(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 June 2017 (15.06.2017)

(10) International Publication Number
WO 2017/100032 A1

(51) International Patent Classification:
G01D 5/14 (2006.01)

(21) International Application Number:
PCT/US2016/063952

(22) International Filing Date:
29 November 2016 (29.11.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/264,572 8 December 2015 (08.12.2015) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: LOW-PROFILE TRANSMISSION GEAR POSITION SENSOR

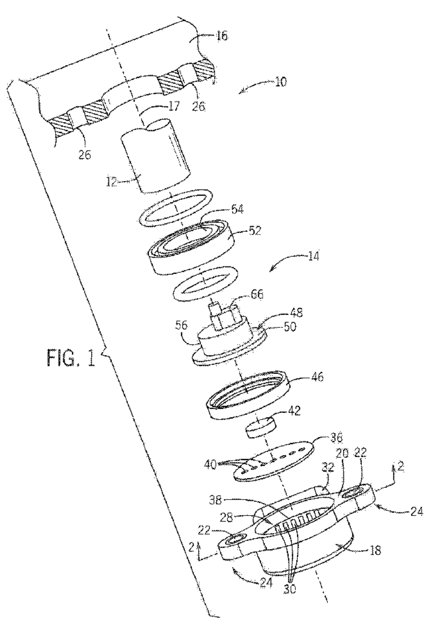

FIG. 1

(57) Abstract: A transmission gear position sensor employs a nonferrous construction using polymer materials spacing a magnet and Hall effect sensor away from ferrous components of the transmission to provide a robust transmission gear selection signal when the transmission gear position sensor is connected to a ferrous gear selector shaft through a polymer spacer shaft. The polymer materials of the spacer shaft permit precise staking of the magnet to the spacer shaft while resisting rotation of the magnet,

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LOW-PROFILE TRANSMISSION GEAR POSITION SENSOR

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional application 62/264,572 filed December 8, 2015, and hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to a sensor suitable for sensing a gear position of a mechanical transmission, and specifically to a Hall effect sensor having an extremely low profile.

BACKGROUND OF THE INVENTION

[0003] A mechanical transmission, for example, as used in an all-terrain vehicle, may provide multiple gear positions, for example: high, low, neutral, reverse, and park, as are generally understood in the art. Often it is desirable to provide an electrical signal indicating the gear position, for example, to provide visual feedback to the user.

[0004] Existing sensors providing an electrical signal indicating gear position may use a set of concentric electrical contacts arranged along arcs about a common center. Such a contact base design desirably produces an extremely low profile sensor system; however, multiple connector wires are required to convey the angular information from the sensor.

[0005] For this reason, an alternative design may use a potentiometer instead of contacts. The potentiometer provides an arbitrarily fine angular resolution eliminating the need for a large number of wires associated with different contacts. Nevertheless, it is difficult to build reliable and low profile potentiometers for use in the field environments for which the sensor is intended.

[0006] US patent application 13/581,374 filed May 4, 2014, assigned to the assignee of the present invention and hereby incorporated by reference, describes an improved sensor using contacts that offer reliable electrical operation. In this design the contacts communicate with a resistor ladder to provide potentiometer-like outputs reducing the number of wires required to communicate with the sensor. The contacts and resistive ladder are fabricated on a printed circuit board allowing the range and resistance values to be readily adjusted for different applications with low tooling costs and providing the desirable low-profile.

[0007] Each of these designs requires close tolerance parts that must make and break electrical contact and that are therefore subject to disruption by contamination and high vibration.

SUMMARY OF THE INVENTION

[0008] The present invention provides a transmission gear position sensor that uses a Hall effect sensor for increased resistance to damage and contamination. Effective use of a Hall effect sensor is made practical in this environment in close proximity to the ferrous components of the transmission through the use of a nonferrous spacer shaft that may accurately hold a magnet within an assembly constructed of nonferrous thermoplastic. Robust construction of the sensor from nonferrous materials such as plastic is made possible through the use of large area bearings suitable for plastic. A low profile is obtained by mounting the Hall effect sensor on the backside of a printed circuit board placed between the nonferrous spacer shaft and the sensor. Precise integration of a magnet into the nonferrous spacer shaft is provided through the use of a crush rib and welding system.

[0009] In one embodiment, the invention provides a transmission gear position sensor for transmission providing a ferrous gear selector shaft. The transmission gear position sensor includes a housing holding a nonferrous spacer shaft, a Hall effect sensor, and a connector. The nonferrous spacer shaft has a first portion interfitting with an end of the gear selector shaft to rotate the nonferrous spacer with rotation of the gear selector shaft along a common axis and has a second end supporting an axially-centered permanent magnet. The Hall effect sensor is positioned proximate to the second end and aligned with the axis to sense rotation of the nonferrous space, and the connector provides conductors exposed through the housing and communicating with a Hall effect sensor to output electrical signals indicating multiple different rotation positions of the nonferrous spacer indicating gear positions of the transmission.

