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- (71) Applicant: THE SECRETARY OF STATE FOR DEFENCE [GB/GB]; DSTL, Porton Down, Salisbury, Wiltshire SP4 0JQ (GB).
- (72) Inventor: JACOB, Suresh George; DSTL IP Group, G01-B Building 005, DSTL Porton Down, Salisbury, Wiltshire SP4 0JQ (GB).
- (74) Agent: FARNSWORTH, Alastair Graham; DIPR Formalities Section, Poplar 2#2214, MOD Abbey Wood (South), Bristol, BS34 8JH (GB).

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(54) Title: A MAGNETIC FIELD SENSING PROBE

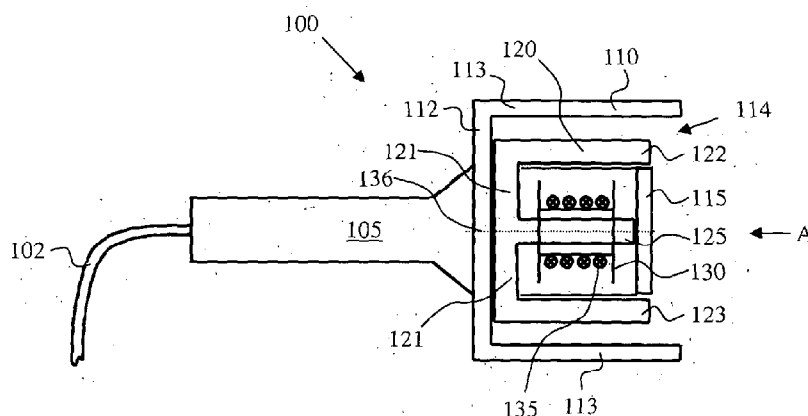


Fig. 1

(57) Abstract: There is provided a magnetic field sensing probe (100) comprising a ferromagnetic material (120), a sense coil (135), and electromagnetic shielding (110, 115). The ferromagnetic material comprises a base portion (121), a coil portion (125) extending from the base portion, and at least one flux portion (122, 123) extending from the base portion. The sense coil (135) comprises sense coil windings that encircle the coil portion (125) about an axis (136). The electromagnetic shielding comprises an electrically conductive can (110) within which the ferromagnetic material (120) and sense coil (135) are housed, the electrically conductive can having sides (113), a base (112) at a first end, and an opening (114) at a second end opposite the first end. The sense coil is rotationally orientated with the axis (136) of the sense coil windings directed through the second end. There is also provided a magnetic field sensing apparatus (500) comprising the magnetic field sensing probe (100) and a signal processing circuit (510).

A MAGNETIC FIELD SENSING PROBE

Technical Field of the Invention

This invention relates to a magnetic field sensing probe, in particular to a magnetic field sensing probe to assist in determining the cause of the magnetic field.

Background to the Invention

Electrical devices typically emit and are sensitive to electromagnetic fields, and so various electromagnetic compatibility (EMC) rules exist specifying the levels of electromagnetic interference that devices may emit, and that devices must be capable of operating within.

EMC tests on the emission levels of a device often comprise tests on the magnetic fields that are present outside of the device, to check that they fall within specified limits. If an excessive magnetic field outside of the device is detected, then the device needs to be re-designed to reduce the level of external magnetic field.

However, it can be difficult to determine the root causes of the excessive magnetic field outside the device so that appropriate action can be taken to reduce it.

There is therefore a need for a magnetic field sensing probe that can help an operator identify the cause of an excessive magnetic field from outside of the device.

Summary of the Invention

According to an embodiment of the invention, there is provided a magnetic field sensing probe comprising a ferromagnetic material, a sense coil, and electromagnetic shielding. The ferromagnetic material comprises a base portion, a coil portion extending from the base portion, and at least one flux portion extending from the base portion. The sense coil comprises sense coil windings that encircle the coil portion about an axis. The electromagnetic shielding comprises an electrically conductive can within which the ferromagnetic material and sense coil are housed. The electrically conductive can has sides, a

base at a first end, and an opening at a second end opposite the first end, and the sense coil is rotationally orientated with the axis of the sense coil windings directed through the second end. The axis of the sense coil windings may also be directed through the first end.

This configuration provides a directional probe that is sensitive to magnetic fields primarily in the direction in which the opening of the electrically conductive can is pointed, so that the areas of a device from which a magnetic field is emanating can be accurately determined by moving the probe around and pointing it in various different directions.

Accordingly, an operator may determine the areas of the device that are emitting the magnetic field, and therefore investigate the device component(s) in that area with a view to modifying them so that they do not emit excessive magnetic fields.

