

[54] **PERMANENT MAGNET DETENT
MEANS FOR A ROTARY SOLENOID**

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340/378

[51] Int. Cl. H01f 7/08

[58] Field of Search 335/229, 253, 254, 272, 234,
335/274; 340/378

[56] **References Cited**

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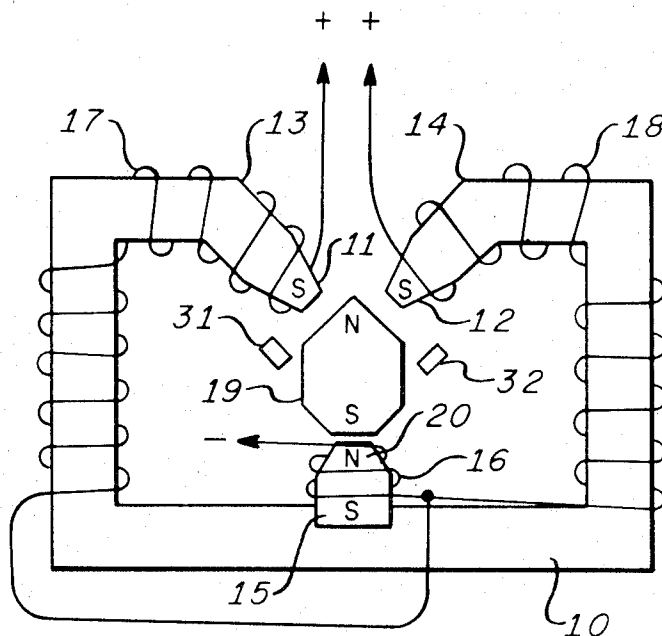
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[57] **ABSTRACT**

An electromagnetic rotary solenoid having a permanent magnet rotor and a plurality of selectable coils utilizes the combination of a permanent magnet and a coil for the no signal or detent position to effect a rotation restraining force on the rotor during a no signal input. The circuit effecting the operation of the solenoid simultaneously energizes the appropriate selectable coil and the coil associated with the permanent magnet whereby the selectable coils magnetic field creates a torque acting on the rotor to position it and the magnetic field of the coil associated with the permanent magnet nulls out the restraining force of the permanent magnet.

14 Claims, 4 Drawing Figures



PRIOR ART

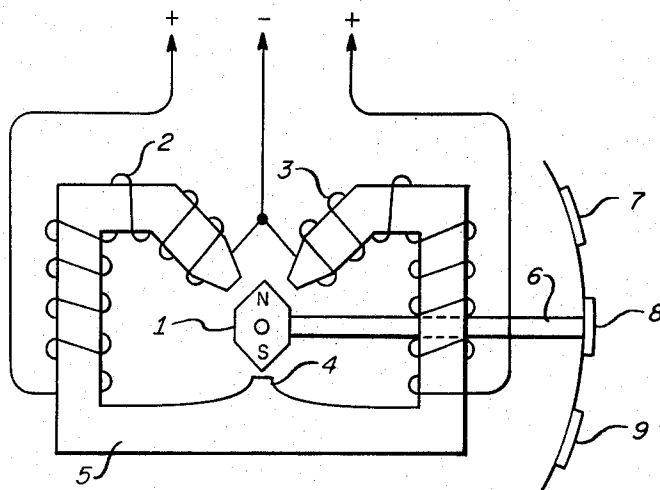


FIG. 1.

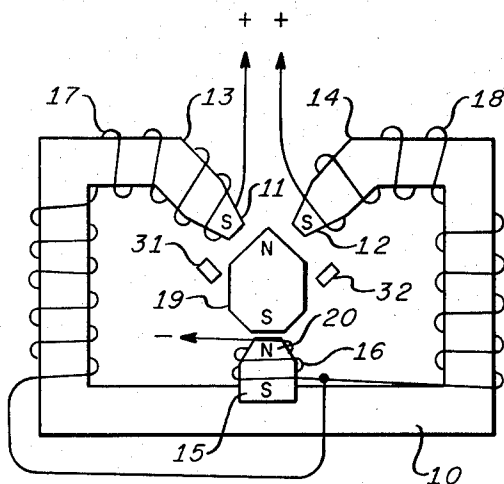


FIG. 2.

