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Wolschlager et al.

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(54) **ROTARY POSITION SENSOR**

(71) Applicants: **Kevin C. Wolschlager**, Elkhart, IN (US); **Robert L. Newman**, Edwardsburg, MI (US); **Kim D. Cook**, Wakarusa, IN (US)

(72) Inventors: **Kevin C. Wolschlager**, Elkhart, IN (US); **Robert L. Newman**, Edwardsburg, MI (US); **Kim D. Cook**, Wakarusa, IN (US)

(73) Assignee: **CTS Corporation**, Elkhart, IN (US)

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G01B 7/30 (2006.01)

(52) **U.S. Cl.**
USPC **324/207.25**

(58) **Field of Classification Search**
USPC 324/207.25
See application file for complete search history.

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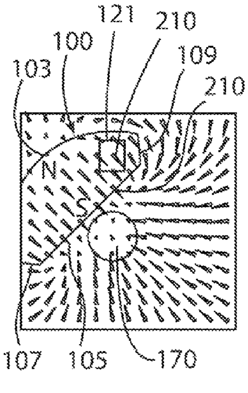
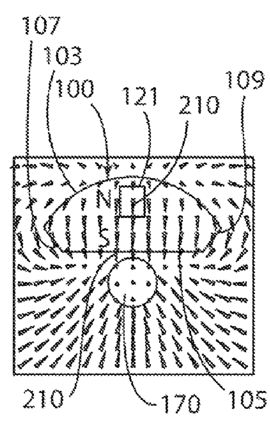
Primary Examiner — Reena Aurora
(74) *Attorney, Agent, or Firm* — Daniel J. Deneufbourg

(57) **ABSTRACT**

A sensor assembly for sensing a movable object which, in one embodiment, includes a housing defining an interior cavity. A rotor is retained in the cavity. The rotor defines a central bore and a magnet is mounted in an off-center pocket defined by the rotor. The rotor is coupled to the shaft of the movable object whose position is to be measured. A sensor is also retained in the cavity in a relationship at least partially overlying the magnet and adapted to sense at least the direction of the magnetic field generated by the magnet to generate an electrical signal indicative of the position of the movable object. In another embodiment, the rotor and sensor are mounted in separate interior housing cavities separated by an interior housing wall.

8 Claims, 10 Drawing Sheets





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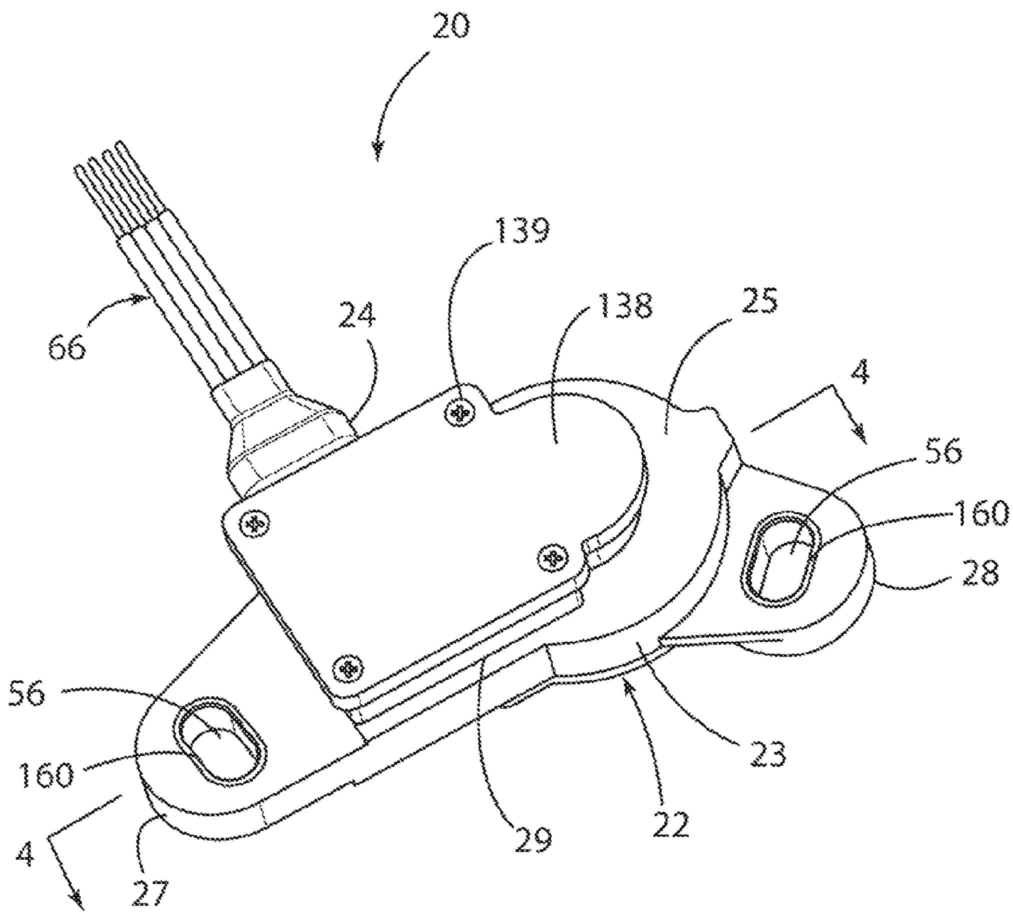

FIGURE 1

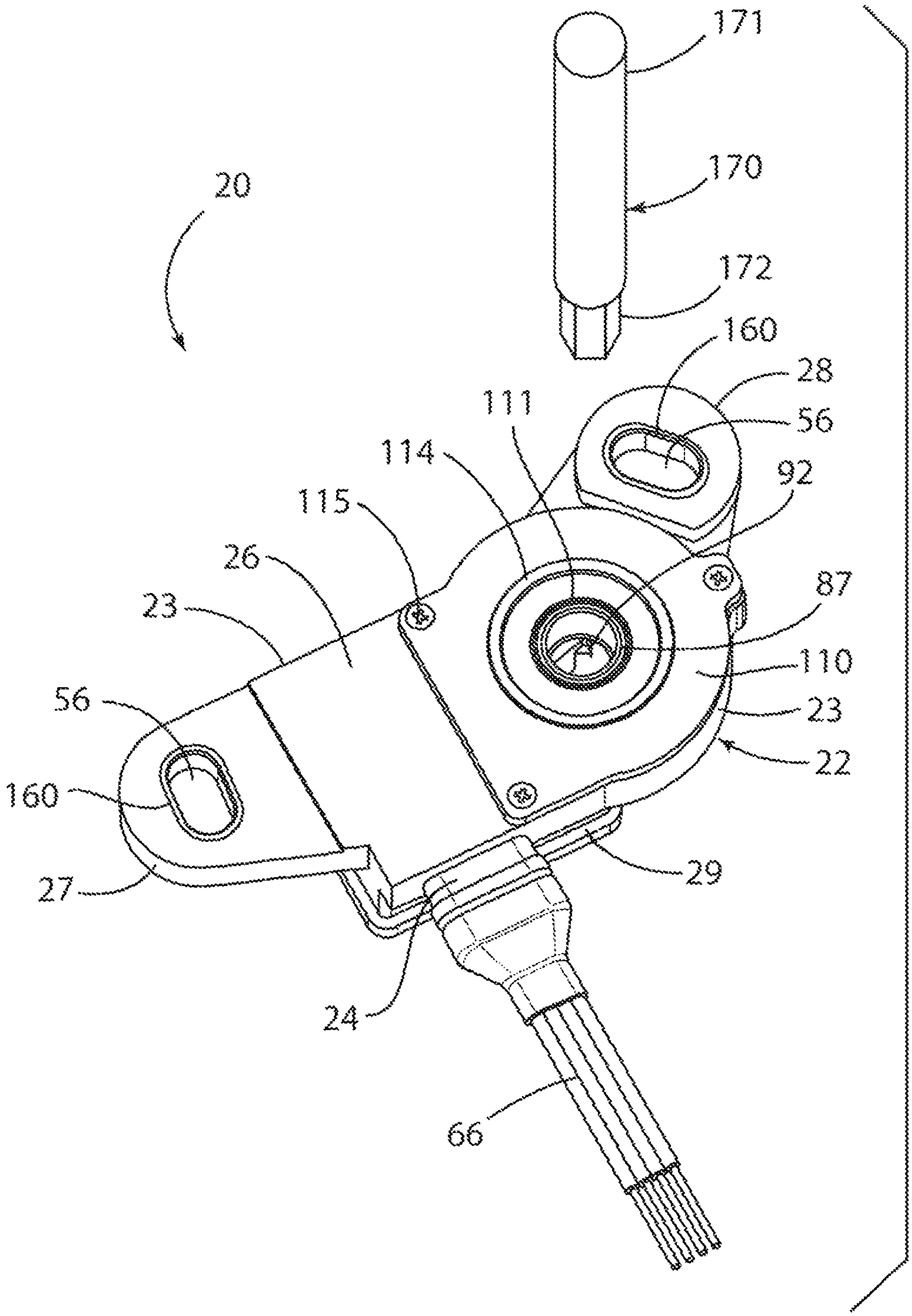
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FIGURE 2