[0010] It is thus a feature of at least one embodiment of the invention to make use of a robust Hall effect sensor and magnet in an extremely compact housing by encasing the magnet and Hall effect sensor in nonferrous materials that space these elements away from the ferrous components of the transmission.

[0011] The nonferrous spacer shaft may be a polymer material and in particular a thermoplastic polymer material.

[0012] It is thus a feature of at least one embodiment of the invention to provide a design employing readily manufactured nonferrous thermoplastic materials that is sufficiently robust for use in the environment of the transmission.

[0013] The housing may include mounting holes parallel to and flanking the axis and further including metal shoulder bushings received in the mounting holes to extend between axial edges of the mounting holes to absorb the force of mounting bolts attaching the housing via the mounting holes.

[0014] It is thus a feature of at least one embodiment of the invention to provide a thermoplastic housing that can be used in lieu of more robust housing materials normally associated with the transmission while reducing the possibility of crushing the thermoplastic material when used with standard mounting bolts.

[0015] The housing may include a first portion providing a cavity open toward the transmission and providing an axially perpendicular stop surface receiving an inner peripheral surface of a printed circuit board holding the Hall effect device; a second portion resting against an outer peripheral surface of the printed circuit board and providing an axially perpendicular stop surface receiving an inner surface of a radially extending flange on the nonferrous spacer shaft; and a third portion having a bore receiving a shaft portion of the nonferrous spacer shaft and fitting over an outer surface of the radially extending flange of the nonferrous spacer shaft to sealably retain the nonferrous spacer shaft within the cavity.

[0016] It is thus a feature of at least one embodiment of the invention to provide a thermoplastic housing that can sealably retain a rotating shaft while holding precise separations between the magnet and Hall effect sensor necessary for a low profile sensor. The multiple elements of the housing provide contact and support surfaces that would otherwise be difficult to fabricate.

[0017] The Hall effect sensor may be supported on a side of the printed circuit board away from the magnet.

[0018] It is thus a feature of at least one embodiment of the invention to provide close proximity between the Hall effect sensor and the magnet by eliminating the need for clearances between other components of the printed circuit board and the magnet.

[0019] The housing may include in-molded electrical connectors extending generally perpendicular to the axis outside of the housing and axially inside the housing to receive the circuit board through an opening in the housing.

[0020] It is thus a feature of at least one embodiment of the invention to provide in-molded connectors offering high-quality sealing against environmental contamination while permitting readily assembly of the printed circuit board and housing.

[0021] The transmission gear position sensor may include a housing that provides an opening extending along the axis and includes a bushing providing a rim perpendicular to the axis and slidably abutting a corresponding rim of the nonferrous spacer shaft to support the nonferrous spacer shaft at constant distance from the Hall effect mounted on the housing.

[0022] It is thus a feature of at least one embodiment of the invention to provide a positive insertion stop with respect to the magnet ensuring precise placement of the magnet with respect to the Hall effect sensor.

[0023] The transmission gear position sensor may further include an elastomeric seal between the housing and a face of the transmission whereby the housing may be sealed against the transmission around the ferrous gear selector shaft.

[0024] It is thus a feature of at least one embodiment of the invention to provide high-quality sealing with low attachment forces that might warp or otherwise distort a thermoplastic housing.

[0025] The housing provides a bore extending along the axis and slidably contacting a cylindrical journal portion of the nonferrous spacer and further provides a channel adjacent to and centered around the bore holding an elastomeric seal between opposed axially extending surfaces of the housing and the nonferrous spacer moving with respect to each other when the nonferrous spacer moves with the ferrous gear selector shaft.

[0026] It is thus a feature of at least one embodiment of the invention to provide for a positive rotational support of the nonferrous spacer between thermoplastic elements as well as an elastomeric seal separated from the rotational support to provide sealing without jeopardizing positional accuracy.

[0027] The transmission gear position sensor may further include an elastomeric seal between the housing and a face of the transmission whereby the housing may be sealed against the transmission around the ferrous gear selector shaft.

[0028] It is thus a feature of at least one embodiment of the invention to provide good sealing properties of the housing to the transmission without excessive forces that could cause distortion or cold flow of the thermoplastic housing.

[0029] The magnet may provide magnet poles positioned on opposite sides of the axis and opposed along a plane substantially perpendicular to the axis.

[0030] It is thus a feature of at least one embodiment of the invention to produce a magnetic flux providing high resolution rotational sensing using a coaxial Hall effect sensor in close proximity to the transmission providing a compact sensor housing.

[0031] The nonferrous spacer shaft may be a thermoplastic material and the second end of the nonferrous spacer may include a bore having crush ribs crushed with installation of the magnet within the bore.