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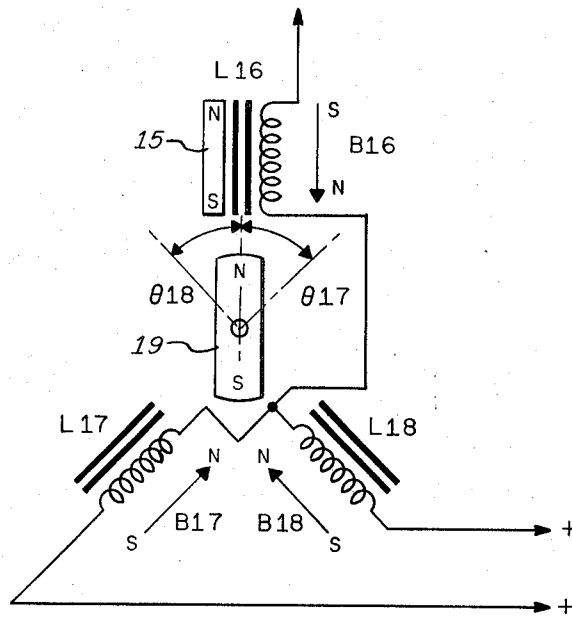


FIG. 3.

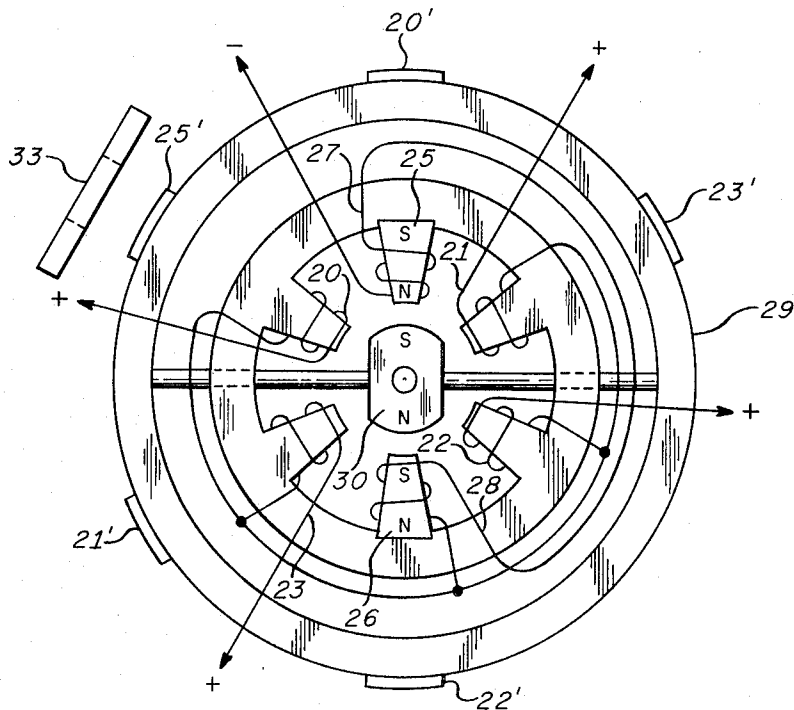


FIG. 4.

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PERMANENT MAGNET DETENT MEANS FOR A ROTARY SOLENOID

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention is related to rotary solenoids employing permanent magnet rotors and having one or more selectable positions and a detent position, the latter indicating a no input command signal or a failure of the indicating mechanism.

2. Background of the Invention

Known rotary solenoids usually embodied a permanent magnet rotor which positions itself in the detent or no signal position as a result of the attraction between the permanent magnet rotor pole and an iron pole. This attraction is caused by the permanent magnet rotor tending to seek the minimum reluctance position for a return path of its inherent residual induction. To actuate the rotor, the actuating force, usually a coil or electromagnet, had to overcome the attraction of the permanent magnet rotor pole to an iron pole, or pole of some other suitable ferromagnetic material. This required more power than otherwise necessary to rotate the rotor. The power requirement could, of course, be reduced by limiting the size or effect of the permanent magnet rotor but this resulted in a less stable detent position and it became possible for erroneous output readings due to a failure of the rotor to rotate. In high reliability situations, such a possibility of variable detent position was unacceptable.