FIGURE 3

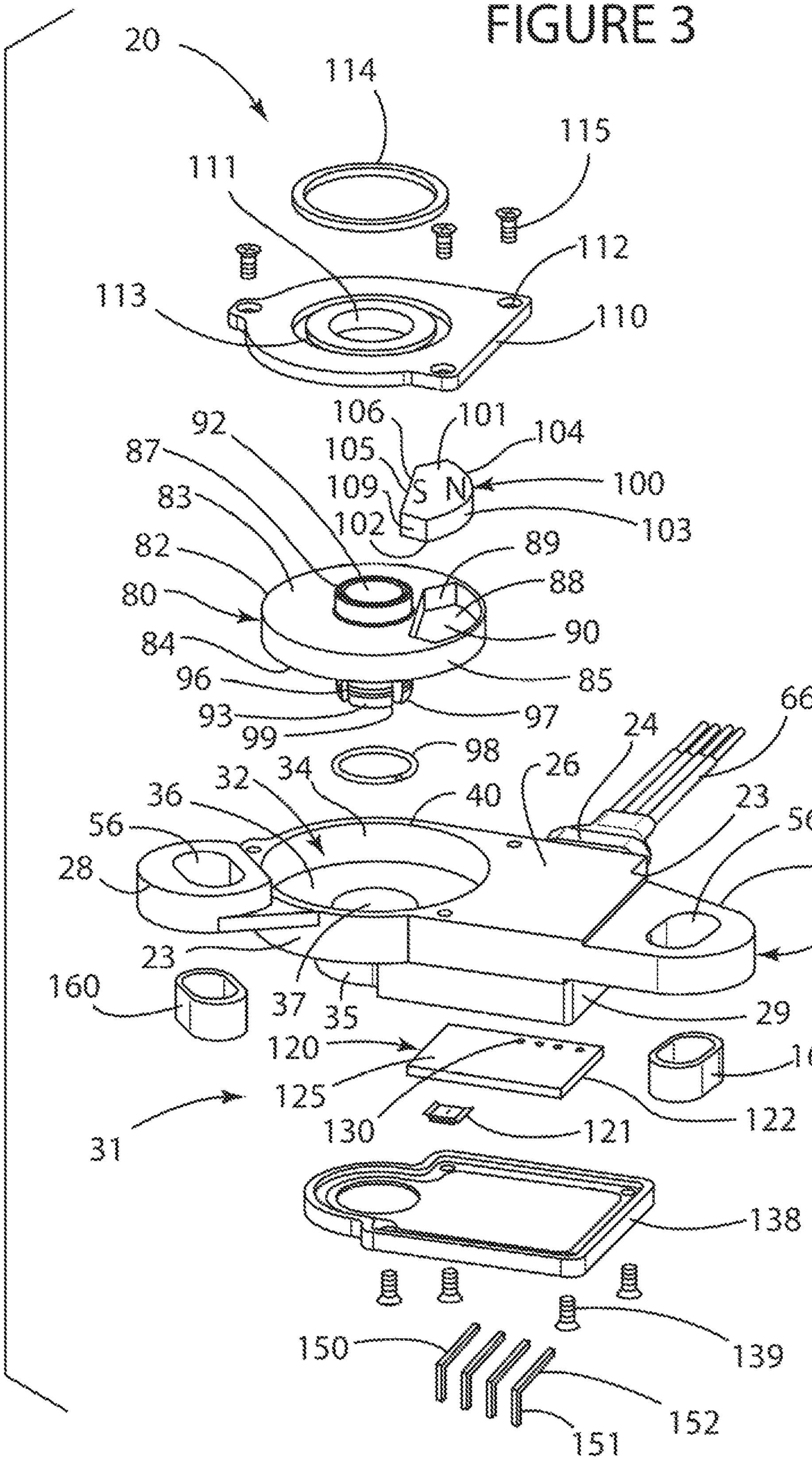
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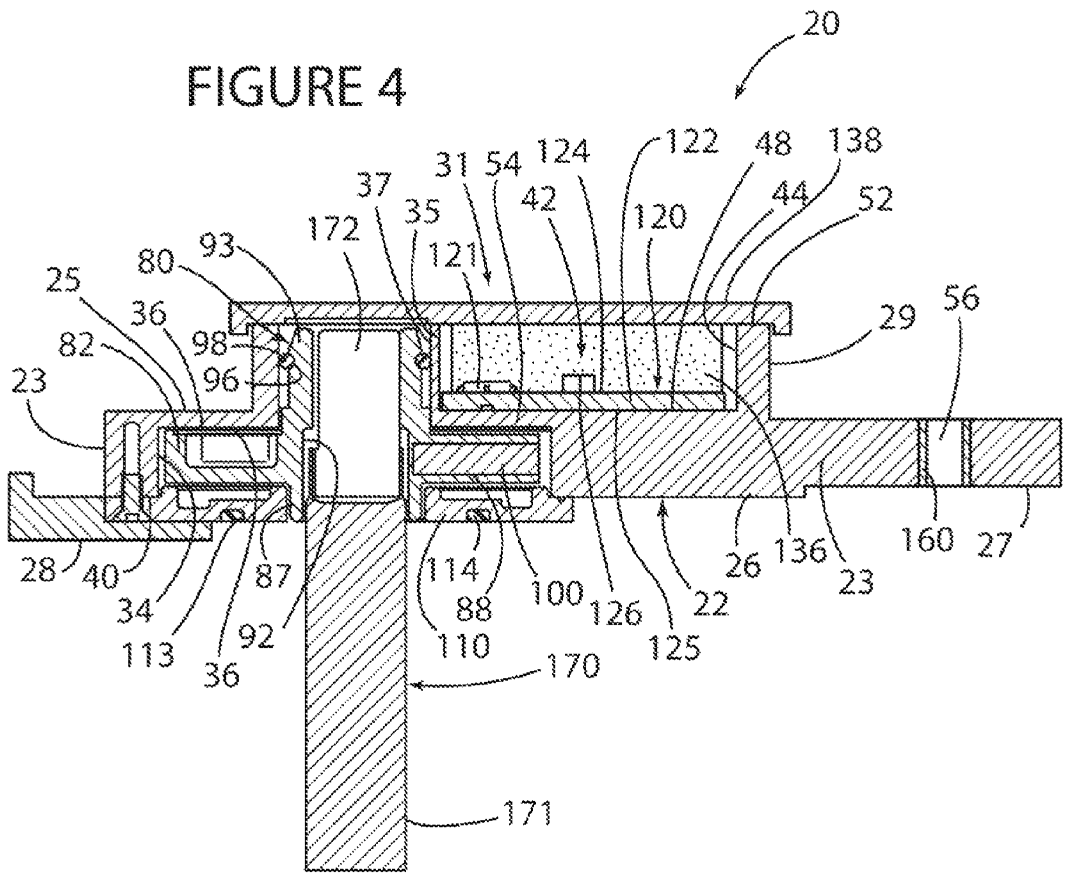
FIGURE 4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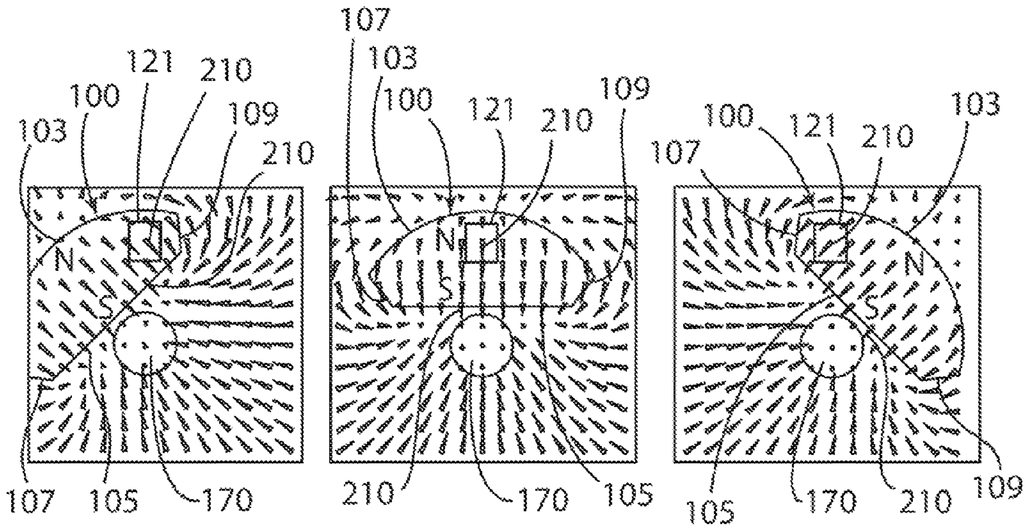