[0032] It is thus a feature of at least one embodiment of the invention to provide a simple method of ensuring rotational fixity of the magnet without damage to the magnet.

[0033] The bore may further include stabilizer ribs that are not crushed with insertion of the magnet within the bore to abut sides of the magnet parallel to the axis when the magnet is placed within the bore.

[0034] It is thus a feature of at least one embodiment of the invention to ensure precise location of the magnet independent of the deformation of the crush ribs.

[0035] The bore may further include tabs of thermoplastic material of the nonferrous spacer meltably retaining the magnet.

[0036] It is thus a feature of at least one embodiment of the invention to positively lock the magnet into the bore using the thermoplastic properties of the nonferrous spacer shaft.

[0037] These and other features and advantages of the invention will become apparent to those skilled in the art upon review of the following detailed description, claims and drawings in which like numerals are used to designate like features.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] Fig. 1 is an exploded view of the sensor system of the present invention and a transmission shifter shaft to which it attaches;

[0039] Fig. 2 is a cross-sectional view along line 2 – 2 of Fig. 1 of the fully assembled sensor prior to attachment to the transmission shifter shaft showing a nonferrous spacer shaft held within a nonferrous housing;

[0040] Fig. 3 is a view of the nonferrous spacer shaft prior to installation of a button magnet;

[0041] Fig. 4 is an end view of a socket on the spacer shaft before receiving the button magnet showing locating and crush ribs; and

[0042] Fig. 5 is a cross-section along line 5 – 5 of Fig. 4 showing an ultrasonic staking of the magnet in place.

[0043] Before the embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. The use of "including" and "comprising" and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items and equivalents thereof.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0044] Referring now to Fig. 1, a transmission 10 may include a gear selector shaft 12 extending along axis 17 from a transmission housing 16 to be received by a gear position sensor 14. Typically the gear selector shaft 12 will be a steel or ferrous shaft and may be exposed through an opening in a transmission housing 16 that may also be a ferrous material such as steel or iron ore which may include ferrous components.

[0045] Referring now to Figs. 1 and 2, the sensor 14 may include an outer sensor housing 18 having an interface surface 20 that may attach to an outer face 15 of the transmission housing 16 as assembled along the axis 17 and as held to the transmission housing 16, for example, by means of bolts (not shown) received through mounting holes 22. The mounting holes 22 are positioned on transversely opposed tabs 24 of the outer sensor housing 18, the tabs extending along the plane of the interface surface 20 and aligned with corresponding threaded holes 26 in the transmission housing 16 that may receive threaded portions of the bolts.

[0046] A blind bore 28 opens from the interface surface 20 and defines a cylindrical cavity 19 that will hold other components of the gear position sensor 14 to be described. A set of electrical conductors 30 may project along axis 17 up from a bottom of the bore 28 parallel to the axis 17 and then may bend by 90 degrees to extend along a transverse axis through a wall of the outer sensor housing 18 as in-molded into the thermoplastic material of the sensor housing 18. The bends in the conductors 30 may be fully embedded in and supported by the molded thermoplastic material of the sensor housing 18 to project out within the cavity 19 at one end and at the other end out of a connector sleeve 32 extending transversely from the sensor housing 18 and adapted to receive and mechanically interconnect with a corresponding connector (not shown) and it's contained conductors. These conductors 30 may desirably be nonferrous brass or copper alloy materials.

[0047] A disk-shaped printed circuit board 36 may be sized to fit within the blind bore 28 to rest on a ledge 38 projecting radially inward along the walls of the bore 28 spaced up from the bottom of the blind bore 28 along axis 17. Conductive pads 40 having holes ringed by electrical printed circuit board traces may receive the projecting ends of the conductors 30 within the cavity 19 to be soldered thereto with solder 41. An inner surface of the printed circuit board 36 adjacent to the bottom of the bore 28 may support a Hall effect sensor 44 capable of measuring a magnetic vector to provide a signal resolving the vector orientation about the axis 17 of approximately 360 degrees. The Hall effect sensor 44 may communicate with the conductors 30 by traces on the printed circuit board 36 (and conductive vias passing therethrough). Hall effect sensors 44 suitable for this purpose are available from a wide variety of vendors including, for example, from Honeywell under the tradename

APS00B "High-Resolution Magnetic Angular Position Sensor IC" and from Allegro Microsystems LLC under the tradename of A1335LLETR-T as well as other manufacturers and may provide an angular range of over 90 degrees and preferably over 180 degrees through one or more continuously varying voltage outputs.