SUMMARY OF THE INVENTION

Rotary solenoids generally embody a permanent magnet as a rotor with appropriate indicia operably attached to the rotor and positioned within a viewing area dependent on the degree of rotation of the rotor. A single or a plurality of coils may be positioned about the periphery of the rotor, which, by selective actuation, are energized and create magnetic flux which induces a torque upon the rotor causing it to rotate. The selectively actuated coil corresponds to the indicia to be presented within the viewing area. During a condition of no signal input, the indicia presented should indicate the absence of a signal. A means for accomplishing this is to place a permanent magnet at a position equivalent to that position of the rotor. Thus, during a no signal input condition, the rotor will respond to the torque presented by the permanent magnet field and rotate until it is aligned therewith. The problem of this type of system is that of achieving an efficient ratio between the torque required to position the rotor in the detent position and the torque required to rotate the rotor to alignment with the energized coil from the detent position. The present invention provides a solution. A coil is wound about the permanent magnet such that current passing through it will establish a magnetic field which effectively opposes and is approximately equivalent to the field of the permanent magnet. This coil is then connected in series with each of the selectable position coils so that on energizing a position coil, the field induced by the permanent magnet is substantially reduced or cancelled and its effect on the rotor is approximately zero. Thus, the position coil need not exert a force much greater than that required to rotate the rotor in the absence of any restraining field and thereby reduces the over-all power requirements. Furthermore, since the magnet force is maximum for a non-signal condition, the reliability of the "return to detent" operation is maximized.

A primary object of the invention is to provide a reliable and accurate no signal or detent position of a multiple position rotary solenoid.

Another object of the invention is to provide means for reducing the power required to rotate a rotor in a rotary solenoid.

Another object of the invention is to provide a means for increasing the force causing the rotor to return to the detent position in the absence of an input signal without increasing the power requirement to position the rotor to a selected position.

Another feature of the invention is to provide a means for reducing the power requirements of a rotary solenoid.

Another object of the invention is to provide for a fail-safe operation of a rotary solenoid.

Another object of the invention is to provide a fail-safe rotary solenoid and yet maintain a high degree of volumetric efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a typical prior art rotary solenoid providing a zero signal detent position;

FIG. 2 illustrates the basic concept of the present invention;

FIG. 3 illustrates the electrical interaction of the components; and

FIG. 4 illustrates an application of the invention in a multiple position rotor assembly.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Rotary solenoids as shown schematically in FIG. 1 are generally comprised of a permanent magnet rotor 1, one or more actuating electromagnetic coils 2, 3 and a zero signal position having a positive magnetic detent. In operation, the rotor 1, absent an input signal to either of coils 2 or 3, will position itself relative to and adjacent a piece of magnetizable metal such that the reluctance between the rotor 1 and the piece of metal is at a minimum, known as the detent position. In FIG. 1, this position is represented by the slightly raised portion, or pole piece 4, of the element 5. Attached to the rotor 1 may be an indicator arm 6 with indicia 7, 8, 9 attached thereto which rotates about the pivot point represented by the center of the rotor 1. In the detent position, the indicia 8 would have symbology interpretable to mean that no signal input was present (additionally, it may also indicate that the power to the indicator was lost if the rotor was normally at a position other than the detent position). On receipt of a command signal to one of the coils 2 or 3, the indicator would be actuated to the corresponding position; that is, an electromagnetic field would be established and a torque proportional to the current and the distance between the rotor 1 and the coil 2 or 3 would be imposed on the rotor 1. This torque would cause it to rotate such that the appropriate pole of the rotor 1 aligned itself with the energized coil. Necessarily, the attached indicia would also rotate and display an indicia indicative of the position of the rotor. The force exerted by the coil would necessarily have to be great enough to overcome the magnetic attraction between the rotor 1 and the pole piece 4.

On cessation of the input signal, the magnetic field of the coil would collapse. The rotor 1 would then be attracted to the element 4, where minimum reluctance to the permanent magnet rotor existed. Necessarily, this would have to be accomplished by a force sufficiently strong to overcome the friction present in the system and the inertia of the rotor and its indicator arm. The stronger the force, the more rapid is the return and the more positive is the positioning of the rotor 1 in its detent position. However, there is a serious practical difficulty in designing the element 5 such that it presents a single point source 4 of lowest reluctance and yet retains a sufficiently strong torque force. Thus, some compromise as to the width of the lowest reluctance point must be made. Such a compromise then increases the arc within which the rotor 1 may rest, resulting in a detent position which will vary with each repositioning and a variance of the position of the indicia. The latter is especially undesirable in situations requiring a high confidence level or high degree of reliability. Further deterioration will occur as the bearings wear and from the possible deposition of foreign matter within the system resulting in non-uniform rotational resistance. The present invention in accordance with the apparatus as shown in FIG. 2 overcomes the above-mentioned problems.

