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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
07 March 2019 (07.03.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/043602 A1

(51) International Patent Classification:
G01R 15/20 (2006.01) *G01R 19/00* (2006.01)

(21) International Application Number:
PCT/IB2018/056602

(22) International Filing Date:
29 August 2018 (29.08.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/693,929 01 September 2017 (01.09.2017) US

(71) Applicant: **TE CONNECTIVITY CORPORATION** [US/US]; 1050 Westlakes Drive, Berwyn, Pennsylvania 19312 (US).

(72) Inventors: **DELACRUZ, Robert Steve Felisilda**; 1421 Halo Street, Columbus, Ohio 43240 (US). **WAHL III, Frank Peter** `; 5676 Amherst Street, VENTURA, California 93003 (US). **MISHRIKEY, Matthew**; 426 Poplar Street, Roslindale, Massachusetts 02131 (US).

(74) Agent: **STROUD, Adam L.**; 4550 Linden Hill Road, Suite 140, Wilmington, Delaware 19808 (US).

(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, JO, JP, KE, KG, KH, 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).

(54) **Title:** HALL EFFECT CURRENT SENSOR

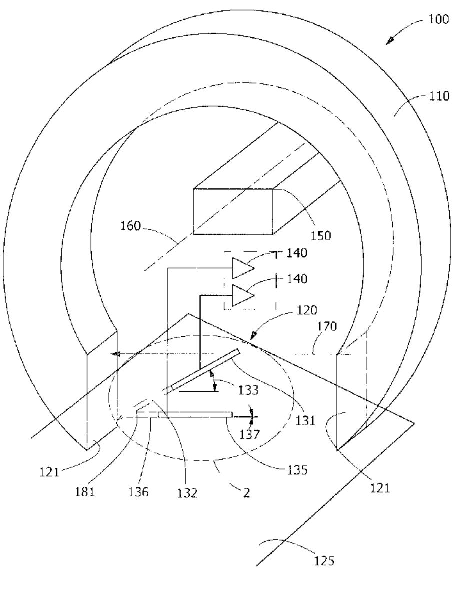

FIG. 1

(57) **Abstract:** A Hall Effect sensor, including a toroid including a gap having opposed surfaces, which are substantially planar and substantially parallel to one another. The toroid further includes a central plane bisecting the opposed surfaces. A first Hall element sensor defining a first sensor plane is positioned at least partially within the gap of the toroid at a first angle and a second Hall element sensor is positioned at least partially within the gap of the toroid at a second angle substantially mutually perpendicular to each of the opposed surfaces. The central plane is substantially perpendicular to the opposed surfaces.

WO 2019/043602 A1

[Continued on next page]

Published:

— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

HALL EFFECT CURRENT SENSOR

[0001] The present invention is directed to Hall Effect current sensors. More particularly, the present invention is directed to Hall Effect current sensors employing at least two Hall plates.

[0002] Hall Effect current sensors are frequently employed to measure current in a variety of applications including microelectronics. The problem to be solved is that conventional Hall sensors are unable to measure the large magnetic flux generated by currents over a few hundred Amperes without becoming saturated. An increase in the size of the Hall plate to that necessary to measure large magnetic fields is impractical.

[0003] The solution is provided by a Hall Effect sensor including a toroid including a gap, the gap including opposed surfaces, the opposed surfaces being substantially planar and substantially parallel to one another, and having a central plane bisecting the opposed surfaces of the toroid. The Hall Effect sensor additionally includes a first Hall element sensor defining a first sensor plane positioned at least partially within the gap of the toroid at a first angle. The Hall Effect sensor additionally includes a second Hall element sensor positioned at least partially within the gap of the toroid at a second angle substantially mutually perpendicular to each of the opposed surfaces. The central plane of the toroid is substantially perpendicular to the opposed surfaces.

[0004] The invention will now be described by way of example with reference to the accompanying drawings in which:

[0005] FIG. 1 is a top view of a Hall sensor according to an embodiment.

[0006] FIG. 2 is an exemplary Hall sensor arrangement from the region 2 of FIG. 1 according to an embodiment.