FIGURE 5A FIGURE 5B FIGURE 5C

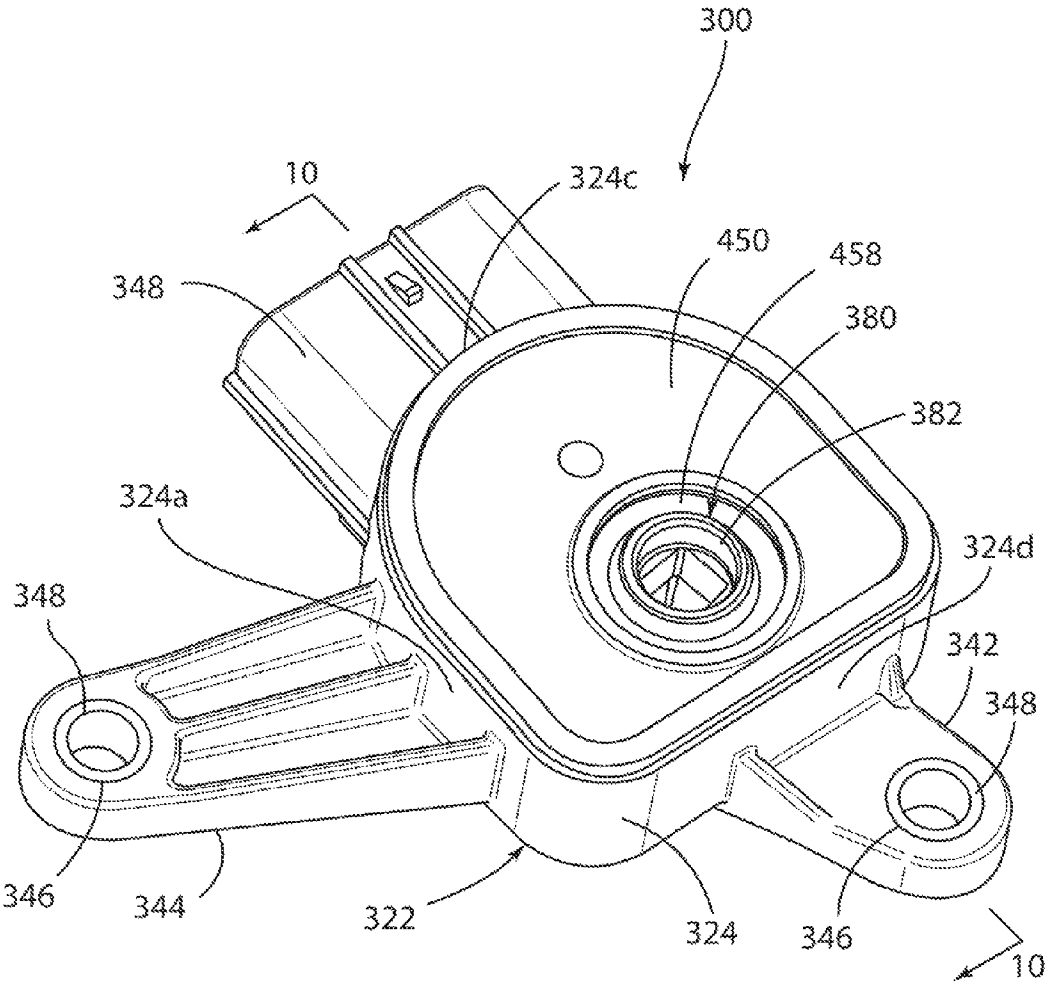
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FIGURE 6

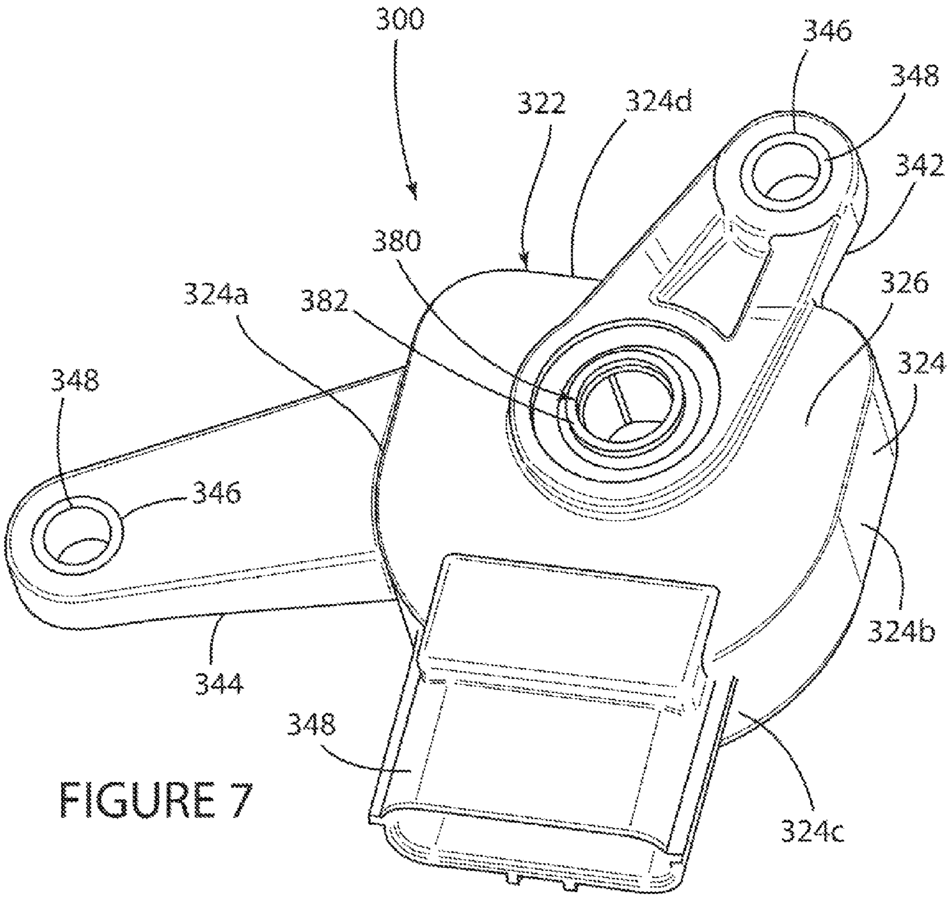
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FIGURE 7

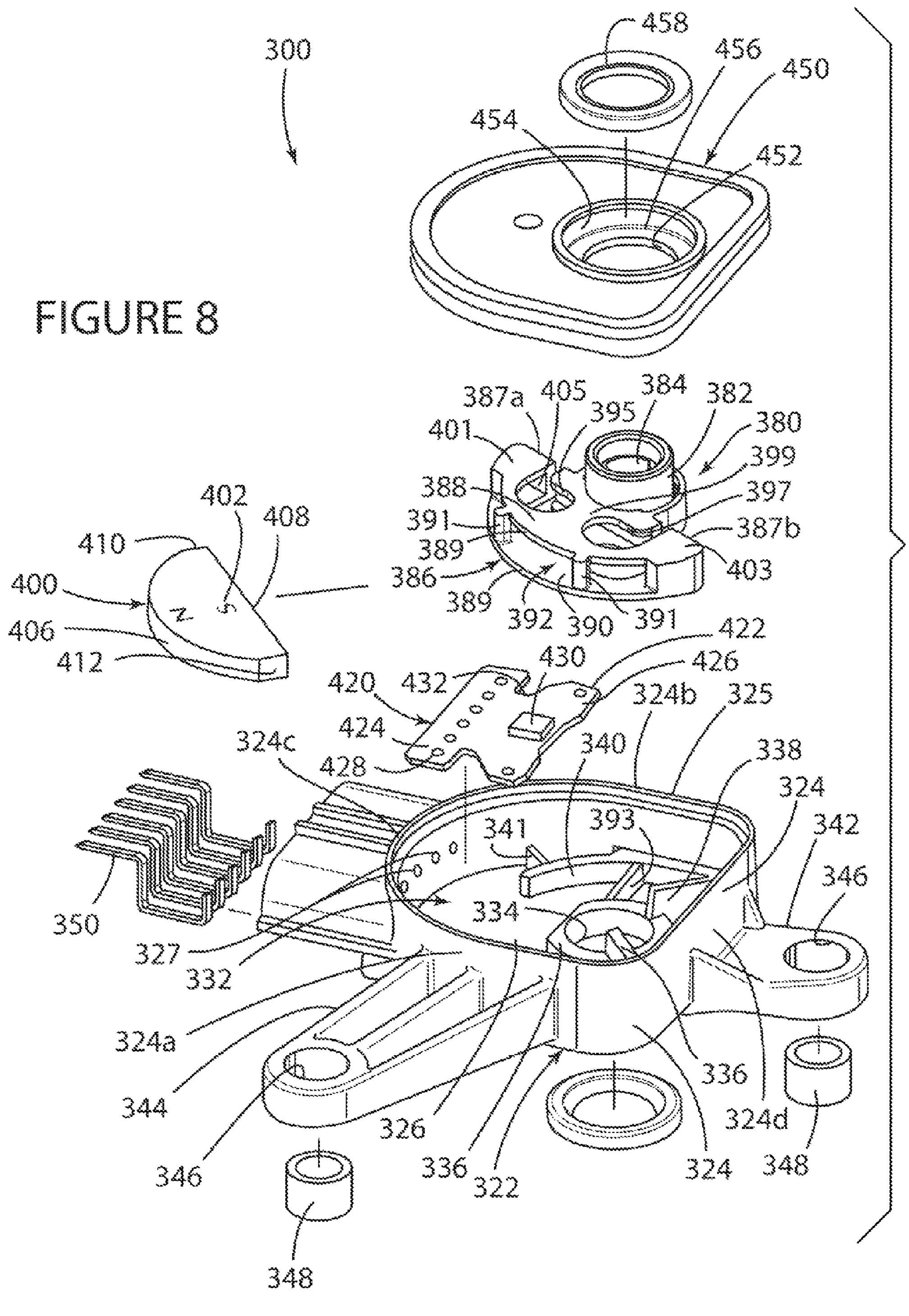
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FIGURE 8