The electromagnetic shielding helps prevent any stray electric fields from influencing the sense coil, and to improve the directionality of the probe. Preferably, the sense coil is entirely within the volume of the electrically conductive can to improve the shielding of the sense coil.

The electrically conductive can may for example be a metal can, or may have a metallic or other electrically conductive coating. The sides of the electrically conductive can typically form a pipe, with the base at one end of the pipe (first end) and the opening at the other end of the pipe (second end). Preferably, the electrically conductive can has a high magnetic permeability to help improve the directionality of the magnetic field sensing probe, for example a relative magnetic permeability of equal or greater than 10,000, or more preferably a relative magnetic permeability of equal or greater than 50,000.

The flux portion(s) of the ferromagnetic material attract lines of magnetic flux into the ferromagnetic material by virtue of the ferromagnetic material's higher permeability relative to the surrounding air, and the lines of flux pass into the coil portion of the ferromagnetic material to induce a current in the sense coil. Ferromagnetic materials in the context of this document are considered to include ferrimagnetic materials, such as for example ferrite.

The base portion may extend adjacent the extension of the at least one flux portion such that the sense coil windings are present between the coil portion and the at least one flux portion. Then, the flux portions help magnetically shield the sense coil from magnetic fields orientated perpendicular to the flux portions and sense coil axis, improving the directionality of the probe.

The directions of extension of the coil portion and at the least one flux portion may be within 45 degrees of one another, for example substantially parallel to one another. The coil portion may extend from the base portion in a direction towards the second end of the electrically conductive can, for example so that the base portion is adjacent the first end (base) of the electrically conductive can. This provides improved performance over orientating the ferromagnetic material with the base portion adjacent the opening and the coil portion extending towards the base.

The base portion of the ferromagnetic material preferably contacts the base of the electrically conductive can, or is connected to the base of the electrically conductive can via further ferromagnetic material, to help form a magnetic circuit through the ferromagnetic material and electrically conductive can. Then flux lines that exit the flux portions of ferromagnetic material in directions that are angled away from the sense coil axis will loop more easily back to the electrically conductive can, improving the directionality of the magnetic field sensing probe towards the sense coil axis.

Advantageously, the magnetic field sensing probe may further comprises an electrically conductive cap portion, the electrically conductive cap portion being at the axial end of the sense coil that is closest to the second end, and covering over an interior region of the sense coil. The covering over of the region inside of the sense coil with the electrically conductive cap portion provides electrostatic shielding that can help prevent stray electric fields from entering this region via the opening and interfering with the detection of the magnetic field. Preferably, the cap portion also covers over the depth of the sense coil windings at the axial end of the sense coil, as well as over the interior region inside the sense coil windings, so that the sense coil windings are also electrostatically shielded.

The electrically conductive cap portion and the electrically conductive can are preferably held at the same electric potential to prevent electric fields from existing between them. The electrically conductive cap portion may be electrically connected to the base of the electrically conductive can by a connecting portion, and the connecting portion may be located through a slot in the at least one flux portion of ferromagnetic material, or between two of the at least one flux portion of ferromagnetic material. The placement of the connecting portion through the slot or between two of the flux portions of ferromagnetic material helps the connecting portion shield the portions of the sense coil adjacent the slot or adjacent the boundary between the two of the flux portions of ferromagnetic material from electric fields. Alternatively, the electrically conductive cap portion may be formed as part of the second end of the electrically conductive can.

Preferably, the flux portions of the ferromagnetic material are not covered by the electrically conductive cap portion or the electromagnetic shielding, so that lines of magnetic flux can flow into the ferromagnetic material via the opening in the electrically conductive can.

Advantageously, the at least one flux portion of ferromagnetic material may comprise two flux portions of ferromagnetic material, the two flux portions being diametrically opposed to one another with respect to the coil portion. The use of two diametrically opposed flux portions helps increase the directivity of the probe, as the spatial width of sensitivity of the probe in a direction perpendicular to the direction between the two flux portions is reduced.

The use of the phrase “diametrically opposed” with respect to the coil portion does not place any restriction on the cross-section of the coil portion or the flux portions, but simply indicates that the flux portions oppose one another along an axis that passes through the coil portion. The cross section of the coil portion may be circular, but could alternatively be other shapes, for example triangular or rectangular.

The statement that the sense coil windings encircle the coil portion does not require that the windings form a cylindrical or circular shape; the windings may for example encircle the coil portion in a triangular or rectangular shape, for example if the coil portion has a triangular or rectangular cross section and the windings are wound directly onto the coil portion.

