South" projection 80 in alignment with teeth 62–7 and 62–8, magnetic axis 88 being aligned with teeth 62–1 and 62–7.

It will be observed, that due to leakage, parallel flux paths 124' and 126' are also established from tooth 62–9 through rotor 50' to tooth 62–12, and from tooth 62–6 through rotor 50' to tooth 62–2. However, with the rotor member 50' initially in another position, upon connection of the A terminal to the positive side and the B and C terminals to the negative side of the source, the rotor member 50' will rotate to the magnetically balanced position shown.

Inspection of FIGS. 8 and 9 will reveal that by selective connection of the external terminals A, B and C to positive, negative and "zero" polarities in accordance with a prearranged code as shown in FIG. 8, 12 discrete rotational positions for rotor member 50' are provided.

In each of the previous embodiments, the different discrete rotor positions are provided by selective connection of the external terminals to positive or negative polarity sides of a source of direct current potential. Referring now to FIGS. 10 and 11 of the drawings, there is shown an embodiment of the invention in which the external terminals are selectively connected to only one polarity side, shown as being positive, with the common connection at all times connected to the opposite polarity side, shown as being negative.

Here, in a 10 position version, ten field windings 150 are provided, each comprising two serially connected coils 153

and 154 wound in toroidal fashion on yoke portion 60 in adjacent slots 68 with one tooth 62 therebetween. All of the coils 153, 154 have substantially the same number of turns and are preferably wound in the same sense.

Thus, coils 153–1 and 154–1 of winding 150 are respectively positioned in adjacent slots 68–2 and 68–3 with tooth 62–3 therebetween, end 155–1 of coil 153–1 being connected to external terminal A, and end 152–1 being connected to coil 154–2 of the diametrically opposite winding 150–2 having its coils 154–2 and 153–2 respectively positioned in slots 62–8 and 62–7. End 157–1 of coil 153–2 is connected to the common connection 104, in turn connected to a common external terminal by lead 157. Similarly, coils 153–3 and 154–3 of winding 150–3 are respectively positioned in slots 68–4 and 68–5, end 155–2 of coil 153–3 being connected to external terminal B, and end 152–2 of coil 154–3 being connected to coil 154–4 of winding 150–4, coils 154–4 and 153–4 being respectively positioned in slots 86–10 and 86–9, with end 157–2 of coil 153–4 being connected to the common connection 104.

Coils 153–5 and 154–5 of winding 150–5 are respectively positioned in slots 68–6 and 68–7, end 155–3 of coil 153–5 being connected to external terminal C, and 152–3 of coil 154–5 being connected to coil 154–6 of winding 150–6. Coils 154–6 and 153–6 of winding 150–6 are respectively positioned in slots 68–2 and 68–1, end 157–3 of coil 153–6 being connected to common connection 104. It will now be observed that coil 154–6 of winding 150–6 shares slot 68–2 with coil 153–1 of winding 15–1.

Likewise, coils 153–7 and 154–7 of winding 150–7 are respectively positioned in slots 62–8 and 62–9, end 155–4 of coil 153–7 being connected to external terminal D, and end 152–4 of coil 154–7 being connected to coil 154–8 of winding 150–8. Coils 154–8 and 153–8 of winding 150–8 are respectively positioned in slots 68–4 and 68–3, end 157–4 of coil 153–8 being connected to common connection 104. Now it will be observed that coil 153–7 of winding 150–7 shares slot 62–8 with coil 154–2 of winding 150–2, and that coils 154–8 and 153–8 of winding 150–8 respectively share slots 68–4 and 68–3 with coil 153–3 of winding 150–3 and with coil 154–1 of winding 150–1.