[0048] The Hall effect sensor 44 is attached to the printed circuit board 36 on the far side of the printed circuit board 36 with respect to the gear selector shaft 12 and with respect to a diametrically magnetized button magnet 42 (as will be described) so as to reduce the profile height measured along axis 17 of the sensor 14 while providing sufficient separation between the magnet 42 and the Hall effect sensor 44 so that the flux lines from the magnet 42 are predominantly organized perpendicular to axis 17 as is necessary for maximum sensitivity. The printed circuit board 36 may be a nonferrous material such as an epoxy fiberglass having copper traces.

[0049] A nonferrous and ideally thermoplastic spacer ring 46 may be placed on top of the printed circuit board 36 to contact its outer peripheral edge when the latter is installed within the bore 28. The spacer ring 46 provides a first axial support surface for a nonferrous transducer spacer shaft 48 by contacting a radially extending flange 50 of the transducer spacer shaft 48. An inner surface of this flange 50 rests on an axial outward exposed surface of the ring 46 to accurately position the transducer spacer shaft 48 at a given separation from the Hall effect sensor 44. The radially extending flange 50 extends by a radius at least twice the radius of the button magnet 42, the latter centered along axis 17 so as to provide for a high degree of axial alignment of the transducer spacer shaft 48 and hence the button magnet 42 with respect to the housing 18 with reasonable tolerances of the spacer ring 46 and transducer spacer shaft 48.

[0050] As will be discussed further below, the button magnet 42 attaches to an inner surface of the transducer spacer shaft 48 facing the printed circuit board 36 and is centered on axis 17. A nonferrous and ideally thermoplastic bearing ring 52 fits over a front end of the transducer spacer shaft 48 and provides a central bore 54 aligned with axis 17 and receiving outer cylindrical journal surface 56 of the transducer spacer shaft 48. The bearing ring 52 has an outer circumference that fits tightly against the inner walls of the cylindrical bore 28 and thereby serves to constrain radial movement of the transducer spacer shaft 48 while allowing it to freely rotate within the bore 54.

[0051] With particular attention to Fig. 2, the bearing ring 52 may include grooves holding O-rings 60 and 62. O-ring 60 is on a face of the bearing ring 52 parallel to and aligned with interface surface 20 to abut the outer surface of the transmission housing 16 when the sensor 14 is placed on the transmission housing 16. In this respect, O-ring 60 seals the opening through which the gear selector shaft 12 is exposed through the transmission housing 16 to prevent transmission fluid from leaking beyond the O-ring 60.

[0052] O-ring 62 seals are placed between the outer journal surface 56 of the transducer spacer shaft 48 and inner bore 58 of the bearing ring 52 to prevent leakage of transmission fluid into the area of the printed circuit board 36 although some leakage can be readily accommodated due to the hermetic nature of the Hall effect sensor 44 and the ability of magnetic fields to pass through such fluid.

[0053] Exposed on an outer end of the cylinder forming the outer journal surface 56 is an axially extending rotational key 66 that may fit within a corresponding keyway 68 cut in the end of the gear selector shaft 12 so that the rotation of the gear selector shaft 12 is communicated to the transducer spacer shaft 48 so that the two rotate together. Ideally there is no rotational play between the rotational key 66 and keyway 68; however, axial play is allowed and this axial play permits the sensor 14 to operate in a manner indifferent to axial end play of the gear selector shaft 12. An outer surface of the flange 50 rests against an interface of the bearing ring 52 to constrain the transducer spacer shaft 48 inside of the housing 18 against movement out of the housing 18.

[0054] The bearing ring 52 may be ultrasonically welded at weld points 69 to the housing 18.

[0055] The holes 22 may include shoulder bushing inserts 70 of a stiffer or stronger material than the thermoplastic of the housing 18 to resist compressive force of the bolts that hold the housing 18 to the transmission housing 16. Desirably these inserts 70 are nonferrous, for example, a glass fiber-reinforced polymer material, and extend through the holes 22 to lie flush with opposite faces of the housing.

[0056] Referring now to Figs. 3 and 4, the button magnet 42 may be generally cylindrical in shape and have a transverse or diametric magnetization along transverse axis 72 perpendicular to axis 17 and the axis of symmetry of the cylinder of the button magnet 42. The inner side of the flange 50 of the transducer spacer shaft 48 may support a generally cylindrical socket 76 exposing an axially aligned and centered opening for receiving the button magnet 42 therein. Generally the opening has radially inward projecting locator tabs 80 which abut an outer periphery of the button magnet 42 when the button magnet 42 is inserted into the socket 76 and which provide an alignment guide for the axis of magnetization which should extend across the wider of the tabs with the south end of the magnet aligned with an eccentric extreme of the key 66 measured perpendicular to axis 17. The socket 76 also includes inwardly extending crush ribs 82 that must deform to admit the magnet 42 and thereby press tightly against the outer periphery of the magnet 42 when it is so installed to present rotation of the button magnet 42 around the axis 17.