The magnetic field sensing probe may comprise more than one of the above-described ferromagnetic material and corresponding sense coil. For example, a plurality of the ferromagnetic materials may comprise at least five of the ferromagnetic materials, and a plurality of the sense coils may comprise at least five of the sense coils. The ferromagnetic materials and the corresponding sense coils may all be housed together within the same electrically conductive can. The use of a multiple ferromagnetic materials and corresponding sense coils can help heighten the sensitivity of the probe in a particular direction (depending on the configuration of the ferromagnetic materials and sense coils). Preferably, the axes of the sense coils windings are all parallel to one another.

Advantageously, two flux portions of a first one of the plurality of ferromagnetic materials may be opposed to one another along a first axis, and the two flux portions of a second one of the plurality of ferromagnetic materials may be opposed to one another along a second axis, the first axis and the second axis being in different directions to one another, for example perpendicular to one another. Each ferromagnetic material is most sensitive to magnetic field polarisations that are in the direction of the axis of opposition between the two flux portions, and so using different directions for different ferromagnetic materials can help improve sensitivity to different magnetic field polarisations. Using two ferromagnetic material having directions that are perpendicular to one another can help to provide good sensitivity to a wide variety of polarisations that are transverse to the axis of the sense coils.

According to another embodiment of the invention, there is provided a magnetic field sensing apparatus comprising the magnetic field sensing probe as hereinbefore described, and a signal processing circuit connected to the or each sense coil. The signal processing circuit is configured to output a signal representative of the magnitude of current induced in the or each sense coil by a magnetic field. The magnetic field sensing apparatus may comprise a speaker and/or visual display may be provided to indicate the strength of the magnetic field. For example, the output signal may be used to drive a speaker to provide an audible indication of the strength of the magnetic field, and/or the output signal may be used to drive a display to provide a visual indication of the strength of the magnetic field.

Brief Description of the Drawings

Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Fig. 1 shows a schematic cross-sectional diagram of a magnetic field sensing probe according to a first embodiment of the invention;

Fig. 2 shows a schematic plan diagram of the magnetic field sensing probe of Fig. 1, taken from direction A marked on Fig. 1;

Fig. 3 shows a schematic plan diagram of a magnetic field sensing probe having a plurality of ferromagnetic materials arranged in a grid array configuration according to a second embodiment of the invention; and

Fig. 4 shows a schematic plan diagram of a magnetic field sensing probe having a plurality of ferromagnetic materials arranged in a circular array configuration according to a third embodiment of the invention.

Fig. 5 shows a schematic diagram of a magnetic field sensing apparatus including the magnetic field sensing probe of Fig. 1 and a signal processing circuit.

Detailed Description

A first embodiment of the invention will now be described with reference to Fig. 1 and Fig. 2, which show schematic cross-sectional and plan diagrams respectively of a magnetic field sensing probe 100. The schematic plan diagram of Fig. 2 is taken looking in a direction A marked on Fig. 1, and the schematic cross-sectional diagram of Fig. 1 is taken along the line B-B marked on Fig. 2.

Referring to Fig. 1, the magnetic field sensing probe 100 has an output cable 102, a handle 105, and an electrically conductive can 110. The electrically conductive can 110 has a base 112, sides 113, and an open end 114 opposite the base 112. The base 112 of the electrically conductive can 110 is connected to the handle 105.

Inside the can 110, there is a ferromagnetic material in the form of a ferrite 120. The ferrite 120 has a base portion 121 contacting the base 112 of the can 100, and the ferrite also has a

coil portion 125 and two flux portions 122 and 123 that all extend perpendicular from the base portion 121, and substantially parallel to one another towards the open end 114. The coil portion 125 is central to the two flux portions 122 and 123 to provide a fair degree of magnetic shielding by the flux portions. The ferromagnetic material is symmetrical about the extension of the coil portion 125 to balance the magnetic flux from each of the flux portions.

A sense coil 135 is wound around a bobbin 130, and the bobbin is held on the coil portion 125 so that the sense coil windings encircle the coil portion about an axis 136 of the sense coil windings. The sense coil windings therefore run in between the coil portion 125 and the flux portions 122 and 123. The coil portion 125 of the ferromagnetic material is rotationally orientated so that the axis 136 is directed through the open end 114 of the can 110.

An electrically conductive cap portion 115 provides electrostatic shielding. The electrically conductive cap portion 115 is placed at the axial end of the sense coil 135 closest the open end 114 of the electrically conductive can, and covers the interior region of the sense coil (the space inside the windings where the winding surface of the bobbin and the coil portion 125 are present). The electrically conductive cap portion 115 also extends beyond the depth of the sense coil windings and ends before the flux portions 122 and 123, the depth of the sense coil windings being the depth to which the bobbin is wound.