Finally, coils 153–9 and 154–9 of winding 150–9 are respectively positioned in slots 68–10 and 68–1, end 155–5 of coil 153–9 being connected to external terminal E, and end 152–5 of coil 154–9 being connected to coil 154–10 of winding 150–10, coils 154–10 and 153–10 of winding 150–10 are respectively positioned in slots 68–6 and 68–5, end 157–5 of coil 153–10 being connected to common connection 104. It will be seen that coils 153–9 and 154–9 respectively share slots 68–10 and 68–1 with coil 154–4 of winding 150–4 and with coil 153–6 of winding 150–6, coils 154–10 and 153–10 of winding 150–respectively sharing slots 68–6 and 68–5 with coil 153–5 of winding 150–5, and with coil 154–3 of winding 150–3.

It will now be seen that in this embodiment, each of the windings 150 has two serially connected coils respectively positioned in two adjacent slots 68, each such winding being serially connected to the diametrically opposite winding, each coil of each winding further sharing its slot with one coil of the adjacent winding. In this embodiment, permanent magnet rotor member 50'' is shown as having intermediate surface portions 72'' and 74'' which are somewhat pointed in configuration, rather than cylindrical or oval as in the previous embodiments.

Assuming now that the it and E terminals are respectively connected to the positive polarity side of a source, with the common terminal connected to the negative polarity side of the same source, thereby to display the numeral "one" in accordance with the code shown in FIG. 11, it will be seen that while coils 153–9 and 154–4 in slot 68–10, and coils 153–10 and 154–3 in slot 68–5 are respectively in bucking relationship, the directions of current flow in and the resulting mmfs. established by coils 153–4 and 154–9 on the one hand, and coils 153–5 and 154–8 on the other hand are such as to polarize teeth 62–10 and 62–1 "South," and to polarize teeth 62–6 and 62–5 "North." Thus, rotor member 50' will be oriented with its "North" projection 78 aligned with teeth 62–10 and 62–1, and with its "South" projection 80 aligned with teeth 62–6 and 62–5, magnetic axis 88 being aligned with teeth 62–10 and 62–5. Once again two parallel flux paths 124, 126 are established, path 124 traversing tooth 62–6, rotor member 50'', tooth 62–10 and yoke portion 60–1, and path 126 traversing tooth 62–5, rotor member 50'', tooth 62–1 and yoke portion 60–2.

Inspection of FIGS. 10 and 11 will reveal that selectively connecting two of the five external terminals A, B, C, D and E to the positive polarity side of the source will result in the provision of 10 discrete positions for rotor member 50'', 180° reversal being provided without detent action as above described. It will also be observed that certain of the rotor positions can be obtained by connecting only one of the external terminals to the positive polarity side of the source. Thus, positions 1, 3, 5, 7 and 9 can be obtained by respectively connecting only terminals A, B, C, D and E, the remaining positions requiring connection of two terminals as shown in FIG. 11.

Referring now to FIG. 12, a somewhat simplified embodiment of the invention is shown in which only one of the six field winding is energized in each rotor position, the energized winding polarizing one adjacent pair of stator core teeth with one magnetic polarity, the diametrically opposite pair of teeth being oppositely polarized as consequent poles, thereby establishing the parallel magnetic flux paths through the permanent magnet rotor member.

In this embodiment in which the rotor member 50 (not shown) may have any of the configurations shown in FIGS. 3, 9 and 10, six field windings 160 are provided, each comprising two serially connected coils 161, 162 wound in toroidal fashion on yoke portion 60 in respective slots 68 which are spaced apart by one slot, i.e., with two teeth 62 therebetween. All of the coils have substantially the same number of turns, and while they may be wound in the same sense, coils 161, 162 of each winding are coupled in bucking relationship. It will be observed that in this embodiment, there is only one coil in each slot 68.

End 163 of each winding is connected to a respective external terminal, while end 164 is connected to the common connection 104, to which a common external terminal is connected. Thus, winding 160–1 has end 163–1 connected to external terminal A, its two coils 161–1 and 162–1 wound on yoke portion 60 in slots 68–1 and 68–3 with tooth 62–2, slot 68–2 and tooth 62–3 therebetween, and its other end 164–1 connected to the common connection 104. It will be seen that coil 161–2 of winding 160–2 is disposed in slot 68–2 between slot 68–1 and coil 161–1, and slot 68–3 and coil 162–1. Similarly, each pair of coils of a winding have a coil of an adjacent winding therebetween in the intermediate slot.