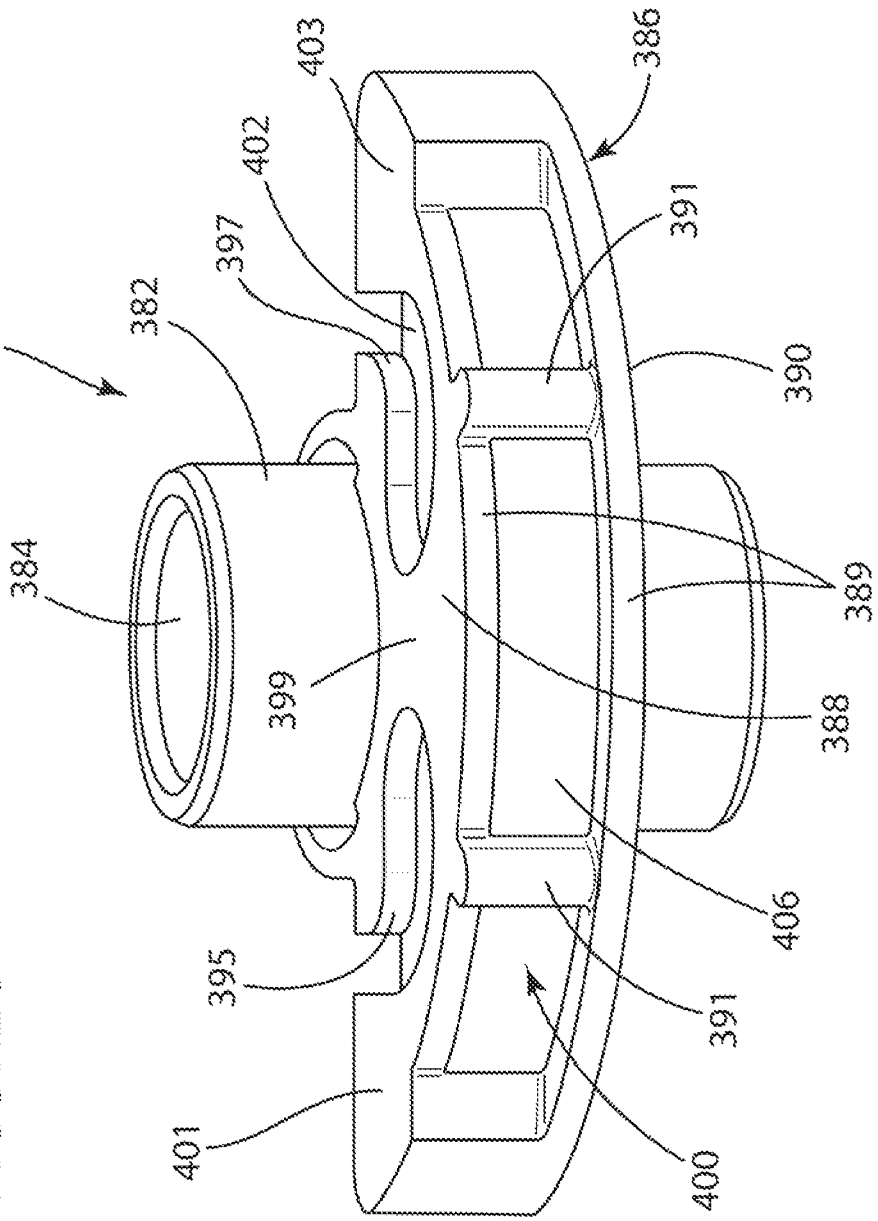
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FIGURE 9

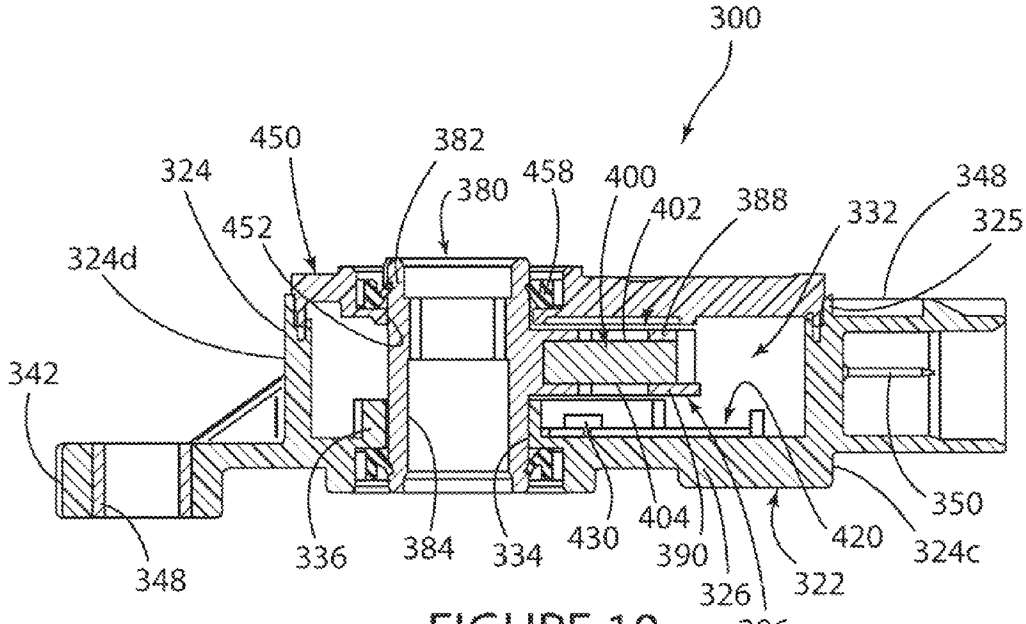

FIGURE 10

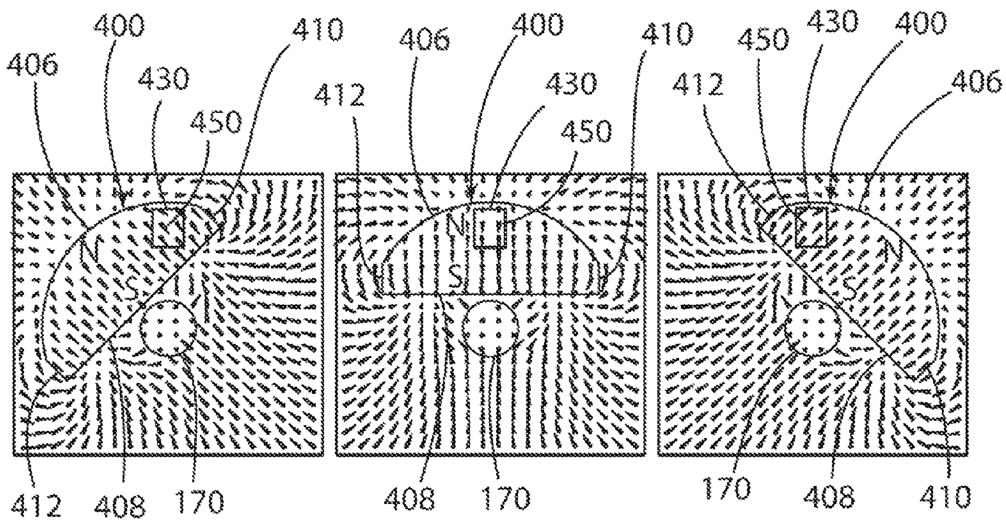

FIGURE 11A FIGURE 11B FIGURE 11C

ROTARY POSITION SENSOR

CROSS-REFERENCE TO RELATED AND CO-PENDING APPLICATIONS

This application is a continuation application which claims the benefit of the filing date of co-pending U.S. patent application Ser. No. 12/706,026 filed on Feb. 16, 2010, entitled Rotary Position Sensor, the disclosure of which is explicitly incorporated herein by reference as are all references cited therein, which claims the benefit of the filing date of U.S. Provisional Patent Application Ser. No. 61/207,755 filed on Feb. 17, 2009, the contents of which are explicitly incorporated by reference, as are all references cited therein.

TECHNICAL FIELD

This invention relates in general to position sensors and, more particularly, to a sensor that uses a Hall effect device to generate signal indicating positional information.

BACKGROUND OF THE INVENTION

Position sensors are used to electronically monitor the position or movement of a mechanical component. The position sensor produces an electrical signal that varies as the position of the component in question varies. Electrical position sensors are included in many products. For example, position sensors allow the status of various automotive components to be monitored and controlled electronically.

A position sensor needs to be accurate, in that it must give an appropriate electrical signal based upon the position measured. If inaccurate, a position sensor could potentially hinder the proper evaluation and control of the position of the component being monitored.