[0007] FIG. 3 is a flow chart of a method of determining current using a Hall Effect sensor according to an embodiment.

[0008] Wherever possible, the same reference numbers will be used throughout the drawings to represent the same parts.

[0009] In an embodiment, a Hall Effect sensor including a toroid including a gap, the gap including opposed surfaces, the opposed surfaces being substantially planar and substantially parallel to one another, and having a central plane bisecting the opposed surfaces of the toroid. The Hall Effect sensor additionally includes a first Hall element sensor defining a first sensor plane positioned at least partially within the gap of the toroid at a first angle. The Hall Effect sensor additionally includes a second Hall element sensor positioned at least partially within the gap of the toroid at a second angle substantially mutually perpendicular to each of the opposed surfaces. The central plane of the toroid is substantially perpendicular to the opposed surfaces.

[0010] In another embodiment, a method of regulating the operation of an electrical system, the electrical system including at least one gapped ferromagnetic toroid, at least one conductive element positioned along a central axis of the toroid, at least two Hall element sensors positioned within the gap, and an amplifier circuit coupled to the at least two Hall element sensors. The method includes receiving, by the amplifier circuit, one or more first measurements, from a first Hall element sensor. The method also includes receiving, by the amplifier circuit, one or more second measurements, from a second Hall element sensor. The method also includes determining, by the amplifier circuit, a current corresponding to a current in the at least one conductive element and regulating, by the amplifier circuit, the operation of one or more actuators based on the current.

[0011] Provided is a Hall Effect current sensor capable of measuring large currents. Embodiments of the present disclosure, for example, in comparison to concepts failing to include one or more of the features disclosed herein, provide a Hall Effect current sensor which is able to measure the magnetic field associated with large currents.

[0012] An embodiment of a Hall Effect sensor is shown in FIG. 1. The Hall Effect sensor 100 includes a toroid magnetic core 110 having a gap 120. The gap 120 includes opposed surfaces 121. The opposed surfaces 121 may be substantially planar and substantially parallel to one another. A central plane 125 bisects the opposed surfaces 121 of the toroid 110. In one embodiment, the central plane 125 bisects the toroid magnetic core 110. In some embodiments, the toroid magnetic core 110 may include at least one ferromagnetic material (e.g., ferrite, iron, metal alloys (e.g., $NiFe_{15}Mo$), amorphous soft magnetic materials (e.g., $Fe_{73}Cu_1Nb_3Si_{16}B_7$) and combinations thereof). In one embodiment, the toroid magnetic core 110 includes iron.

[0013] In the example of FIG. 1, a first Hall element sensor 131 defining a first sensor plane 132 is positioned at least partially within the gap 120 of the toroid 110 at a first angle 133 from central plane 125. For purposes herein, the term "within the gap" in the context of the toroid is meant to convey that components are contained within the three dimensional space extending between the opposed surfaces 121 of the toroid 110 and the outer peripheral surfaces that would otherwise extend between the surfaces. A second Hall element sensor 135 defining a second sensor plane 136 is positioned at least partially within the gap 120 of the toroid 110 at a second angle 137 from central plane 125. As shown, second angle 137 is coincident with central plane 125. In other words second angle 137 is zero. In some embodiments, the first Hall element sensor 131 and/or second Hall element sensor 135 may include at least one semiconductor Hall plate (e.g., gallium arsenide, indium arsenide, indium phosphide, indium antimonide, graphene, and combinations thereof).

[0014] In some embodiments, the Hall element sensors are electrically connected to at least one amplifier circuit 140 (e.g., operational amplifier (e.g., non-inverting amplifier, inverting amplifier, inverting summing amplifier, differential amplifier, Schmitt Trigger), software programmable gain amplifier (SPGA), microcontroller, microprocessor, and combinations thereof). In some embodiments, the at least one amplifier circuit 140 additionally includes a processing unit (e.g., CPU, GPU, memory, and combinations thereof). A conductive element 150 (e.g., bus bar) is arranged along a main axis 160 (e.g., a central axis) of the toroid magnetic core 110.