It will now be observed that with the external terminal A and the common terminal respectively connected to the negative and positive polarity sides of a source of direct current potential, the B through F terminals being connected to neither side of the source with windings 160–2 through 160–6 thus being deenergized, the directions of current flow in coils 161–1 and 162–1 of winding 160–1 and the resulting mmfs. are such that teeth 62–2 and 62–3 between coils 161–1 and 162–1 are polarized as "South," the diametrically opposite teeth 62–8 and 62–9 being polarized as "North" consequent poles. It will there be seen that with the permanent magnet rotor member of any of the previous FIGS. positioned in the bore, the two parallel magnetic flux paths are again established, the rotor being thereby positioned with its "-North" projection 78 in alignment with teeth 62–2 and 62–3, and with its "South" projection 80 in alignment with teeth 62–8 and 62–9.

Inspection of FIGS. 12 and 13 will show that by selective connection of external terminals A through F, and the com-

mon terminal to positive and negative polarities in accordance with the prearranged code shown, 12 discrete rotational positions for the rotor member are provided. It will also be seen that 180° reversal and absence of detent action upon deenergization are also provided.

It will readily be understood that the embodiment of FIG. 12 may be employed in a 10-tooth stator core member to provide 10 discrete rotor positions, or in a stator core member having more than 12 teeth to provide a correspondingly greater number of rotor positions.

Referring now to FIG. 14 an embodiment is shown similar to the embodiment of FIG. 12, but employing an external lead for each rotor position plus a common lead. Thus, 10 field windings are provided, only one of which energized for each rotor position, the energized winding again polarizing an adjacent pair of stator core teeth with one polarity, the diametrically opposite pair of teeth again being oppositely polarized. As in the embodiment of FIG. 12, the rotor member **50** (not shown) may have any of the configurations shown in the previous embodiments.

Here, the 10 field windings **166** each comprise two serially connected coils **167, 168** toroidally wound on yoke portion **60** in respective slots **68**, again spaced apart by one slot, i.e., with two teeth **62** therebetween. All of the coils are substantially identical, the coils of each winding being arranged in bucking relationship. End **169** of each winding is connected a respective external terminal and end **170** to the common connection **104**. It will here be observed that each slot **68** has therein the coil **167** of one winding and the coil **168** of the adjacent winding.

Thus, winding **166–1** has its end **169–1** connected to external terminal A, its two coils **167–1** and **168–1** wound on yoke portion **60** respectively in slots **68–1** and **68–3** with tooth **62–2**, slot **68–2**, and tooth **62–3** therebetween, and its other end **170–1** connected to common connection **104**. It will be seen that coil **168–9** of winding **166–9** shares slot **68–1** with coil **167–1**, and that coil **167–3** of winding **166–3** likewise shares slot **68–3** with coil **168–1**. Coil **167–2** of winding **166–2**, and coil **168–10** of winding **166–10** share the intermediate slot **68–2**.

Assuming now that external terminal A and the common terminal are respectively connected to the negative and positive sides of a direct current source, the B through J terminals being disconnected therefrom and windings **166–2** through **166–10** thus deenergized, the direction of current flow in coils **167–1** and **168–1** and the resulting mmfs. are such that the adjacent pair of teeth **62–2** and **62–3** between coils **167–1** and **168–1** are polarized "South," the diametrically opposite adjacent pair of teeth **62–7** and **62–8** being polarized as "North" consequent poles. Thus, with rotor member **50** of any of the previous embodiments positioned in the bore, the parallel magnetic flux paths **124, 126** are again established, with the rotor positioned with its "North" projection **78** aligned with teeth **62–2, 62–3** and its "South" projection **80** aligned with teeth **62–7, 62–8**.