The present invention will now be explained in reference to the functional drawing in FIG. 2 and the schematic diagram of FIG. 3. The electromagnet includes a base piece 10 and two

pole pieces 11 and 12. Coils 17 and 18 are wound about each of the pole pieces to thereby form two separate electromagnets 13, 14. The base piece 10 has mounted therein a permanent magnet 15 of high coercive strength and including a further coil 16 wound therearound. Each of the coils 17, 18 are connected in series with coil 16 such that energization of either of them will also energize coil 16. A permanent magnet rotor 19 is disposed within the enclosure defined by the electromagnets 13, 14 and the permanent magnet 15 and is responsive to the magnetic flux emanating therefrom.

The shape of the rotor as shown in FIG. 2 will enhance the operation of the solenoid in the following manner. The blunt end of the rotor 19 cooperating with the selectively energizable coils will provide a large amount of magnetic flux. Thus, the amount of torque available to cause the rotor 19 to rotate is maximized. The shape or pointed end of the rotor 19 will tend to concentrate the magnetic flux within a small area and the rotor 19 will tend to align itself with the magnet 15 more precisely than if it had a second blunt end. The high concentration of magnetic flux will tend to limit the degree of off positioning due to a rapid increase of torque away from the null position. Thus, the positioning of the rotor 19 with respect to the magnet 15 will be repeatable.

In the absence of any input signals, the permanent magnet 15 will attract one pole of the rotor 19, resulting in a positioning as shown in the diagram. For additional positional accuracy, a pole piece 20 may be attached to the magnet to focus the lines of magnetic flux.

The operation of the solenoid may be more easily described in reference to FIG. 3. On receipt of an input signal, a current will flow through either coil L17 or coil L18 (depending on switching circuitry not shown) to ground. Current through either coil L17 or coil L18 will create a magnetic flux vector B17 or B18, respectively. The presence of either B17 or B18 will cause the permanent magnet rotor to align itself with this magnetic field resulting in a rotation through an angle $\theta 17$ or $\theta 18$, where $\theta 17$ and $\theta 18$ represent the angular displacement between the respective coil and the detent position. Coil L16 is always in series with either coil L17 or L18 and when current flows through either L17 or L18, it also flows through L16. The current flow through L16 is always in the same direction and L16 is so designed that the field B16 opposes and substantially cancels the magnetic flux of the magnet 15. Thus, the normal restraining force in holding the rotor in the detent position is effectively reduced or nulled out. When the input signal ceases, the magnetic flux B16 drops to zero along with the magnet fluxes B17 or B18, depending on which coil was energized. The magnetic field of the permanent magnet 15 is now again unopposed and the attraction force between the permanent magnet rotor 19 and the permanent magnet 15 will create a torque to cause the permanent magnet rotor 19 to align itself with the permanent magnet 15. As mentioned, magnet 15 must, for practical purposes, be of material having a very high coercive force. Unless such material is used, the permanent magnet 15 will become de-energized by the continuing application of the opposing field and in due course reduce the amount of torque available to bring the permanent magnet rotor 19 back to the detent position.

In the basic two selectable position solenoid with a detent position arrangement as shown in FIG. 2, stops 31, 32 may be placed such that the rotor 19 contacts a stop just short of fully positioning itself in respect to the actuating electromagnet (i.e., stop 31 and electromagnet 13). In this configuration, the large area of magnetic flux at the blunt end will create a constant torque acting on the rotor 19 during the energized state as the center of this magnetic flux will not be aligned with that of the energized pole. The rotor 19 will be prevented from oscillating or quivering about the selected position. This in effect damps the rotor 19 and its associated indicia without increasing the friction or requiring extra high tolerance and additional equipment.

FIG. 4 illustrates a practical application of the invention in a multi-position rotary solenoid. For illustrative purposes, there

are shown four positioning coils 20, 21, 22, 23, each representing one position indicative of a discrete indicia (20', 21', 22', 23') to be displayed. Each such coil is individually energizable by driving circuitry (not shown) in response to a predetermined condition. In this embodiment, there are shown two detent magnets 25, 26 each having an associated opposing coil 27, 28. The use of the two detent magnets 25, 26, provides a higher possible ultimate torque and thereby permits the use of larger or higher inertia indicating devices 29 without any sacrifice of reliability or speed of operation. At the center of the circularly disposed coils is a permanent magnet rotor 30 similar in operation to the rotors previously discussed.