[0015] A current flowing through the conductive element 150 produces a principal magnetic field 170 which is concentrated in the gap 120 of the toroid magnetic core 110. The principal magnetic field 170 is substantially parallel to the central plane 125. The principal magnetic field 170 subsequently produces a voltage across at least one of the first Hall element sensor 131 and/or the second Hall element sensor 135. The voltage may be amplified by the at least one amplifier circuit 140 (e.g., non-inverting amplifier, inverting amplifier, inverting summing amplifier, differential amplifier, Schmitt Trigger, and combinations thereof).

[0016] In some embodiments, the first Hall element sensor 131 is oriented in the gap 120 at a first angle 133 relative to the central plane 125 and/or principal magnetic field 170 such that the principal magnetic field 170 results in a Hall voltage across the Hall element sensor 131. The sensitivity of the element sensor 131 may decrease as the angle of incidence of the principal magnetic field 170 deviates from 90 degrees. In some embodiments, the first angle may be an acute angle, such as, any angle greater than zero and less than 90 degrees. In some embodiments, the first angle may be less than about 85 degrees, less than about 80 degrees, less than about 75 degrees, less than about 60 degrees, less than about 50 degrees, about 45 degrees, at least about 5 degrees, at least about 10 degrees, at least about 15 degrees, at least about 30 degrees, at least about 40 degrees, and combinations thereof. In some embodiments, the first angle may be greater than 90 degrees and less than 180 degrees. In some embodiments, the first angle may be less than about 175 degrees, less than about 170 degrees, less than about 165 degrees, less than about 160 degrees, less than about 140 degrees, about 135 degrees, at least about 95 degrees, at least about 100 degrees, at least about 105 degrees, at least about 120 degrees, at least about 130 degrees, and combinations thereof.

[0017] In some embodiments, the second Hall element sensor 135 is oriented in the gap 120 at a second angle 137 relative to the central plane 125 and/or principal magnetic field 170 such that the principal magnetic field 170 results in a substantially zero Hall voltage across the second Hall element sensor 135. In some embodiments, the second Hall element sensor 135 is oriented substantially mutually perpendicular to each of the opposed surfaces 121. In some embodiments, the second angle 137 may be about 0 or about 180 degrees relative to the principal magnetic field 170. In some embodiments, a line of intersection 181 of the first sensor plane 132 and the second sensor plane 136 is substantially parallel with the opposed surfaces 121. In one embodiment, the line of intersection 181 is coincident with the central plane 125.

[0018] In some embodiments, the Hall voltage generated across the second Hall element sensor 135 may be substantially due to spurious magnetic fields. A spurious magnetic field is defined as any magnetic field incident on the first Hall element sensor 131 or the second Hall element sensor 135 that is generated by a source other than the current flowing through the conductive element 150. For example, spurious magnetic fields may be generated by sources such as nearby electrical components.

[0019] In some embodiments, the at least one amplifier circuit 140 may individually amplify the voltage signals generated by the first Hall element sensor 131 and/or the second Hall element sensor 135. In some embodiments, the at least one amplifier circuit 140 may additively combine the voltages generated by the first Hall element sensor 131 and the second Hall element sensor 135. In one embodiment, the at least one amplifier circuit 140 may combine the voltages generated by the first Hall element sensor 131 and the second Hall element sensor 135 in order to substantially eliminate voltages generated by spurious magnetic fields from the Hall voltage of the first Hall element sensor 131.