It will now be seen that selective connections of external terminals A through J to the negative side of the source with the common terminal connected to the positive side (or vice versa) will result in the provision of 10 discrete rotational positions of the rotor member, 180° reversal and absence of detent action again being provided. It will also be seen that the embodiment of FIG. 14 may be employed with 12 or higher number of teeth to provide a greater number of rotor positions. Likewise, a lesser number of teeth to provide fewer positions may be employed.

It will now be understood that there are other winding configurations which in combination with the permanent magnet rotor member **50** of FIGS. **3, 9** or **10** will provide the desired number of discrete rotational positions without a detent action of the rotor between the energized and deenergized conditions, the basic requirement being that each pole face portion **82, 84** of the rotor span an adjacent pair of stator pole face areas with the magnetic axis **88** being aligned with one such pole face area and thus angularly displaced from the other. It will thus be understood that the rotor member projections **78, 80** need not necessarily be diametrically opposite and that the magnetic axis need not extend diametrically through the rotor.

While there have been described above the principles of this invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of the invention.

I claim:

**1.** Electromagnetic indicating apparatus comprising:

a magnetic stator structure having means for forming a plurality of spaced discrete pole face areas defining a bore; winding means on said stator structure for selectively energizing one preselected adjacent pair of said pole face areas with one magnetic polarity and another preselected adjacent pair with the opposite magnetic polarity; and a permanent magnet rotor member rotatably mounted in said bore and having a plurality of discrete rotational positions corresponding to the number of said pole face areas, said rotor member having peripheral surface portions defining a first plurality of radial airgaps with said pole face areas and means for forming a pair of spaced discrete pole face portions thereon projecting radially outwardly from said surface portions and respectively defining a second plurality of radial airgaps with said stator pole face areas which are narrower than said first airgaps, said rotor pole face portions respectively having an angular extent generally corresponding to the angular extent of each said adjacent pair of stator pole face areas and being respectively generally aligned with said one and other adjacent pairs of said stator pole face areas in each position of said rotor member, said rotor member being polarized on a magnetic axis which extends through said pair of rotor pole face portions and which is generally aligned with one stator pole face area respectively of said one and other adjacent pairs in each position of said rotor member.

**2.** The apparatus of claim **1** wherein said stator pole face area forming means comprises a plurality of spaced, inwardly extending, polar projections having inner ends respectively forming said pole face areas.

**3.** The apparatus of claim **2** wherein said stator structure includes a magnetic yoke portion with said polar projections extending inwardly therefrom and defining slots therebetween, said winding means comprising a plurality of field windings.

**4.** The apparatus of claim **3** wherein said windings are positioned on said yoke portion in said slots.

**5.** The apparatus of claim **3** wherein said windings are positioned on said polar projections.

**6.** The apparatus of claim **3** wherein each of said windings comprises first and second coils connected in series with its first coil positioned on said yoke portion in one of said slots and its second coil positioned on said yoke portion in an adjacent slot, there being a first coil of one winding and a second coil of an adjacent winding in each said slot, said first and second coils of each said winding being arranged in aiding relationship.

**7.** The apparatus of claim **6** wherein each said polar projection is diametrically opposite another polar projection, said one and other adjacent pairs being diametrically opposite, each one of said windings being connected in series with another winding diametrically opposite said one winding to form a pair of said windings with their first and second coils respectively disposed on opposite sides of a pair of diametrically opposite polar projections, and further comprising circuit means for selectively coupling an adjacent pair of said series-connected windings for energization from a unidirectional current source with preselected polarities with their respective opposite pairs of polar projections forming said one and other adjacent pairs thereby selectively to provide said discrete rotor member positions.

**8.** The apparatus of claim **7** wherein said circuit means selectively couples one end of each of said series-connected

pairs of windings to a preselected polarity of said source, the other ends of all of said series-connected pairs of windings being connected together.