It is also typically required that a position sensor be adequately precise in its measurement. However, the precision needed in measuring a position will obviously vary depending upon the particular circumstances of use. For some purposes, only a rough indication of position is necessary; for instance, an indication of whether a valve is mostly open or mostly closed. In other applications, more precise indication of position may be needed.

A position sensor should also be sufficiently durable for the environment in which it is placed. For example, a position sensor used on an automotive valve may experience almost constant movement while the automobile is in operation. Such a position sensor should be constructed of mechanical and electrical components sufficient to allow the sensor to remain accurate and precise during its projected lifetime, despite considerable mechanical vibrations and thermal extremes and gradients.

In the past, position sensors were typically of the “contact” variety. A contacting position sensor requires physical contact to produce the electrical signal. Contacting position sensors typically consist of potentiometers which produce electrical signals that vary as a function of the component’s position. Contacting position sensors are generally accurate and precise. Unfortunately, the wear due to contact during movement of contacting position sensors has limited their durability. Also, the friction resulting from the contact can degrade the operation of the component. Further, water intrusion into a potentiometric sensor can disable the sensor.

One important advancement in sensor technology has been the development of non-contacting position sensors. A non-contacting position sensor (“NPS”) does not require physical contact between the signal generator and the sensing element.

Instead, an NPS utilizes magnets to generate magnetic fields that vary as a function of position, and devices to detect varying magnetic fields to measure the position of the component to be monitored. Often, a Hall effect device is used to produce an electrical signal that is dependent upon the magnitude and polarity of the magnetic flux incident upon the device. The Hall effect device may be physically attached to the component to be monitored and thus moves relative to the stationary magnets as the component moves. Conversely, the Hall effect device may be stationary with the magnets affixed to the component to be monitored. In either case, the position of the component to be monitored can be determined by the electrical signal produced by the Hall effect device.

The use of an NPS presents several distinct advantages over the use of a contacting position sensor. Because an NPS does not require physical contact between the signal generator and the sensing element, there is less physical wear during operation, resulting in greater durability of the sensor. The use of an NPS is also advantageous because the lack of any physical contact between the items being monitored and the sensor itself results in reduced drag.

While the use of an NPS presents several advantages, there are also several disadvantages that must be overcome in order for an NPS to be a satisfactory position sensor for many applications. Magnetic irregularities or imperfections can compromise the precision and accuracy of an NPS. The accuracy and precision of an NPS can also be affected by the numerous mechanical vibrations and perturbations likely to be experienced by the sensor. Because there is no physical contact between the item to be monitored and the sensor, it is possible for them to be knocked out of alignment by such vibrations and perturbations. A misalignment can result in the measured magnetic field at any particular location not being what it would be in the original alignment. Because the measured magnetic field can be different than the measured magnetic field when properly aligned, the perceived position can be inaccurate. Linearity of magnetic field strength and the resulting signal is also a concern.

Devices of the prior art also require special electronics to account for changes in the magnetic field with temperature. The field generated by a magnet changes with temperature and the sensor must be able to differentiate between changes in temperature and changes in position.

SUMMARY OF THE INVENTION

It is a feature of the present invention to provide a sensor assembly for sensing the position of a movable object coupled to a shaft which, in one embodiment, comprises a magnet coupled to the shaft of the movable object in an off-center relationship. The shaft and the magnet are adapted for rotation and the magnet is adapted to generate a magnetic flux field having a direction which is normal with at least one of the surfaces of the magnet. A sensor is retained in the housing in proximity to the magnet. The magnet and the sensor are movable relative to each other and the sensor is adapted to sense the direction of the flux field and generate an electrical signal that is indicative of the direction of the flux field, the position of the shaft, and the position of the movable object coupled to the shaft.

In one embodiment, the sensor assembly comprises a housing and a rotor in the housing defines a bore adapted to receive the shaft of the movable object. The magnet is located in a pocket in the rotor.

In one embodiment, the rotor includes a collar and the pocket is offset from the collar. The rotor and the sensor are located in the housing in at least a partially overlying relationship. In one embodiment, the collar of the rotor is seated against a collar formed in the housing.

In one embodiment, the rotor includes a housing which at least partially surrounds the collar, defines the pocket for the magnet, and defines at least one slot which divides the housing into first and second portions wherein the second portion is adapted to flex independently of the first portion in response to a change in temperature.

In another embodiment, the housing defines first and second cavities separated by an interior wall and the rotor and the sensor are located in the first and second cavities respectively in at least a partially overlying and spaced relationship. First and second plates cover the first and second cavities respectively.

In one embodiment, the shaft extends into the housing and into the bore and collar of the rotor.

In one embodiment, the magnet is semi-circularly shaped, includes a straight surface, and the direction of the magnetic field is generally normal with the straight surface of the magnet.

There are other advantages and features of this invention, which will be more readily apparent from the following detailed description of one embodiment of the invention, the drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings that form part of the specification, and in which like numerals are employed to designate like parts throughout the same:

FIG. **1** is a top perspective view of a rotary position sensor in accordance with the present invention;

FIG. **2** is a bottom perspective view of the rotary position sensor of FIG. **1** with a shaft of the component whose rotary position is to be measured shown in exploded form;

FIG. **3** is an exploded simplified perspective view of the rotary position sensor of FIGS. **1** and **2**;

FIG. **4** is a simplified horizontal cross-sectional view of the rotary position sensor of the present invention taken along the line **4-4** in FIG. **1**;

FIGS. **5A-5C** are flux diagrams depicting the flux generated by the magnet of the rotary position sensor of the present invention at three different measurement angles/magnet positions;

FIG. **6** is a top perspective view of another embodiment of a rotary position sensor in accordance with the present invention;

FIG. **7** is a bottom perspective view of the rotary position sensor in FIG. **6**;

FIG. **8** is a simplified, exploded, perspective view of the rotary position sensor shown in FIGS. **6** and **7**;

FIG. **9** is an enlarged, broken perspective view of the rotor and associated magnet housing with the magnet over-molded therein;

FIG. **10** is a simplified horizontal sectional view of the rotary position sensor taken along the line **10-10** in FIG. **6**; and

FIGS. **11A-11C** are flux diagrams depicting the flux generated by the magnet of the rotary position sensor of FIGS. **6-10** at three different measurement angles/magnet positions.

DETAILED DESCRIPTION OF THE EMBODIMENTS

A first embodiment of a rotary position sensor assembly **20** according to the present invention is shown in FIGS. **1-4**

which comprises, among other elements, a housing **22**, a rotor **80**, a magnet **100** (FIG. **3**), and a circuit board sensor assembly **120** (FIGS. **3** and **4**).

Housing **22** includes opposed top and bottom surfaces **25** and **26** respectively and defines a generally circular base or rotor portion **23** and a generally square sensor portion **29** unitary with and adjacent to the base or rotor portion **23**. A connector portion **24** (FIGS. **1** and **2**) extends unitarily outwardly from a side of the sensor portion **29**. Mounting flanges or brackets **27** and **28** are formed on, and protrude outwardly from, opposing diagonal corners of the housing **22**. Bracket **27** protrudes outwardly from a side of sensor portion **29** and bracket **38** protrudes outwardly from a side of rotor portion **23**. Housing **22** can be formed from injected molded plastic.

Housing **22** defines two sections, cavities or enclosures. Specifically, base portion **23** of housing **22** defines a rotor cavity **32** (FIG. **3**) that houses the rotor **80** and the sensor portion **29** defines a sensor or electronics cavity **42** (FIG. **4**) that houses circuit board assembly **120**.

Rotor cavity **32** is generally cylindrically-shaped and is located and defined on the side surface **26** of housing **22**. Sensor cavity **42** (FIG. **4**) is generally square-shaped and is defined in the opposed side surface **25** of housing **22**, and thus respective cavities **32** and **42** are positioned in a partially overlapping relationship on opposite sides of the housing **22**.

Rotor cavity **32** (FIGS. **3** and **4**) is defined by the combination of circular interior vertical peripheral wall **34** and an interior horizontal wall or surface **36**. Wall **34** defines an outer peripheral circumferential rim **40** on surface **26**. A collar and cylindrical wall **35** defining a central bore or through-hole **37** is defined in and extends from the horizontal surface **36** in the direction of housing surface **25**.

Sensor cavity **42** (FIG. **4**) is defined by the combination of circumferentially extending interior vertical side wall **44**, the collar wall **35**, and an interior bottom wall or surface **48** normal to side wall **44**.

The side wall **44** defines a circumferential outer rim **52** (FIG. **4**) at the top of surface **25**. A generally horizontal separation wall **54** (FIG. **4**) is formed in the interior of housing **22** and, together with the vertical collar wall **35**, separates and isolates the sensor cavity **42** from the rotor cavity **32**. Separation wall **54** is unitary with, and oriented substantially normal to, the rotor cavity wall **34** and sensor cavity wall **44**. Bottom surface **36** of rotor cavity **32** is located on one side of separation wall **54** and bottom surface **48** of sensor cavity **42** is located on the other side of separation wall **54**.