The cable 102 is a coaxial cable that passes into the handle 105. An outer sheaf of the coaxial cable 102 is connected to the base 112 of the metal can 110, and a signal conductor of the coaxial cable is connected to the sense coil 135.

Referring to Fig. 2 that shows a plan diagram looking from direction A of Fig. 1, the flux portions 122 and 123 are substantially semi-circular and surround the coil portion 125. The flux portions 122 and 123 are diametrically opposed about the coil portion 125 along the line B-B, and have gaps between them so that the electrically conductive cap portion 115 can be electrically connected to the base 112 of the can via connecting portions 116. The connecting portions 116 therefore extend alongside the extension of the flux portions 122 and 123 down to the base 112 of the can, and are joined to the base 112 of the can at joints 117, for example by soldering.

The bobbin 130 and sense coil 135 are shown in dotted lines beneath the electrically conductive cap portion 115, and the sense coil terminates with wires 136 and 137 that pass over the flux portions and down to the handle 105. One of the wires 136 and 137 is connected to the base 112, and the other of the wires 136 and 137 is connected to the signal conductor of the co-axial cable 102. Other possible routes for the wires 136 and 137 will be apparent to those skilled in the art.

In this embodiment, the second end of the electrically conductive can is constituted by the open end 114, which is fully open, although in alternate embodiments that second end may not be fully open, for example the second end may comprise one or more openings in electromagnetic shielding for exposing the at least one flux portion to an external magnetic field. The second end may only be open at position(s) corresponding to the position(s) of the at least one flux portion(s). The electrically conductive cap portion 115 may be formed as part of the second end.

In this particular embodiment the electrically conductive can 110 is a metal can of high magnetic permeability, for example a metal can made from a nickel alloy material such as Mumetal^(TM). The high magnetic permeability helps shield the ferromagnetic material from magnetic fields that are not orientated in the direction that the probe is pointed in.

A second embodiment of the invention will now be described with reference to Fig. 3, which shows a schematic plan diagram of another magnetic field sensing probe 300. The second embodiment is similar to the first embodiment, except for that nine 321 – 329 of the ferromagnetic materials 120 and nine corresponding sense coils 135 are all incorporated together in a single electrically conductive can 310. The nine ferromagnetic materials 321 – 329 and corresponding sense coils are arranged in an array of three rows and three columns, and they act together to increase the sensitivity and directionality of the magnetic field sensing probe. The signal magnitudes from each one of the sense coils may for example be added together to give a combined output signal representative of the level of magnetic field.

The ferromagnetic materials 323 and 327 have flux portions that diametrically oppose one another in a direction D1, the ferromagnetic materials 324 and 326 have flux portions that diametrically oppose one another in a direction D2, the ferromagnetic materials 321 and 329

have flux portions that diametrically oppose one another in a direction D3, and the ferromagnetic materials 322, 325, and 328 have flux portions that diametrically oppose one another in a direction D2. The directions D1 and D3 are perpendicular to one another, and the directions D2 and D4 are perpendicular to one another.

Since each ferromagnetic material has the broadest angle of sensitivity in the direction that the flux portions oppose one another, and has the greatest sensitivity to magnetic field polarisations that are orientated in line with the direction that the flux portions oppose one another, the set of orientations shown in Fig. 3 provide good directivity, and sensitivity to different magnetic field polarisations.

The schematic plan diagram of Fig. 4 shows a magnetic field sensing probe 400 according to a third embodiment of the invention, which is similar to the second embodiment, except for that the ferromagnetic materials are now arranged in a circular configuration instead of a grid configuration.

Fig. 5 shows a schematic diagram of a magnetic field sensing apparatus 500 including the magnetic field sensing probe 100 of Fig. 1 and a signal processing circuit 510. The signal processing circuit receives the signal from the sense coils 135 via the cable 102, and measures the magnitude of the induced current to determine the magnetic field strength. The strength of the magnetic field is displayed on an LCD display 530, and a speaker 520 is driven to give an audible signal that gets louder the stronger the magnetic field strength. Accordingly, an operator may use the apparatus 500 to determine whereabouts the magnetic fields around a device are the strongest,

Various alternate embodiments of the invention falling within the scope of the appended claims will be apparent to the skilled person. The features recited in the various dependent claims are not essential to various different embodiments of the invention that will be apparent to those skilled in the art. For example, although the specific embodiments have focussed on ferromagnetic materials having two flux portions, other embodiments having only one flux portion or three or more flux portions are also possible.