[0057] Referring to Fig. 5, the button magnet 42 may be placed slightly below a lip 84 of the socket 76 limited by a stop element 83 projecting slightly upward from the bottom of the socket 76, and the tabs 80 may be compressed downward by ultrasonic welding tool 86 to provide an inwardly extending lip 88 of melted material that passes over the top of the edge of the button magnet 42 to retain it within the socket 76. In this way, the magnet 42 may be firmly and accurately placed in the transducer spacer shaft 48 without the need for metallic attachment elements.

[0058] Various features of the invention are set forth in the following claims. It should be understood that the invention is not limited in its application to the details of construction and arrangements of the components set forth herein. The invention is capable of other embodiments and of being practiced or carried out in various ways. Variations and modifications of the foregoing are within the scope of the present invention. It also being understood that the invention disclosed and defined herein extends to all alternative combinations of two or more of the individual features mentioned or evident from the text and/or drawings. All of these different combinations constitute various alternative aspects of the present invention. The embodiments described herein explain the best modes known for practicing the invention and will enable others skilled in the art to utilize the invention.

CLAIMS

WHAT IS CLAIMED IS:

1. A transmission gear position sensor for a transmission providing a ferrous gear selector shaft, the sensor comprising:

a housing holding:

a nonferrous spacer shaft having a first portion interfitting with an end of the gear selector shaft to rotate the nonferrous spacer with rotation of the gear selector shaft along a common axis and further having a second end supporting an axially centered permanent magnet;

a Hall effect sensor positioned proximate to the second end and aligned with the axis to sense rotation of the nonferrous spacer; and

a connector having conductors exposed through the housing and communicating with a Hall effect sensor to provide electrical signals indicating multiple different rotation positions of the nonferrous spacer indicating gear positions of the transmission.

2. The transmission gear position sensor of claim 1 wherein the nonferrous spacer shaft is a polymer material.

3. The transmission gear position sensor of claim 2 wherein the nonferrous spacer shaft is a thermoplastic polymer material.

4. The transmission gear position sensor of claim 3 wherein the housing is a thermoplastic material.

5. The transmission gear position sensor of claim 4 wherein the housing includes mounting holes parallel to and flanking the axis and further including shoulder bushings received in the mounting holes to extend between axial edges of the mounting holes to absorb the force of mounting bolts attaching the housing via the mounting holes.

6. The transmission gear position sensor of claim 4 wherein the housing includes:

a first portion providing a cavity open toward the transmission and providing an axially perpendicular stop surface receiving an inner peripheral surface of a printed circuit board holding the Hall effect device;

a second portion resting against an outer peripheral surface of the printed circuit board and providing an axially perpendicular stop surface receiving an inner surface of a radially extending flange on the nonferrous spacer shaft; and

a third portion having a bore receiving a shaft portion of the nonferrous spacer shaft and fitting over an outer surface of the radially extending flange of the nonferrous spacer shaft to sealably retain the nonferrous spacer shaft within the cavity.

7. The transmission gear position sensor of claim 4 wherein the Hall effect sensor is supported on a nonferrous printed circuit board held by the housing;

8. The transmission gear position sensor of claim 7 wherein the Hall effect sensor is supported on a side of the printed circuit board away from the magnet.

9. The transmission gear position sensor of claim 7 wherein the housing includes in-molded electrical connectors extending generally perpendicular to the axis outside of the housing and axially inside the housing to receive the circuit board through an opening in the housing.

10. The transmission gear position sensor of claim 4 wherein the housing provides a bore extending along the axis and slidably supporting a cylindrical journal portion of the nonferrous spacer and further provides a channel adjacent and centered around the bore holding an elastomeric seal between opposed axially extending surfaces of the housing and the nonferrous spacer moving with respect to each other when the nonferrous spacer moves with the ferrous gear selector shaft.

11. The transmission gear position sensor of claim 4 further including an elastomeric seal between the housing and a face of the transmission whereby the housing may be sealed against the transmission around the ferrous gear selector shaft.

12. The transmission gear position sensor of claim 4 wherein the housing includes a circumferential rim providing a stop surface perpendicular to the axis slidably receiving a corresponding surface of the nonferrous spacer shaft limiting insertion of the nonferrous spacer shaft along the axis into the housing to a predetermined distance.

13. The transmission gear position sensor of claim 1 wherein the magnet provides magnet poles positioned on opposite sides of the axis and opposed along a plane substantially perpendicular to the axis.

14. The transmission gear position sensor of claim 13 wherein the nonferrous spacer shaft is a thermoplastic material and the second end of the nonferrous spacer includes a bore having radially inwardly extending crush ribs crushed with installation of the magnet within the bore.

15. The transmission gear position sensor of claim 14 wherein the bore further includes radially inwardly extending stabilizer ribs that are not crushed with insertion of the magnet within the bore to abut sides of the magnet parallel to the axis when the magnet is placed within the bore.