[0020] FIG. 2, which is an alternate embodiment of FIG. 1 and taken from region 2 of FIG. 1, utilizes a pair of first Hall element sensors 131a, 131b positioned within the gap of the toroid 110. First Hall element sensor 131a is oriented at a first angle 133a relative to the central plane 125 (FIG. 1) and/or principal magnetic field 170 such that the principal magnetic field 170 results in a Hall voltage across the Hall element sensor 131a. Additionally, first Hall element sensor 131b is oriented at an angle 134 relative to Hall element sensor 131a, such as about 15 degrees, about 30 degrees, about 45 degrees, about 60 degrees, about 90 degrees, about 120 degrees, or about 150 degrees. Other magnitudes of angle 134 may be used so long as first Hall element sensor 131b is oriented at a first angle 133b relative to the central plane 125, in which angle 133b is the same as angle 133a. Furthermore, the intersections of the second sensor plane 136 of second Hall element sensor 135, and the planes 132a, 132b of respective first Hall element sensors 131a, 131b are coincident with the line of intersection 181, which is substantially parallel with the opposed surfaces 121. In one embodiment, the line of intersection 181 is coincident with the central plane 125.

[0021] FIG. 3 is a flowchart of a method 200 of regulating the operation of an electrical system using a Hall Effect sensor 100. At block 210, the amplifier circuitry 140, receives one or more first measurements (e.g., voltage) from a first Hall element sensor 131. At block 220, the amplifier circuitry 140, receives one or more second measurements (e.g., voltage) from a second Hall element sensor 135. At block 230, the amplifier circuitry 140, determines a current corresponding to a current in the at least one conductive element 150. At block 240, the amplifier circuitry 140 regulates the operation of one or more actuators (e.g., electromechanical switch) based on the current.

Claims

What is claimed is:

1. A Hall Effect sensor (100), comprising:

a) a toroid including a gap (120), the gap (120) including opposed surfaces (121), the opposed surfaces (121) being substantially planar and substantially parallel to one another the toroid having a central plane (125) bisecting the opposed surfaces (121);

b) a first Hall element sensor (131) defining a first sensor plane (132) is positioned at least partially within the gap (120) of the toroid at a first angle (133); and

c) a second Hall element sensor (135) positioned at least partially within the gap (120) of the toroid at a second angle (137) substantially mutually perpendicular to each of the opposed surfaces; and

wherein the central plane is substantially perpendicular to the opposed surfaces.

2. The sensor (100) of claim 1, wherein the second Hall element sensor (135) defines a second sensor plane (136) and the second sensor plane (136) is substantially parallel with the central plane (125) of the toroid.

3. The sensor (100) of claim 2, wherein a line of intersection (181) of the first sensor plane (132) and the second sensor plane (136) is substantially parallel with the opposed surfaces.

4. The sensor (100) of claim 3, wherein the line of intersection (181) of the first sensor plane (132) and the second sensor plane (136) is substantially coincident with the central plane (125) of the toroid.

5. The sensor (100) of claim 1, wherein the first angle (133) is an acute angle.

6. The sensor (100) of claim 5, wherein the first angle (133) is between 5 degrees and 85 degrees.

7. The sensor (100) of claim 6 wherein the first angle (133) is between 5 degrees and 45 degrees.

8. The sensor (100) of claim 1, further comprising at least one amplifier circuit (140).

9. A method of regulating the operation of an electrical system, the electrical system

including at least one gapped ferromagnetic toroid, at least one conductive element (150) positioned along a central axis of the toroid, at least two Hall element sensors (131a), (131b) positioned within the gap (120), and an amplifier circuit coupled to the at least two Hall element sensors, the method comprising:

receiving, by the amplifier circuit (140), one or more first measurements, from a first Hall element sensor (131);

receiving, by the amplifier circuit (140), one or more second measurements, from a second Hall element sensor (135);

determining, by the amplifier circuit (140), a current corresponding to a current in the at least one conductive element;

regulating, by the amplifier circuit (140), the operation of one or more actuators based on the current.

10. The method of claim 9, wherein the first measurement includes a voltage measurement corresponding at least in part to a current in the at least one conductive element (150).