A pair of oval-shaped apertures or through-holes **56** (FIGS. **1-4**) are defined in and pass through the respective flanges **27** and **28** of housing **22**. Oval-shaped closed metal inserts **160** (FIGS. **1-4**) are mounted in apertures **56** by press fitting or the like. A fastener (not shown) is adapted to pass through each of the apertures **56** and inserts **160** to attach housing **22** to another object.

Connector portion or housing **24** (FIG. **2**) extends outwardly from one of the sides of sensor housing portion **29**. A wire harness **66** is connected to connector portion **24**. Terminals **150** (FIG. **3**) are adapted to be located within connector portion **24** and mate with wire harness **66**. Wire harness **66** electrically connects sensor assembly **20** to another electrical circuit.

A generally circular rotor **80** is shown in FIGS. **2-4** which includes a central plate or disc **82** with an upper horizontal surface **83**, a lower horizontal surface **84**, and an outer circumferential vertical surface or wall **85** therebetween. Rotor **80** can be formed from injected molded plastic.

A first cylindrical collar **87** extends normally outwardly from the center of upper surface **83** of the disc **82** and defines a central shaft bore or through-hole **92**. A second cylindrical collar **93** extends normally outwardly from the center of the lower surface **84** of disc **82**. Shaft bore or through-hole **92** extends through the rotor **80** and, more specifically, successively through the collar **87**, the disc **82** and the collar **93**.

Collar **93** is split into four sections or segments **97** by elongate, generally vertical slots **99**. Segments **97** extend circumferentially around wall **93** in a spaced-apart and parallel relationship.

An off-center or off-shaft or off-axis magnet recess or pocket **88** is defined in the disc **82** of rotor **80** by the combination of an interior side wall **89** and a bottom wall **90** which is normal to side wall **89**. Magnet pocket **88** is defined on an off-center portion of disc **82** located between the central bore **92** and outer circumferential wall **85**. Magnet **100** is received and seated in the pocket **88**.

A circumferential recess **96** (FIG. **4**) is defined in and located in the outside surface of collar **93**. A metal grip ring **98** (FIGS. **3** and **4**) surrounds the collar **93** and is seated in recess **96** and adapted to provide a seal between the rotor **80** and the housing collar wall **35** and also to retain rotor **80** in a relationship normal to the housing **22**.

The bore **92** of rotor **80** receives the shaft **170** of the object whose rotary position is to be measured. In the embodiment shown, shaft **170** has a mating feature such as, for example, a rectangularly-shaped end **172** (FIG. **2**). Shaft **170** also has an opposite cylindrically-shaped end **171**. Shaft **170** extends generally normally outwardly from housing **22** and can be attached to any type of object whose rotary position is to be measured.

Rectangular end **172** of shaft **170** extends through the rotor bore **92** and into the interior of collar **93**. The compression and flexing of the segments **97** of collar **93** inwardly against the outer surface of the rectangular end **172** of shaft **170** secures the shaft **170** to the rotor **80**.

As shown in FIGS. **3**, **4**, and **5**, the magnet **100** is generally semi-circular or moon-shaped and is adapted to be mounted in pocket **88** defined in the disc **82** of rotor **80** in an off-set or off-axis relationship relative to the bore **92** of rotor **80** and is held in place therein with a heat stake (not shown) or, alternatively, is press fitted therein. In the embodiment shown, the pocket **88** has the same general shape as the magnet **100**. Magnet **100** is a permanent magnet that is polarized in a manner wherein it defines a north pole **104** and a south pole **105** (FIGS. **5A-5C**). Magnet **100** can be made from several different magnetic materials such as, but not limited to, ferrite or samarium cobalt or neodymium-iron-boron.

Magnet **100** defines a top horizontal surface **101**, a bottom horizontal surface **102** spaced from, opposed to, and parallel to the surface **101**; a curved semi-circular side vertical surface **103**; a straight vertical side surface **106** opposite the semi-circular surface **103**; and a pair of opposed end side vertical surfaces **107** and **109** extending between the ends of surfaces **103** and **106**.

Rotor **80** is seated and supported in rotor cavity **32** for rotary movement therein in a relationship wherein the collar **93** of rotor **80** extends through the aperture **37** in cavity **32** and into the collar **35** in housing **22** and the disc **82** of rotor **80** is seated in rotor cavity **32**. A cover plate **110** (FIGS. **2-4**) is mounted over the surface **26** and rim **40** of housing **22**, covers the cavity **32**, and thus the rotor **80** housed therein. Cover **110** defines a central aperture **111** and peripheral screw apertures **112**. An annular slot or recess **113** is defined in cover **110** and surrounds and is spaced from the shaft aperture **111**. A ring or face seal **114** is press fit into the slot **113**. Fasteners or screws **115** extend through the respective apertures **111** to attach the cover **110** to the housing **22**. Face seal **114** forms a seal with another mounting surface (not shown) to which sensor housing **22** is adapted to be mounted. Collar **87** of rotor **80** extends through the aperture **111** in plate **110**.

FIGS. **3** and **4** depict a circuit board sensor assembly **120** seated and mounted in sensor cavity **42** defined in housing portion **29** and including a generally rectangular printed circuit board **122** having a top surface **124**, a bottom surface **125** abutted against the floor **125** of separation wall **54**, and plated through-holes **130** extending between the top and bottom surfaces **124** and **125**. Printed circuit board **122** can be a conventional printed circuit board formed from FR4 material.

A sensor **121** such as, for example, a magnetic field sensor, is mounted to top surface **124** by conventional electronic assembly techniques such as, for example, soldering. Magnetic field sensor **121** can be a model number MLX90316 Hall effect integrated circuit from Melexis Corporation of Ieper, Belgium which is adapted to measure both the magnitude and direction of a magnetic field or flux generated by the magnet **100**. Other electronic components **126** (FIG. **4**) including, for example, capacitors, resistors, inductors, and other types of conditioning, amplifying and filtering devices are mounted to the top surface **124** using conventional electronic assembly techniques.

Sensor **121** is preferably seated on board **120** in cavity **42** in a relationship overlying the magnet **100** in recess **88** of rotor **80** seated in cavity **32**.

A potting compound **136** (FIG. **4**) such as, for example, a silicone gel is applied over printed circuit board **122**, the sensor **121**, and the other components **126** on the surface **124** to seal the printed circuit board **122**, the sensor **121**, and the components **126** from the outside environment.

Several generally L-shaped electrically conductive metal terminals **150** (FIG. **3**) also extend through one of the housing walls between the connector **24** at one end and the printed circuit board **122** at the other end. Specifically, terminals **150** defines ends **151** and **152** that are bent at a generally ninety (90) degree angle relative to each other. Although not shown or described in any detail, it is understood that terminal ends **151** are soldered to the respective through-holes **130** in printed circuit board **122** and that the terminal ends **152** extend out of the housing **22** and into connector portion **24** where they are connected to wire harness **66**.

Another cover plate **138** (FIGS. **1**, **3** and **4**) is seated over the rim **52** of housing portion **29** to cover the cavity **42** and printed circuit board **122** therein. Cover plate **138** is attached to the rim **52** of housing portion **29** of housing **22** by fasteners or screws **139**.

Rotary position sensor assembly **20** is used to ascertain the position of a rotating or movable object such as shaft **170** which, as described above, includes a first end **172** which extends through the aperture **111** in cover plate **110** and through the bore **92** in rotor **80**; and an opposite end **171** which is adapted for connection to a wide variety of rotating or moving objects including, for example, a vehicle transmission.

As shown in FIGS. **4** and **5A-5C**, when shaft **170** is rotated, rotor **80** and magnet **100** are also rotated relative to the stationary sensor **121** which, as described above, is spaced from and overlies the magnet **100**. Interior horizontal housing wall **54** and printed circuit board **122** separate the sensor **121** from the magnet **100**. The magnetic flux field generated by the magnet **100** passes through the interior housing wall **54** and printed circuit board **122** and the magnitude/strength and direction/polarity of the magnetic flux field is sensed by the sensor **121**. Specifically, it is understood that the magnetic field can vary in magnitude/strength and in polarity/direction depending upon the position of the magnet **100** and the location at which the magnet parameters (lines of flux) are measured.

Sensor **121** produces an electrical output signal that changes in response to the position of magnet **100** and the position of shaft **170**. As the magnetic field (i.e., magnitude/strength and polarity/direction) generated by the magnet **100** varies with rotation of the shaft **170** and rotor **80**, the electrical output signal produced by sensor **121** changes accordingly, thus allowing the position of shaft **170** to be determined or ascertained. Sensor **121** senses the changing magnetic field (i.e., magnitude/strength and polarity/direction) as magnet **100** is rotated. In one embodiment, the electrical signal produced by sensor **121** is proportional to the position of shaft **170**.

FIGS. **5**A-**5**C depict the location and orientation of the magnetic field/flux lines **210** in a horizontal plane above magnet **100** and passing over and through the magnetic flux sensor **121** at three different shaft and magnet rotation angles or positions, i.e., zero degrees (FIG. **5**A), forty-five degrees (FIG. **5**B), and ninety degrees (FIG. **5**C).

More specifically, magnet **100** generates flux lines **210** that point and flow from the top curved North Pole surface **103** of magnet **100** in the direction of and generally straight through the width of, and opposed bottom straight South Pole surface **105** of, the magnet **100** in an orientation and relationship generally normal to the magnet surface **105**.