The coil portion may be at the centre of the ferromagnetic material, and/or central to the at least one flux portions, and/or along a centre axis of the electrically conductive can, however may not be one of more of those things depending on the particular embodiment. For example, in one embodiment a U shaped ferromagnetic material may be used with one arm of the U supporting the sense coil, the other arm of the U acting as the at least one flux portion, and the base of the U acting as the base portion.

CLAIMS

1. A magnetic field sensing probe comprising a ferromagnetic material, a sense coil, and electromagnetic shielding, wherein:
 - the ferromagnetic material comprises a base portion, a coil portion extending from the base portion, and at least one flux portion extending from the base portion;
 - the sense coil comprises sense coil windings that encircle the coil portion about an axis; and
 - the electromagnetic shielding comprises an electrically conductive can within which the ferromagnetic material and sense coil are housed, the electrically conductive can having sides, a base at a first end, and an opening at a second end opposite the first end, the sense coil being rotationally orientated with the axis of the sense coil windings directed through the second end.
2. The magnetic field sensing probe of claim 1, wherein the base portion extends adjacent the extension of the at least one flux portion such that the sense coil windings are present between the coil portion and the at least one flux portion.
3. The magnetic field sensing probe of claim 1 or 2, wherein the coil portion and at the least one flux portion are within 45 degrees of one another.
4. The magnetic field sensing probe of claim 1, 2 or 3, wherein the coil portion extends from the base portion in a direction towards the second end of the electrically conductive can.
5. The magnetic field sensing probe of claim 4, further comprising an electrically conductive cap portion, the electrically conductive cap portion being at an axial end of the sense coil windings that is closest to the second end, and covering over an interior region of the sense coil.
6. The magnetic field sensing probe of claim 5, wherein the electrically conductive cap portion is electrically connected to the base of the electrically conductive can by a connecting portion.

7. The magnetic field sensing probe of claim 6, wherein the connecting portion is located through a slot in a flux portion of the at least one flux portion, or located between two flux portions of the at least one flux portion.
8. The magnetic field sensing probe of claim 5, wherein the electrically conductive cap portion is comprised in the second end of the electrically conductive can.
9. The magnetic field sensing probe of claim 5, 6, 7, or 8, wherein the at least one flux portion is not covered by the electrically conductive cap portion.
10. The magnetic field sensing probe of any preceding claim, wherein the at least one flux portion is unshielded to external magnetic fields entering through the opening in the second end of the electrically conductive can.
11. The magnetic field sensing probe of any preceding claim, wherein the at least one flux portion of ferromagnetic material comprises two flux portions of ferromagnetic material, the two flux portions being diametrically opposed to one another with respect to the coil portion.
12. The magnetic field sensing probe of any preceding claim, wherein the ferromagnetic material is one of a plurality of the ferromagnetic materials, and wherein the sense coil is one of a plurality of the sense coils, each one of the sense coils associated with a respective one of the ferromagnetic materials, the plurality of the ferromagnetic materials and the plurality of sense coils all being housed within the electrically conductive can.
13. The magnetic field sensing probe of claim 12 when appended to claim 11, wherein the two flux portions of a first one of the plurality of ferromagnetic materials are opposed to one another along a first axis, wherein the two flux portions of a second one of the plurality of ferromagnetic materials are opposed to one another along a second axis, and wherein the first axis and the second axis are in different directions to one another, for example perpendicular to one another.
14. The magnetic field sensing probe of claim 12 or 13, wherein the axes of the plurality of sense coil windings are all parallel to one another.

15. A magnetic field sensing apparatus comprising the magnetic field sensing probe of any preceding claim and a signal processing circuit connected to the or each sense coil and configured to output a signal representative of the magnitude of current induced in the or each sense coil by a magnetic field.