9. The apparatus of claim 8 wherein the said one ends of all of said series-connected pairs of windings are simultaneously connected to preselected polarities of said source in accordance with a prearranged code.

10. The apparatus of claim 9 wherein said one and other adjacent pairs of polar projections mutually define a polar axis, said circuit means respectively connecting the coils on each side of said polar axis in aiding relationship.

11. The apparatus of claim 6 wherein each of said windings is substantially identical, said first coils having a greater number of turns than said second coils.

12. The apparatus of claim 6 wherein each of said windings is substantially identical, said first and second coils of each winding being substantially identical.

13. The apparatus of claim 3 wherein each of said windings comprises first and second coils connected in series with its first coil positioned on one said polar projection and its second coil positioned on an adjacent polar projection, there being a first coil of one winding and a second coil of an adjacent winding on each said polar projection, said first and second coils of each said winding being arranged to provide mmfs. of the same polarity in the respective polar projections.

14. The apparatus of claim 13 wherein each said projection is diametrically opposite another projection, said one and other adjacent pairs being diametrically opposite, each one of said windings being connected in series with another winding to form a pair of said windings with their first and second coils respectively positioned on diametrically opposite pairs of adjacent polar projections, and further comprising circuit means for selectively coupling one of said series-connected windings for energization from a unidirectional current source with preselected polarities thereby forming said one and other adjacent pairs of polar projections selectively to provide said discrete rotor member positions.

15. The apparatus of claim 14 wherein said circuit means couples said windings adjacent said one winding for energization by said source with polarities so that the coils thereof positioned on said one and other pairs of adjacent polar projections are in aiding relationship, respectively, with the coils of said one winding.

16. The apparatus of claim 14 wherein said circuit means selectively couples one end of each said series-connected pairs of windings to a preselected polarity of said source, the other ends of all of said series-connected pairs of windings being connected together.

17. The apparatus of claim 16 wherein the said one ends of all of said series-connected pairs of windings are simultaneously connected to preselected polarities of said source in accordance with a prearranged code.

18. The apparatus of claim 17 wherein said circuit means connects said windings with the coils thereof positioned on said one and other pairs of adjacent polar projections being respectively in aiding relationship and the coils positioned on the remaining polar projections being respectively in bucking relationship.

19. The apparatus of claim 3 wherein each of said polar projections is diametrically opposite another projection, said one and other adjacent pairs being diametrically opposite and mutually defining a polar axis, and further comprising circuit means for selectively coupling at least some of said windings for energization from a unidirectional current source with preselected polarities to provide parallel magnetic flux paths on each side of said polar axis, each path traversing said rotor member, the polar projections of said one and other adjacent pairs on the respective side of said polar axis, and the yoke portion therebetween thereby to provide the opposite magnetic polarization of said one and other adjacent pairs of polar projections.

20. The apparatus of claim 19 wherein there are 12 of said polar projections and six of said windings, each of said windings comprising first, second and third coils connected in series and positioned on said yoke portion respectively in adjacent slots, the first coil of one winding and third coil of an adjacent winding being in the same slot, said coils of each winding being arranged in aiding relationship.

21. The apparatus of claim 20 wherein each one of said windings is connected in series with another winding diametrically opposite said one winding to form a pair of said windings with their first, second and third coils being respectively disposed on opposite sides of diametrically opposite pairs of adjacent polar projections.

22. The apparatus of claim 21 wherein said circuit means simultaneously couples one end of at least two of said series-connected pairs of windings to said source with preselected polarities, in accordance with a prearranged code, the other ends of said series-connected pairs of windings being connected together.

23. The apparatus of claim 19 wherein there are 12 of said polar projections and six of said windings, each of said windings comprising first, second, third and fourth coils respectively positioned on adjacent polar projections and arranged to provide mmfs. of the same polarity therein, the first and second coils of one winding and the third and fourth coils of an adjacent winding being positioned on the same polar projection.