At the shaft and magnet rotation or position angle of zero degrees (FIG. **5**A), the flux lines or vectors **210** have flux directions that point generally diagonally from the top left corner to the bottom right corner of magnetic flux sensor **121**, i.e., flux lines or vectors oriented at a forty-five degree angle relative to each of the sensor side faces. Sensor **121** senses this direction of the magnetic field **210** and generates an electrical signal which is representative of the flux direction, the position of the magnet **100**, the position of the rotor **80**, the position of the shaft **170**, and ultimately, the position of the object coupled to the shaft **170**.

At a shaft or magnet rotation or position angle of forty-five degrees (FIG. **5**B), flux lines or vectors **210** have flux directions that point generally straight across from the top to the bottom of magnetic flux sensor **121**, i.e., flux lines or vectors oriented in a relationship parallel to two of the sensor side surfaces and normal to the other two sensor side surfaces. Sensor **121** senses this direction of the magnetic field flux lines **210** and creates an electrical signal representative of the direction and thus the position of the magnet **100** and shaft **170** as described above.

At a shaft or magnet rotation or position angle of ninety degrees (FIG. **5**C), flux lines or vectors **210** have flux directions that point generally diagonally from the top right corner to the bottom left corner of magnetic flux sensor **121**, i.e., flux lines or vectors oriented at a forty-five degree angle relative to each of the sensor side surfaces. The angular direction and orientation of the flux lines **210** in FIG. **5**C is directly opposite the angular direction and orientation of the flux lines **210** in FIG. **5**A.

The present invention has several advantages. The use of a central bore **92** extending through rotor **80** and the positioning of magnet **100** in rotor **80** adjacent to, and off-center from, the shaft **170** allows the end **172** of shaft **170** to extend fully through the bore **92** and rotor **80** and allows the sensor assembly **20** to be used in applications where the length of the shaft **170** must be accommodated by the sensor assembly.

Additionally, the mounting of the rotor **80** and magnet **100** in a housing section or cavity **32** separate from the electronic components (Hall effect sensor) cavity **42** allows for a more compact design and allows the electronic components in cavity **42** to be better isolated, protected, and sealed from outside environmental conditions. This allows the sensor assembly **20** to be used in more demanding applications with high heat and humidity.

Moreover, the use of the MLX90316 integrated circuit Hall Effect sensor reduces or eliminates the need for temperature compensation electronics since the MLX90316 device measures the direction of the magnetic field vectors in orthogonal axes and uses this information to compute position.

Still further, the semi-circular or moon shape of magnet **100** provides for the generation of a uniform flux field therethrough which, at all times, and irrespective of the angle or position of magnet **100** generates a field with a direction oriented and extending generally normally through the width and base surface **105** of magnet **100** so as to assure and provide uniform signal output linearity.

FIGS. **6**-**10** depict another embodiment of a rotary position sensor **300** in accordance with the present invention which comprises, among other elements, a housing **322**, a rotor **380**, a magnet **400**, and a printed circuit board sensor assembly **420** as described in more detail below.

Housing **322** is generally semi-oval in shape, is made of plastic, and includes a peripheral circumferential vertical wall **324** including a pair of opposed, spaced-apart and generally parallel straight sections **324***a* and **324***b*, a curved section **324***c* joining the two straight sections **324***a* and **324***b* at one end thereof, and a straight section **324***d* opposite the curved section **324***c* and joining together the opposed ends of the two straight sections **324***a* and **324***b*. Housing **322** also includes a bottom surface or floor **326** which, in combination with the wall **324**, defines an interior housing cavity **332**. Housing wall **324** additionally defines a circumferential peripheral rim **325** (FIG. **8**).

A circular aperture **334** (FIGS. **8** and **9**) is defined in the floor **326** of housing **322** at a location adjacent and spaced from the housing wall section **324***d*. Aperture **334** is surrounded by a collar **336** which protrudes outwardly from the floor **326** into the cavity **332**. A pair of spaced-apart posts or stops **336** and **338** protrude outwardly from the rim of the collar **336** and the interior surface of housing wall **324**. A curved wall **340** protrudes outwardly from the floor **326** of housing **322** adjacent and spaced from the collar **336**. A pair of straight walls **341** and **343** also protrude outwardly from the floor **326**. Wall **341** extends between the interior of housing wall section **324**C and the wall **341**. Wall **343** extends between the wall **340** and collar **336**.

An angled mounting flange or bracket **342** protrudes and extends outwardly from the outer surface of the wall section **324***b* of housing **322**. An angled mounting flange or bracket **344** protrudes and extends outwardly from the outside surface of the wall portion **324***a* of housing **322**. In the embodiment shown, bracket **344** is longer than bracket **342**. Each of the brackets **342** and **344** defines a circular aperture or through-hole **346** which receives a circular closed insert **348**. A fastener (not shown) is adapted to extend through each of the respective apertures **346** and associated inserts **348** for mounting and securing the rotary position sensor **300** to another structure.

A hollow connector portion or housing **348** extends and protrudes outwardly from the outside surface of the wall portion **324***c* of housing **322**. A plurality of connector terminals **350** (FIGS. **8** and **9**) extend through respective apertures **327** defined in the wall **324***c* of housing **322** and into the cavity **332** of housing **322**.

The rotor **380** (FIGS. **6**-**10**) includes an elongate, generally cylindrical central collar **382** defining an interior, generally cylindrical through-hole or aperture **384**. A generally semi-circular or moon-shaped magnet housing **386** is coupled to, and extends outwardly from, a lower portion of the outside surface of the collar **382** in an off-center or off-axis or off-set relationship.

Magnet housing **386** includes a top horizontal surface **388** and a bottom horizontal surface **390** spaced from, and parallel to, the top surface **388** and together defining a housing **386** with open interior cavity **392** (FIG. **8**) therebetween. The magnet housing **386** and, more specifically, each of the top and bottom surfaces **388** and **390** thereof, includes a peripheral elongate semi-circular outside edge **389** which is spaced from, and follows the curve and shape of, the central collar **382**. A plurality of posts **391** extend between the edge **389** of top surface **388** and the edge **389** of bottom surface **390** in a spaced apart and generally parallel relationship.

The magnet housing **386** and, more specifically, each of the top and bottom surfaces **388** and **390** thereof, further defines a pair of diametrically opposed generally tear drop shaped slots **395** and **397** which define and separate the magnet housing **386** into a central base portion **399** which is coupled to, and extends outwardly from, the outside surface of the collar **382**, and a pair of diametrically opposed peripheral curved elongate finger or wing portions **401** and **403** extending unitarily outwardly from opposed sides of the base **399** and defined in part by the outside edge **389** of respective top and bottom surfaces **388** and **390**. Each of the fingers **401** and **403** curves in the direction of the collar **382** and, as a result of being separated from the base **399** by respective slots **395** and **397**, is adapted to flex and bend either towards or away from, the base **399** in response to changes in temperature as described in more detail below. The fingers **401** and **403** terminate in respective vertical distal end walls **387***a* and **387***b* (FIG. **8**) which together with the top and bottom housing surfaces **388** and **390** define a distal closed pocket **405** at the end of each of the fingers **401** and **403**.

Magnet **400** (FIGS. **8** and **9**) is generally semi-circularly- or moon-shaped, is made of the same material as the magnet **100**, and includes top and bottom opposed, spaced-apart, and parallel surfaces **402** and **404**; a first peripheral curved side surface **406** extending generally normally between the top and bottom surfaces **402** and **404** and defining the north pole of the magnet; a second peripheral straight side surface **408** opposed to the first curved side surface **406** and defining the south pole of the magnet; and third and fourth diametrically opposed straight peripheral side surfaces **410** and **412** extending between the ends of the curved side surface **406** and straight side surface **408**.

Magnet housing **386** is made of a plastic material which, as shown in FIG. **9**, is over-molded around the magnet **400** in a relationship wherein the top surface **388** of magnet housing **386** and, more specifically, the top surface of the base **399** thereof, abuts the top surface **402** of magnet **400**; the bottom surface **390** of magnet housing **386** and, more specifically, the bottom surface of the base **399** thereof, abuts the bottom surface **404** of magnet **400**; the posts **391** of magnet housing **386** abut the outside face of the curved peripheral surface **406** of magnet **400**; and the ends **410** and **412** of magnet **400** extend into, and are wrapped around, the respective pocket **405** defined at the distal end of each of the respective flexible fingers **401** and **403** of the magnet housing **386**.

According to the invention, the shape and flexible construction and configuration of the magnet housing **386** prevents the plastic material comprising the magnet housing **386** from cracking or breaking when exposed to temperature variation. Specifically, it is understood that magnet materials typically have very small dimensional changes over temperature while plastics used for over-molding typically have larger (by comparison) dimensional changes over temperature. Thus, if the magnet **400** were over-molded with a full cover of plastic material and exposed to temperature extremes or to temperature cycling as required for automotive applications, the difference in dimensional changes, i.e., small for the magnet **400** and larger for the plastic material, could result in cracking or breakage of the plastic material and thus movement or shifting of the magnet **400** over-molded therein. Movement or shifting of the magnet **400** is undesirable of course since the position of magnet **400** is used to sense and measure the position of the shaft **170**.