16. The transmission gear position sensor of claim 12 further including tabs of thermoplastic material of the nonferrous spacer meltably retaining the magnet.

17. The transmission gear position sensor of claim 1 wherein the first end of the nonferrous spacer includes a key element received in a corresponding key slot in the shaft resisting relative rotation between the second end and the shaft.

18. A transmission gear position sensor for transmission providing a ferrous gear selector shaft, the sensor comprising:

a printed circuit board holding a Hall effect sensor;

a polymer spacer shaft having a first portion interfitting with an end of the gear selector shaft to rotate the polymer spacer shaft with rotation of the gear selector shaft along a common axis and further having a second end supporting an axially centered permanent magnet;

a polymer housing having:

(a) a first portion providing a cavity open toward the transmission and providing an axially perpendicular stop surface receiving an inner peripheral surface of the printed circuit board;

(b) a second portion resting against an outer peripheral surface of the printed circuit board and providing an axially perpendicular stop surface receiving an inner surface of a radially extending flange on the polymer spacer shaft; and

(c) a third portion having a bore receiving a shaft portion of the polymer spacer shaft and fitting over an outer surface of the radially extending flange of the polymer spacer shaft to sealably retain the polymer spacer shaft within the cavity;

a Hall effect sensor positioned proximate to the second end and aligned with the axis to sense rotation of the polymer spacer; and

a connector having conductors exposed through the housing and communicating with a Hall effect sensor to provide electrical signals from the Hall effect sensor indicating multiple different rotation positions of the polymer spacer indicating gear positions of the transmission.

19. The transmission gear position sensor of claim 18 wherein the magnet provides magnet poles positioned on opposite sides of the axis and opposed along a plane substantially perpendicular to the axis.

20. The transmission gear position sensor of claim 19 wherein the second end of the polymer spacer includes a bore having crush ribs crushed with installation of the magnet within the bore and stabilizer ribs that are not crushed with insertion of the magnet within the bore to abut sides of the magnet parallel to the axis when the magnet is placed within the bore and further including tabs of thermoplastic material of the polymer spacer shaft meltably retaining the magnet.

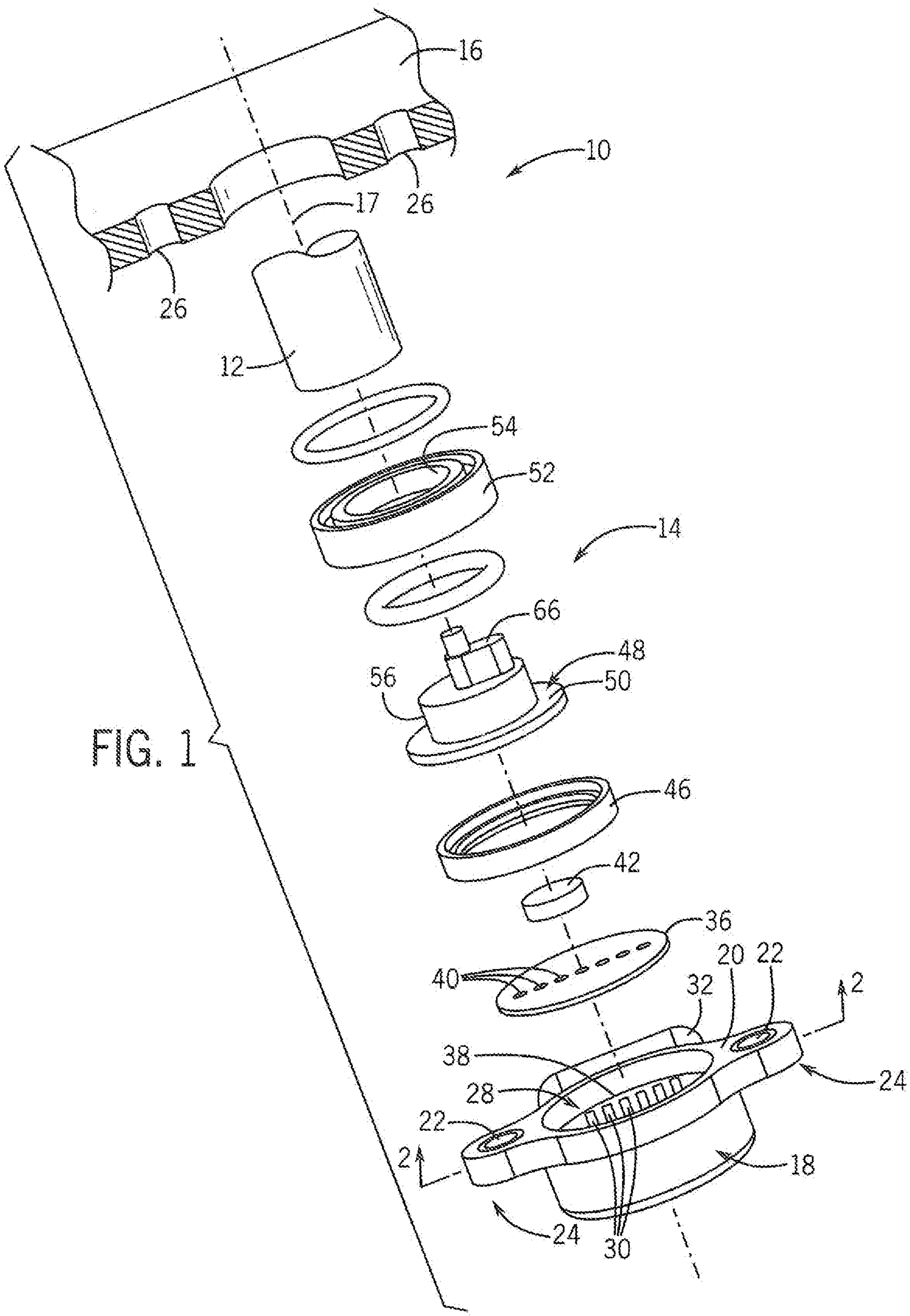
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FIG. 1