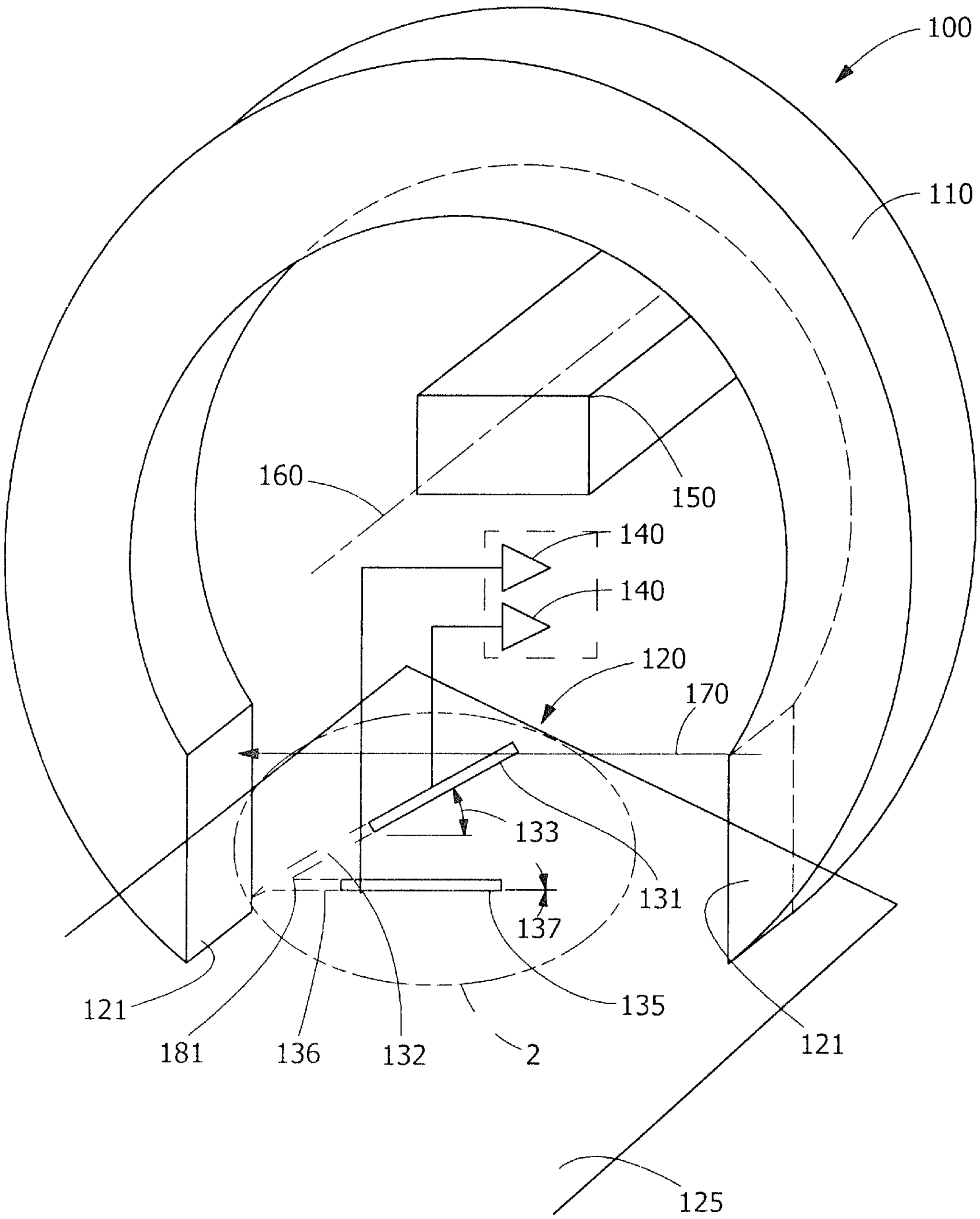
100
110
160
150
140
140
120
170
133
131
137
121
181
136
132
2
135
121
125