16. A magnetic field sensing probe substantially as described herein with reference to the accompanying drawings.

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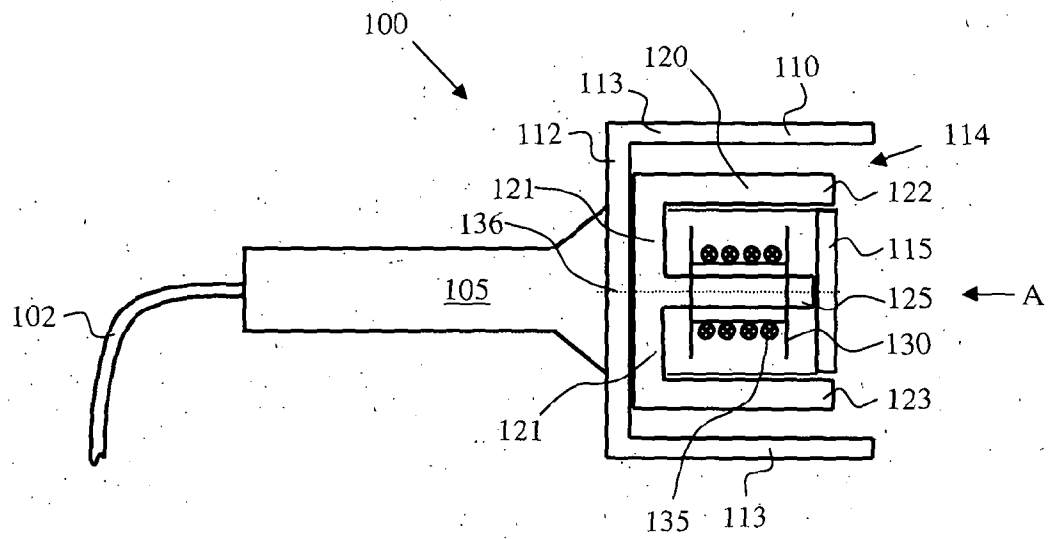