24. The apparatus of claim 23 wherein each one of said windings is connected in series with another winding diametrically opposite said one winding to form a pair of said windings with their first, second, third and fourth coils respectively disposed on diametrically opposite pairs of adjacent polar projections.

25. The apparatus of claim 24 wherein said circuit means simultaneously couples one end of at least two of said series connected pairs of windings to said source with preselected polarities, the other ends of said series-connected pairs of windings being connected together.

26. The apparatus of claim 7 wherein said circuit means selectively couples one end of at least one of said series-connected pairs of windings to a preselected polarity of said source in each position of said rotor member, the other ends of all of said series-connected pairs of windings being connected together and to the opposite polarity of said source.

27. The apparatus of claim 3 wherein said circuit means selectively couples one end of two of said series-connected pairs of windings to said preselected polarity in at least some of the positions of said rotor member.

28. The apparatus of claim 3 wherein each said polar projection is diametrically opposite another polar projection, said one and other adjacent pairs being diametrically opposite, each of said windings comprising first and second coils arranged when energized to polarize said one adjacent pair of polar projections with one magnetic polarity and to oppositely polarize said other adjacent pair as consequent poles.

29. The apparatus of claim 28 wherein one end of each of said windings is connected to an external terminal, the other ends of all of said windings being connected to a common terminal.

30. The apparatus of claim 29 wherein the first and second coils of each of said windings is positioned on said yoke portion in a respective slot with at least one slot therebetween.

31. The apparatus of claim 30 wherein there are a pair of polar projections and one slot between the first and second coils of each of said windings, said pair of polar projections being the one adjacent pair when the respective winding is energized.

32. The apparatus of claim 31 wherein one coil of an adjacent winding is positioned in each said one slot between the first and second coils of a respective winding.

33. The apparatus of claim 32 wherein each slot has one only coil therein, there being one-half as many windings as there are said polar projections.

34. The apparatus of claim 32 wherein each slot has one coil of one winding and one coil of one adjacent winding therein,

the number of said windings being equal to the number of said polar projections and slots.

35. In electromagnetic indicating apparatus including a magnetic stator structure with a plurality of equally spaced inwardly extending polar projections having inner ends defining a bore: a permanent magnet rotor member rotatably mounted in said bore, said rotor member having first means for respectively defining first airgaps having a first reluctance with said inner ends of two different adjacent pairs of said polar projections and second means for respectively defining second airgaps having reluctances higher than said first reluctance with the inner ends of the remaining ones of said polar projections, said rotor member being magnetically polarized on an axis which extends through said first means and which is generally aligned with one inner end of each of said adjacent pairs of polar projections.

36. The apparatus of claim 35 wherein said first means comprises two pole face areas, said magnetic axis extending through said pole face areas.

37. The apparatus of claim 36 wherein each of said pole face areas has an angular extent generally equal to the angular extent of the inner ends of two adjacent polar projections.

38. The apparatus of claim 37 wherein said second means comprises surface areas respectively intermediate said pole face areas, said first means comprising projections extending radially outwardly from said surface areas and respectively defining said pole face areas.

39. The apparatus of claim 37 wherein said pole face areas are diametrically opposite.

# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,588,888 Dated June 28, 1971

Inventor(s) Phillip L. Harden #2

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

IN THE SPECIFICATION

Column 1, line 38, "R" should be ---F---;
Column 4, line 15, "9-6" should be ---92-6---;
Column 8, line 6, ---146-6--- should be inserted after "147-6";
Column 9, line 23, insert ---end--- after "and";
Column 9, line 29, "15-1" should be ---150-1---;
Column 9, line 52, "150-" should be ---150-10---;
Column 9, line 66, "it" should be ---B---;
Column 11, line 63, "number" should be ---numbers---,(first occurrence).

Signed and sealed this 9th day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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