FIG. 1

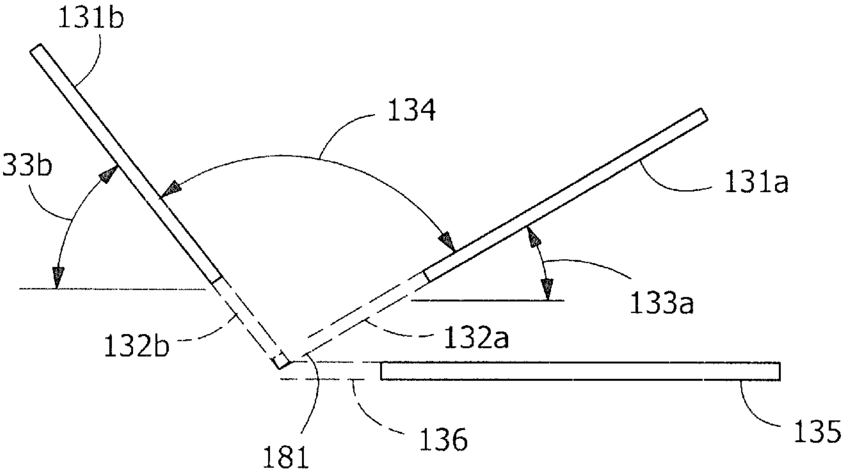

FIG. 2

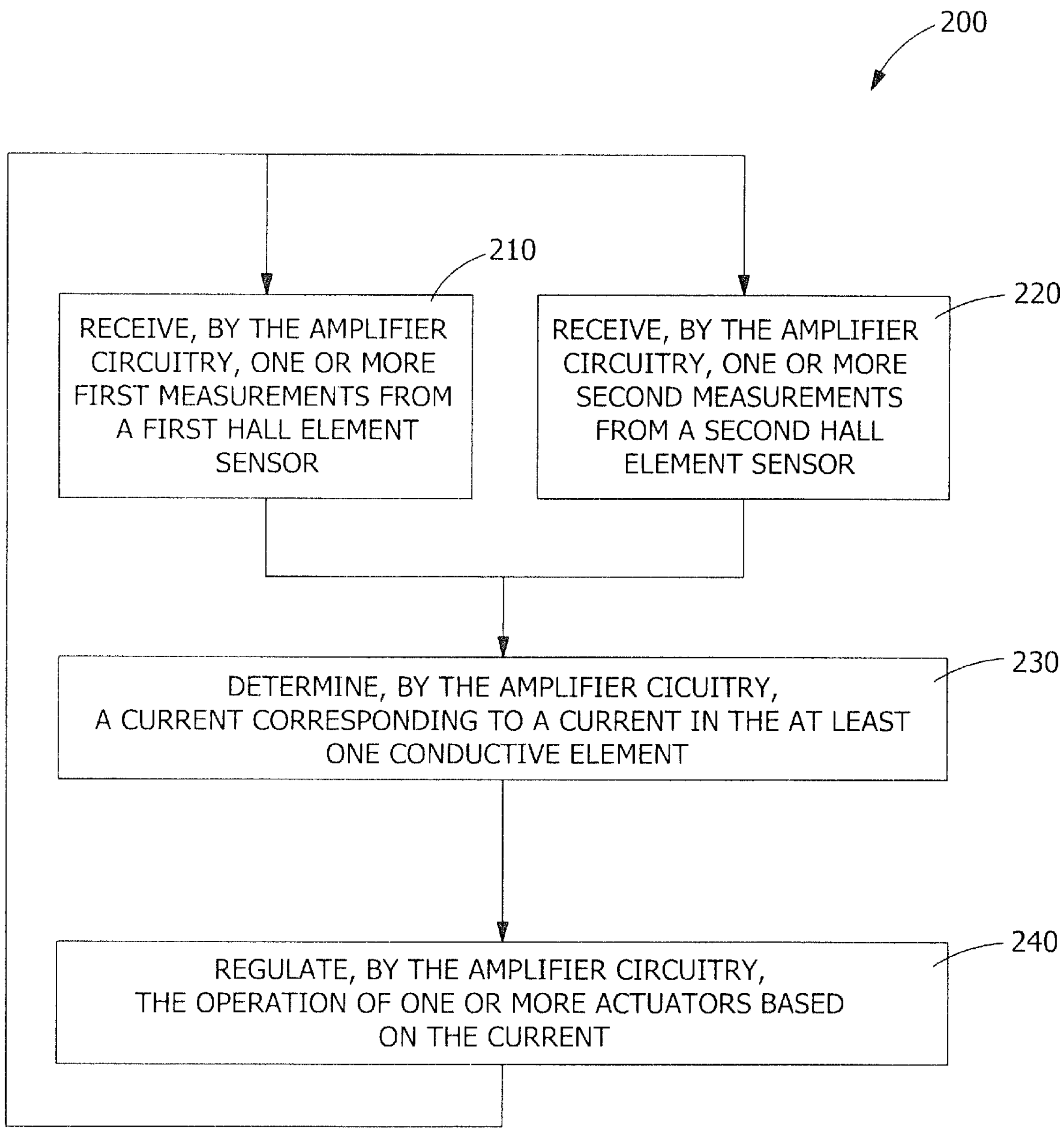
200
210
RECEIVE, BY THE AMPLIFIER CIRCUITRY, ONE OR MORE FIRST MEASUREMENTS FROM A FIRST HALL ELEMENT SENSOR
220
RECEIVE, BY THE AMPLIFIER CIRCUITRY, ONE OR MORE SECOND MEASUREMENTS FROM A SECOND HALL ELEMENT SENSOR
230
DETERMINE, BY THE AMPLIFIER CICUITRY, A CURRENT CORRESPONDING TO A CURRENT IN THE AT LEAST ONE CONDUCTIVE ELEMENT
240
REGULATE, BY THE AMPLIFIER CIRCUITRY, THE OPERATION OF ONE OR MORE ACTUATORS BASED ON THE CURRENT