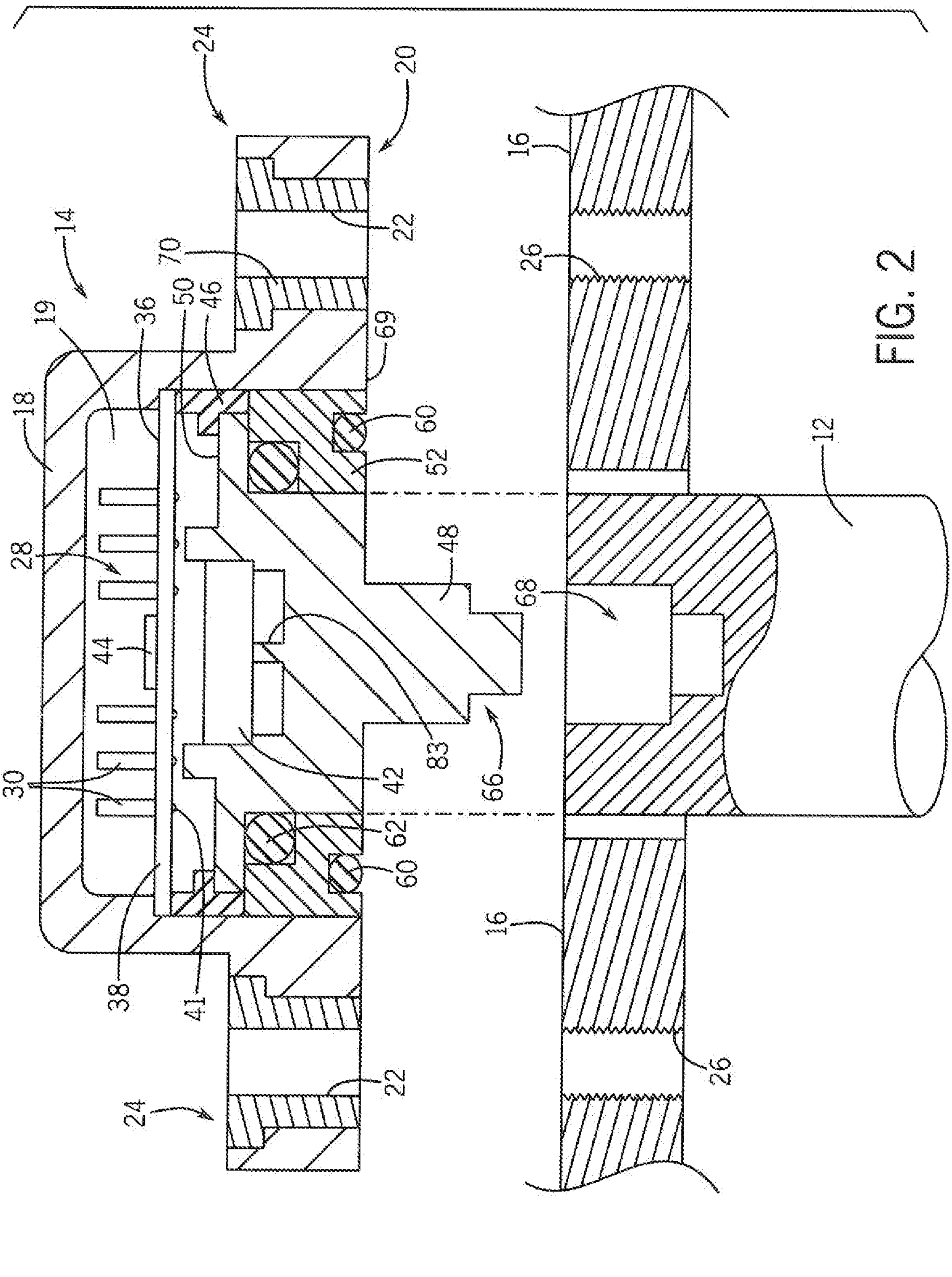
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FIG. 2