The curved shape of magnet housing **386** together with the incorporation therein of a base **399** and fingers **401** and **403** separated by respective slots **395** and **397**, creates a magnet housing **386** where the fingers **401** and **403**, in response to changes in temperature and resultant dimensional changes to both the magnet **400** and housing **386**, are allowed to flex and bend independently of the base **399** to minimize stresses on the surfaces **388** and **390** of the magnet housing **386** which in turn eliminates the risk of cracking or breakage of the magnet housing **386** and thus eliminates the risk of movement or shifting of the magnet **400** over-molded therein.

Printed circuit board assembly **420** (FIGS. **8** and **10**) includes a printed circuit board **422** having a generally rectangularly-shaped terminal or base section **424** and a top side sensor section **426** unitary therewith. Terminal section **424** defines a plurality of spaced-apart, co-linear plated terminal receptacles or through-holes **428** and sensor section **426** includes a sensor **430** seated and mounted on the top surface thereof. A slot **432** is defined in the board **422** between the terminal and sensor sections **424** and **426** respectively.

Although not shown or described in detail, it is understood that the printed circuit board assembly **420** is seated in the cavity **332** of housing **322** against the outer surface of the floor **326** of housing **322** in a relationship adjacent the collar **336** wherein the end of the terminal section **424** of the printed circuit board **422** is wedged between the housing walls **340** and **341**, and the sensor section **426** of the printed circuit board **422** is wedged between the housing wall **340** and collar **336**. The ends of respective terminals **350** are received in the respective terminal receptacles **428** defined in the board **422**.

The rotor **380**, in turn, and as shown in FIGS. **8** and **10**, is seated in the cavity **332** of housing **322** in a relationship wherein the bottom of the collar **382** of rotor **380** is seated on top of the rim of the collar **336** defined in the cavity **332** and the bore **384** defined in the collar **336** in housing **322** is aligned with the bore **334** defined in the collar **382** of the rotor **380**.

The lower surface **390** of magnet housing **386** on the rotor **380** is, in turn, seated adjacent the top rim portion of the wall **340** in housing cavity **332** in a relationship spaced and parallel to the floor **332** of housing **322** and in a relationship spaced from and overlying the sensor section **422** of board assembly **420** and, more specifically, in a relationship overlying and spaced from the sensor **430** mounted on top of the board assembly **420**.

The end abutment surfaces or walls **387***a* and **387***b* at the end of each of the fingers **401** and **403** of magnet housing **386** are adapted to contact and abut against the stops **336** and **338** in housing cavity **332** to limit the rotation of rotor **380** and, more specifically, magnet housing **386** thereof, in housing cavity **332** to a total of ninety degrees.

A cover plate **450** (FIGS. **6**, **8**, and **10**) is seated on the rim **325** of the wall **324** of housing **322** to cover and enclose the cavity **332** and, more specifically, the board assembly **420** and rotor **380** housed therein. The contour of plate **450** is generally semi-oval and follows the generally semi-oval shape of the housing **322**. Plate **450** defines a generally circular aperture **452** and includes a generally circular vertical interior wall **454** surrounding and spaced from the aperture **452** and defining a recess **456** in the plate **450** surrounding the aperture **452**.

Plate **450** is coupled to the housing **322** in a relationship wherein the top of the collar **382** of rotor **380** extends through the aperture **452** of plate **450** and into the recess **456**. A seal ring **458** is seated in recess **456** between the collar **382** of rotor **380** and the wall **454** of cover plate **450** to provide a seal between the plate **450** and the rotor **380**.

Although not shown or described herein in any detail, it is understood that a shaft similar to the shaft **170** shown and described earlier with respect to rotary position sensor **20** is adapted to extend into the sensor assembly **300** and, more specifically, through the aperture **334** in the floor **326** of housing **322** and through the bore **384** in the collar **382** of the rotor **380**.

Moreover, and although also not described in any detail, it is further understood that the sensor assembly **300** operates in substantially the same manner as the sensor **20** and provides the same advantages as described above with respect to the sensor assembly **20** and thus the earlier description of the operation and advantages of the sensor assembly **20** is incorporated herein by reference with respect to the sensor assembly **300**.

Specifically, when shaft **170** is rotated, rotor **380** and magnet **400** are also rotated relative to the stationary sensor **430** which is spaced from and overlies the magnet **400**. The magnetic field generated by the magnet **400** and, more specifically, at least the direction of the magnetic field thereof, is sensed by the sensor **430**. More specifically, and as described above with respect to the sensor assembly **20**, it is understood that the magnetic field can vary in magnitude/strength and in polarity/direction depending upon the position and location at which the magnet parameters (lines of flux) are measured.

Sensor **430** produces an electrical output signal that changes in response to the position of magnet **400**. As the magnetic field (i.e., magnitude and polarity/direction) generated by the magnet **400** varies with rotation of the shaft **170** and rotor **480**, the electrical output signal produced by sensor **430** changes accordingly, thus allowing the position of shaft **170** to be determined or ascertained. Sensor **430** senses the changing magnetic field (i.e., changing magnitude and polarity/direction) as magnet **400** is rotated.

FIGS. **11A-11**C depict the location and orientation of the magnetic field/flux lines **450** in a horizontal plane above magnet **400** and passing over and through the magnetic flux sensor **430** at three different shaft and magnet rotation angles or positions, i.e., zero degrees (FIG. **11**A), forty-five degrees (FIG. **11**B), and ninety degrees (FIG. **11**C).

More specifically, magnet **400** generates flux lines **450** that point and flow from the top, curved North Pole surface **406** of magnet **400** in the direction of and generally straight through the width and opposed bottom straight South Pole surface **408** of magnet **400** in a direction and orientation generally normal to the surface **408**.

At the shaft and magnet rotation or position angle of zero degrees (FIG. **11**A), the flux lines or vectors **450** have flux directions that point generally diagonally from the top left corner to the bottom right corner of magnetic flux sensor **430**, i.e., flux lines or vectors oriented at a forty-five degree angle relative to each of the sensor side faces. Sensor **430** senses this direction of the magnetic field **210** and generates an electrical signal representative of this direction and thus the position of the magnet **400** and shaft **170**.

At the shaft or magnet rotation or position angle of forty-five degrees (FIG. **11**B), flux lines or vectors **450** have flux directions that point generally straight across from the top to the bottom of magnetic flux sensor **430**, i.e., flux lines or vectors oriented in a relationship parallel to two of the sensor side surfaces and normal to the other two sensor side surfaces. Sensor **430** senses this direction of the magnetic field **210** and generates an electrical signal representative of this direction and thus the position of the magnet **400** and shaft **170**.

At a shaft or magnet rotation or position angle of ninety degrees (FIG. **11**C), flux lines or vectors **450** have flux directions that point generally diagonally from the top right corner to the bottom left corner of magnetic flux sensor **430**, i.e., flux lines or vectors oriented at a forty-five degree angle relative to each of the sensor side surfaces. The angular direction and orientation of the flux lines **450** in FIG. **11**C is directly opposite the angular direction and orientation of the flux lines **450** in FIG. **11**A.

While the invention has been taught with specific reference to two embodiments, someone skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and the scope of the invention. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A sensor assembly for sensing the position of a movable object, comprising:
- a housing defining an interior cavity;
- a sensor located in the housing;
- a rotor located in the cavity, the rotor defining a longitudinal axis, the sensor being located in the housing in a horizontally spaced and off-axis relationship relative to the longitudinal axis of the rotor;
- a magnet located on the rotor, the magnet including at least a first straight side surface and the magnet generating a magnetic field extending through and in a direction generally normal to the first straight side surface of the magnet irrespective of the position of the magnet, the magnet being located on the rotor in a horizontally spaced and off-axis relationship relative to the longitudinal axis of the rotor and the magnet and the rotor being located in in a vertically overlying and spaced relationship relative to each other; and
- the magnet and the sensor being movable relative to each other and the sensor being adapted to sense the magnitude and direction of the magnetic field and generate an electrical signal in response to the magnetic field sensed by the sensor.

2. The sensor assembly of claim **1**, further comprising a plate secured to the housing and covering the cavity, the plate defining an aperture in alignment with the collar of the rotor.

3. The sensor assembly of claim **1**, wherein the rotor includes a collar and a housing for the magnet at least partially surrounding the collar.

4. The sensor assembly of claim **3** wherein the housing for the magnet is made of a plastic material over-molded around the magnet.

5. The sensor assembly of claim **3** wherein the housing for the magnet defines at least one slot dividing the housing into first and second portions, the second portion being adapted to flex independently of the first portion in response to a change in temperature.

6. The sensor assembly of claim **1**, wherein the sensor is located in the cavity of the housing.

7. The sensor assembly of claim **1** wherein the interior cavity in the housing defines a first interior cavity, the housing defining a second interior cavity, the rotor being located in the first interior cavity of the housing and the sensor being located in the second interior cavity of the housing, the first and second interior cavities being located in the housing in a vertically overlying and spaced relationship.

8. The sensor assembly of claim **1** wherein the magnet includes a curved side surface opposed and spaced from the first straight side surface.

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