In operation, a signal energizing one of the selectable coils simultaneously energizes both of the coils 27, 28 operably associated with the permanent magnets 25, 26. The selected energized coil creates a magnetic flux to attract one of the poles of the permanent magnet rotor 30, and a torque will exist tending to rotate the rotor 30. Simultaneously, the coils 27, 28 about the permanent magnets will create a magnetic field opposite to the normal field of the permanent magnets and in effect cancel or tend to null out the attracting force between the rotor and the permanent magnets. Thus, the rotor 30 is now free to rotate in response to the magnetic torque exerted by the energized coil. As the rotor rotates to the commanded position, the indicia to be displayed through the viewing aperture of display 33 will be that corresponding to the selected position, i.e., indicia 21' on activating coil 21. On de-energization of the selected coil, the magnetic field associated therewith will collapse and thereby remove the attracting force. Similarly, the opposing field about the permanent magnets will collapse and the magnetic field due to the permanent magnets will again establish a torque on the rotor 30. The rotor 30 will thus rotate to the detent position and the indicia 25' associated therewith will again be displayed.

Although only four selectable coils are shown it is intended that more or less may be used without departing from the scope of the invention. In example the circuitry of the selectable coils may be modified such that the opposing positioned coils work together as a pair to provide an attracting force to each of the poles of the rotor.

The increased volume required to incorporate the instant invention is insignificant, if any. Thereby, rotary solenoids including the invention may be utilized in presently existing equipments and without undue difficulty.

In a modification of the invention, a small Hall effect generator chip could be mounted on the permanent magnet. As it would be sensitive to any changes in the magnetic field, appropriate sensing circuitry could be attached thereto to detect this change. Thereby, it is possible to build into the system a self-checking feature. Suitable alarm means could then be actuated if the Hall effect generator output was not as expected at the appropriate time.

While the invention has been described in its preferred embodiment, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

I claim:

1. A rotary solenoid comprising

a stator having at least one selectively energizable electromagnetic pole,

a magnetic rotor disposed in operable proximity to said stator and having one pole of said rotor attracted to an energized electromagnetic pole,

a magnet attached to said stator for attracting another pole of said rotor, whereby said rotor will rotate to align itself with said magnet in the absence of an energized electromagnetic pole.

2. The rotary solenoid as claimed in claim 1 wherein one pole end of said rotor is generally pointed, and

said another pole end is generally blunt, whereby said pointed end will tend to align itself with said magnet, and said blunt end will tend to align itself with said electromagnetic pole.

3. The rotary solenoid as claimed in claim 2 including a plurality of stops, whereby the rotation of said rotor in response to said energized electromagnetic pole is limited.

4. A rotary solenoid comprising

a stator having at least one selectively energizable electromagnetic pole,

a magnetic rotor disposed in operable proximity to said stator and having one pole thereof attracted to an energized electromagnetic pole,

a detent magnet attached to said stator for attracting another pole of said rotor to maintain said rotor in a detent position,

means for counteracting the magnetic field of said magnet, and

means for initiating said counteracting means upon energization of an electromagnetic pole.

5. The solenoid as claimed in claim 4 wherein said counteracting means comprises a coil wound about said detent magnet.

6. The solenoid as claimed in claim 5 wherein said stator comprises a plurality of selectively energizable electromagnetic poles, and wherein said initiating means is operably dependent upon energization of any electromagnetic pole.

7. The stator as claimed in claim 6 wherein

each said electromagnetic pole includes a coil, and

said coil wound about said magnet is serially connected to

each said electromagnetic pole coil, whereby energization of said electromagnetic pole coil will also energize said magnet coil.

8. The stator as claimed in claim 4 including a pole piece attached to the pole of said detent magnet extending from said

stator, whereby the magnetic flux of said magnet may be focussed.

9. The rotary solenoid as claimed in claim 4 including a plurality of rotation limiting devices, whereby the rotation of said rotor in response to said energized electromagnetic pole is limited.

10. The rotor as claimed in claim 4 wherein

the end portion of said rotor operably cooperating with said magnet is a generally apex shaped, and

the end portion of the rotor operably cooperating with any electromagnetic pole is a generally blunt shaped, whereby the apex shaped end will tend to align itself with said magnet and the blunt shaped end will tend to align itself with said energized electromagnetic pole.

11. The rotary solenoid as claimed in claim 10 including a plurality of rotation limiting devices, whereby the rotation of said rotor in response to said energized electromagnetic pole is limited.

12. The rotary solenoid as claimed in claim 4 wherein said stator comprises

a circular member closed upon itself, and

a plurality of electromagnetic poles facing inwardly and toward the center of said circular stator.

13. The stator as claimed in claim 11 wherein said magnet is attached to said stator.

14. The stator as claimed in claim 13 including

a second magnet, each said magnet being attached to the stator and extending toward the center of said circular stator,

second means for counteracting the magnetic field of said second magnet, and

means for operating both said counteracting means upon energization of an electromagnetic pole.

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