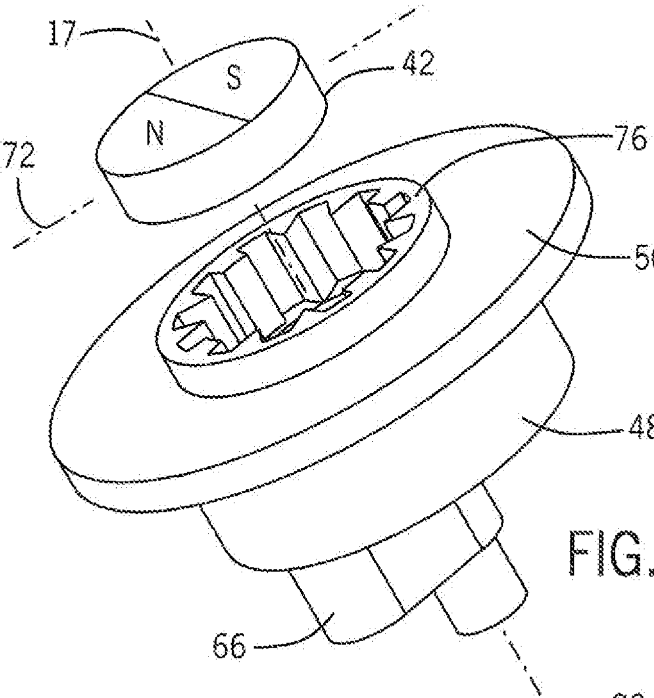

FIG. 3

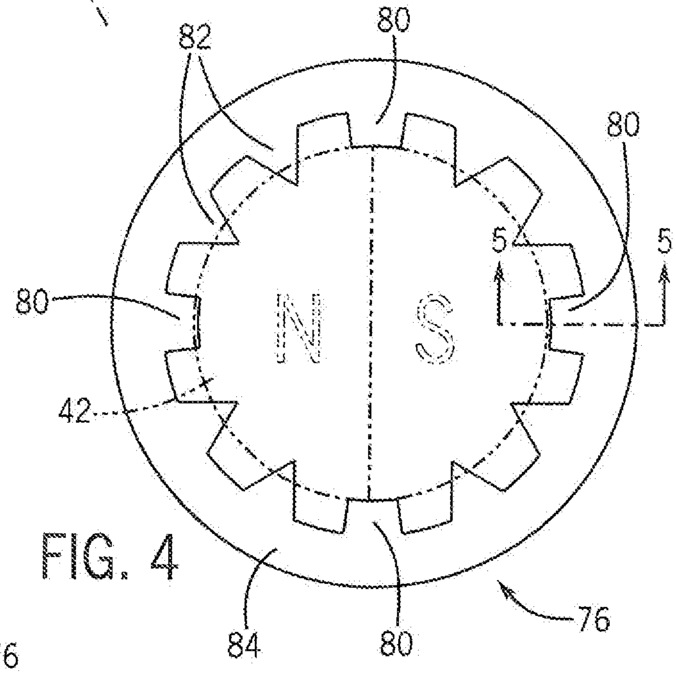

FIG. 4

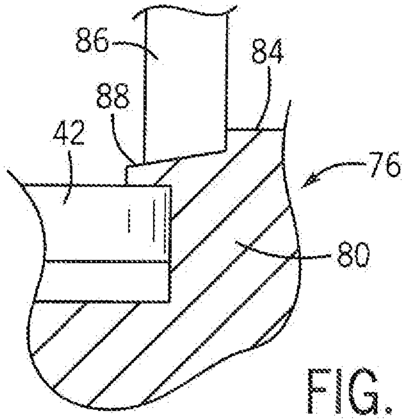

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/063952

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01D5/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	EP 1 729 094 A1 (DELPHI TECH INC) 6 December 2006 (2006-12-06) abstract; figures 2,3,4,5 paragraphs [0002], [0009], [0012], [0023] - [0032], [0039] - [0040], [0043] - [0045]	1-13, 17-19 14,16 15,20
X Y	US 6 316 935 B1 (VANZUILEN) 13 November 2001 (2001-11-13) abstract; figures 1-3 column 1, lines 6-9,22-23 columns 2-4	1-13, 17-19 14,16
Y	US 2009/140730 A1 (NEWMAN ET AL) 4 June 2009 (2009-06-04) figures 2-4 and 9-11 paragraphs [0039], [0070]	14,16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 March 2017	21/03/2017

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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