Fig. 1

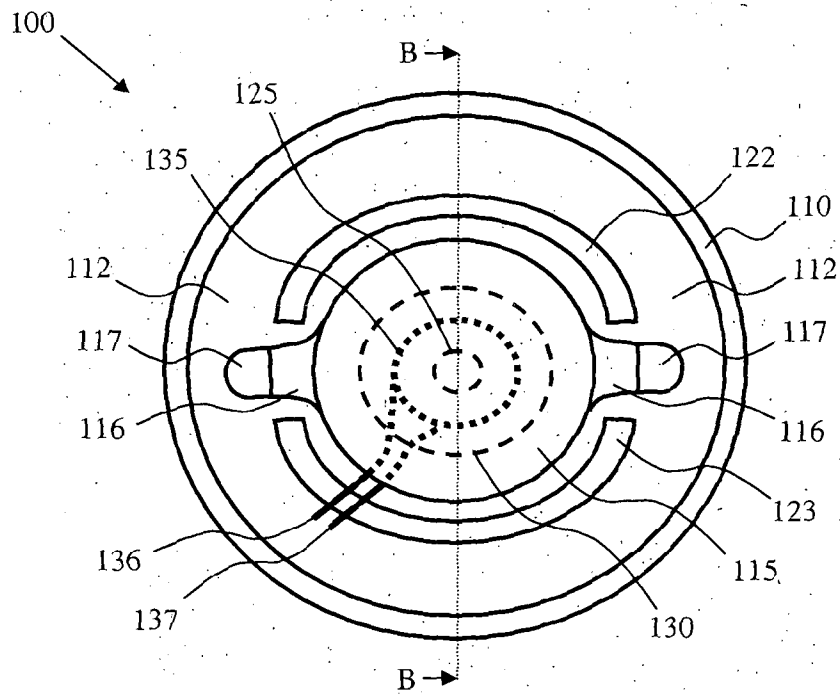


Fig. 2

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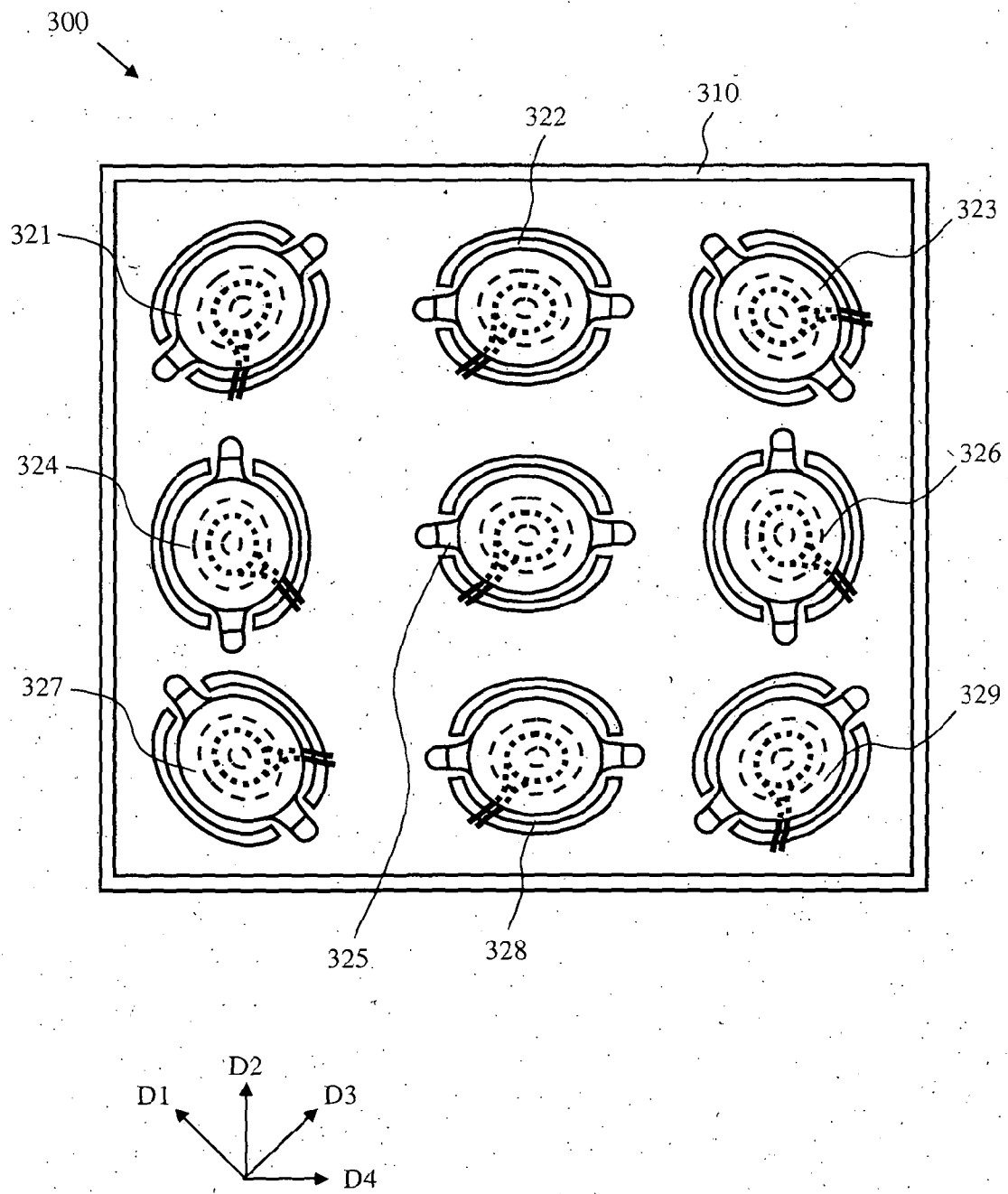


Fig. 3

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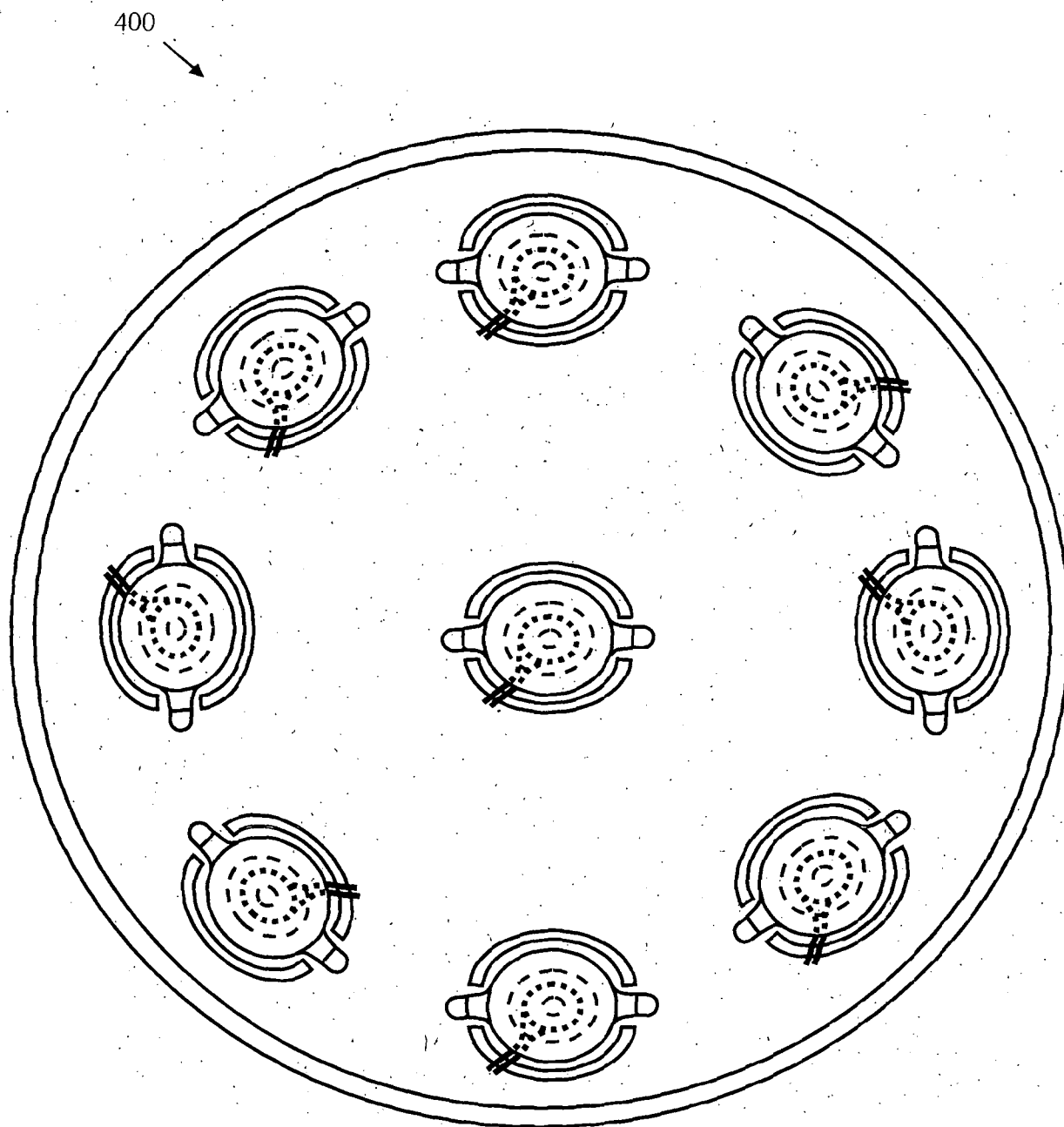