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/056602

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R15/20 G01R19/00
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)
G01R

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	JP 2011 017574 A (TAMURA SEISAKUSHO KK) 27 January 2011 (2011-01-27) paragraphs [0001], [0052] - [0058]; figure 5	1-10
A	JP H07 20218 A (FUJITSU LTD) 24 January 1995 (1995-01-24) paragraphs [0037], [0049]; figures 1,2	1-10
A	US 2016/266172 A1 (OSTRICK BERNHARD [DE] ET AL) 15 September 2016 (2016-09-15) paragraphs [0004], [0010], [0011]; figures 2,3	1-10
A	US 2008/048642 A1 (ARATANI MASAHIRO [JP] ET AL) 28 February 2008 (2008-02-28) paragraph [0041]; figures 1-3	1-10

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 November 2018	29/11/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	O'Callaghan, D

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 455 515 A (UZUKA MITSUO [JP]) 19 June 1984 (1984-06-19) claim 3; figure 3	1-10
A	WO 2017/052676 A1 (FARADAY & FUTURE INC [US]) 30 March 2017 (2017-03-30) paragraphs [0014] - [0016], [0037] - [0039]; figures 4,5	1-10

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2018/056602

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
JP 2011017574	A	27-01-2011	NONE		
JP H0720218	A	24-01-1995	NONE		
US 2016266172	A1	15-09-2016	DE 102013112628	A1	21-05-2015
			EP 3069150	A1	21-09-2016
			JP 6317443	B2	25-04-2018
			JP 2016537629	A	01-12-2016
			US 2016266172	A1	15-09-2016
			WO 2015071102	A1	21-05-2015
US 2008048642	A1	28-02-2008	JP 2008051704	A	06-03-2008
			US 2008048642	A1	28-02-2008
US 4455515	A	19-06-1984	AT 378086	B	10-06-1985
			AU 557354	B2	18-12-1986
			BR 8203407	A	31-05-1983
			CA 1180751	A	08-01-1985
			CH 662912	A5	30-10-1987
			DE 3221993	A1	30-12-1982
			ES 8304724	A1	01-03-1983
			FR 2507840	A1	17-12-1982
			GB 2101428	A	12-01-1983
			IT 1159065	B	25-02-1987
			JP S57206295	A	17-12-1982
			NL 8202337	A	03-01-1983
			US 4455515	A	19-06-1984
WO 2017052676	A1	30-03-2017	CN 108027393	A	11-05-2018
			US 2017082660	A1	23-03-2017
			US 2017082661	A1	23-03-2017
			WO 2017052676	A1	30-03-2017