Fig. 4

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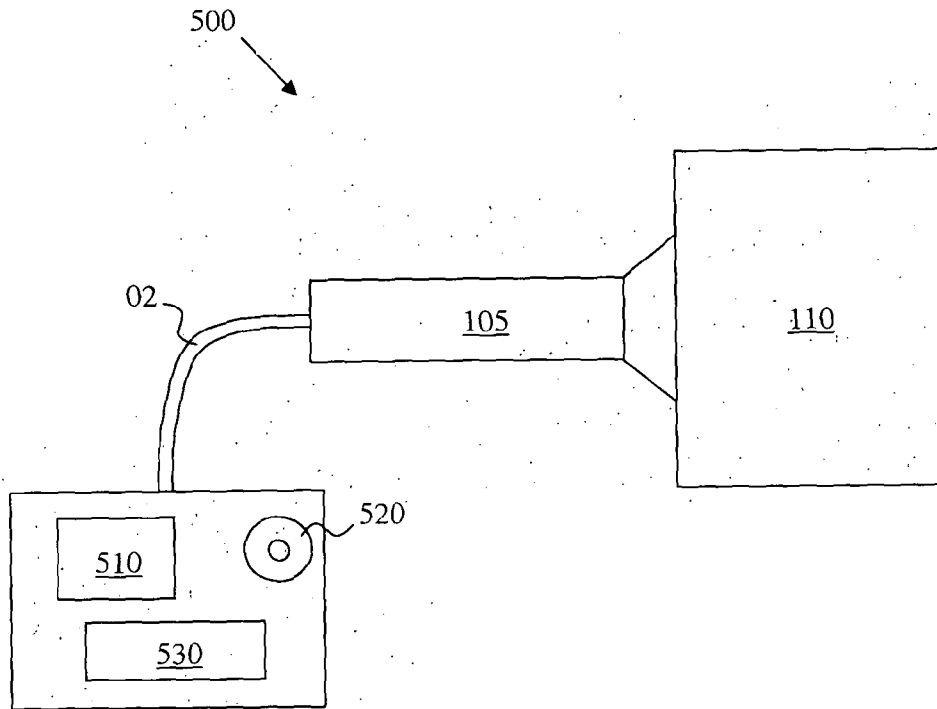


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/000172

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/028 G01R33/12
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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 724 390 A (RAUSCHER ELIZABETH A [US] ET AL) 9 February 1988 (1988-02-09)	1-6, 10-12, 14-16
A	abstract; figure 2 column 11, line 33 - line 59 -----	7-9,13
X	GB 2 260 413 A (BIRJANDI MOHAMMAD JAVAD [GB]) 14 April 1993 (1993-04-14)	1-6, 10-12, 14-16
A	the whole document -----	7-9,13
X	CN 101 750 589 A (QIXIN NI) 23 June 2010 (2010-06-23)	1-6, 10-12, 14-16
A	the whole document -----	7-9,13



Further documents are listed in the continuation of Box C.



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

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"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

9 July 2013

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Böhm-Pélissier, A

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2013/000172

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4724390	A	09-02-1988	NONE	

GB 2260413	A	14-04-1993	NONE	

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