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(54) **Title:** A POWERED JOINT WITH WIRELESS TRANSFER

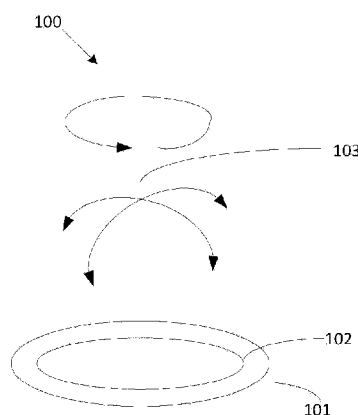


Figure 1A

(57) **Abstract:** A powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including one or more power transmission coils associated with the first component; a plurality of power receiving coils associated with the second component; a sensor which determines the orientation of the second component with respect to the first component; and a control circuit for selectively connecting one of the plurality of power receiving coils to a power receiving circuit based on information received from the sensor.



A POWERED JOINT WITH WIRELESS TRANSFER

FIELD

5 The present invention relates to a powered joint having an inductive power transfer (IPT) system. More particularly, although not exclusively, the invention relates to coil and core topologies for use in the transmitters and receivers of such systems.

BACKGROUND

10 IPT systems are a well-known area of established technology (for example, wireless charging of electric toothbrushes) and developing technology (for example, wireless charging of handheld devices on a 'charging mat'). Typically, a primary side generates a time-varying magnetic field from a transmitting coil or coils. This magnetic field induces an alternating current in a suitable receiving coil that can then be used to charge a battery, or power a device or other load. In
15 some instances, it is possible for the transmitter or the receiver coils to be connected with capacitors to create a resonant circuit, which can increase power throughput and efficiency at the corresponding resonant frequency.

A basic problem that must be overcome in any IPT system design is ensuring efficient power transfer. One approach to improve performance has been to
20 require precise alignment of the transmitter and receiver coils, such as in the case of wireless charging of electric toothbrushes that use a dedicated charging mount. However, powered joints often require a large range of relative movement between joint components and so such tightly coupled solutions are unsuitable.

25 Powered joints may be employed in applications such as robotics where power transfer is required between the parts of complex articulated joints, including

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ball joints and universal joints. The use of a wired connection may constrain the range of motion, suffer from failure due to material fatigue, or result in vulnerable and unsightly exterior wiring. Typical IPT systems may not be useful, due to their inability to efficiently supply power over a wide range of movement.

5 US20030214255 discloses that providing a plurality of orthogonal transmitter coils improves the likelihood of a receiver coil intersecting the flux lines of the magnetic field. However, no detail is given as to a suitable receiver coil for this arrangement or how it may be implemented in a powered joint.

10 US20010000960 discloses an array of in-phase spiral current loops disposed adjacent to one another, defining a non-planar surface such as a sphere. However, again no detail is given on a suitable receiver coil arrangement or how it may be implemented in a powered joint.

15 WO2013/141717 discloses a range of transmitter and receiver coil topologies utilizing orthogonal sets of coils but there is no disclosure as to how these may be implemented within a joint.

It is an object of the invention to provide a powered joint providing effective power transfer over a wide range of movement, or to at least provide the public with a useful choice.

SUMMARY

20 According to one example embodiment there is provided a powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:

25 one or more power transmission coils associated with the first component;

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a plurality of power receiving coils associated with the second component;

a sensor which determines the orientation of the second component with respect to the first component; and

5 a control circuit for selectively connecting one of the plurality of power receiving coils to a power receiving circuit based on information received from the sensor.

According to another example embodiment there is provided a powered joint having a first joint component and second joint component in which the first
10 joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:

a plurality of power transmission coils associated with the first component;

one or more power receiving coils associated with the second
15 component;

a sensor which determines the orientation of the second component with respect to the first component; and

a control circuit for selectively connecting one of the plurality of power transmitting coils to a coil drive circuit based on information
20 received from the sensor.

According to a further example embodiment there is provided a powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:

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one or more power transmission coil associated with the first component; and

one or more power receiving coil associated with the second component,

5 wherein the receiving coil is spaced away from the transmitting coil and remains generally aligned with a radial line from the center of the transmitting coil throughout the range of movement of the joint.

According to another example embodiment there is provided a core formed of a magnetically permeable material comprising an outer partial hemisphere having
10 a central post projecting from the hemisphere towards the center of the hemisphere.

According to a still further example embodiment there is provided a powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to
15 the second joint component, the powered joint including:

one or more power transmission coils associated with the first component; and

one or more power receiving coil associated with the second component;

20 wherein each coil has an associated magnet so that proximate transmitter and receiver coil pairs are maintained in alignment due to magnetic attraction between the magnets.

According to a yet further example embodiment there is provided a powered joint having a first joint component and second joint component in which the

5

first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:

a plurality of power transmission coils associated with the first component; and

5 a plurality of power receiving coils associated with the second component;

wherein the transmission and receiving coils are spaced apart and are rotatably movable relative to each other.

10 According to another example embodiment there is provided a powered joint having a first joint component and second joint component in which the first joint component has one or more degrees of rotational freedom with respect to the second joint component, the powered joint including:

a power transmission coil associated with the first component; and

a power receiving coil associated with the second component

15 wherein the power receiving coil is moveable with respect to the second component so that it can be maintained in a desired alignment with the power transmission coil.

20 According to a still further example embodiment there is provided an arrangement for powering a device having free spatial movement in two or more dimensions including a powered support connected to two or more relatively moveable elements by a powered joint having a first joint component and a second joint component, the first joint component having multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:

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a plurality of power transmission coils associated with the first component; and

a plurality of power receiving coils associated with the second component;

5 wherein the transmission and receiving coils are spaced apart and are rotatably movable relative to each other.

According to a yet further example embodiment there is provided a powered ball and socket joint having a ball having multiple degrees of rotational freedom with respect to socket, the powered joint including:

10 a helically wound power transmission coil provided in the ball; and

a helically wound power receiving coil provided in the socket.

It is acknowledged that the terms “comprise”, “comprises” and “comprising” may, under varying jurisdictions, be attributed with either an exclusive or an inclusive meaning. For the purpose of this specification, and unless otherwise
15 noted, these terms are intended to have an inclusive meaning – i.e., they will be taken to mean an inclusion of the listed components which the use directly references, and possibly also of other non-specified components or elements.

Reference to any document in this specification does not constitute an admission that it is prior art, validly combinable with other documents or that it forms part
20 of the common general knowledge.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings which are incorporated in and constitute part of the specification, illustrate embodiments of the invention and, together with the general description of the invention given above, and the detailed description of

embodiments given below, serve to explain the principles of the invention, in which:

- Figures 1A** shows a single transmitter coil and a single receiver coil rotatable with multiple degrees of rotational freedom;
- 5 **Figures 1B** shows the arrangement of Figure 1A when one coil is rotated with respect to the other;
- Figures 2A** shows a coil arrangement consisting of 3 orthogonal receiver coils having multiple degrees of rotational freedom with respect to a spaced apart transmitter coil;
- 10 **Figures 2B** shows a coil arrangement consisting of 3 orthogonal receiver coils having multiple degrees of rotational freedom with respect to a surrounding transmitter coil;
- Figures 2C** shows a coil arrangement consisting of 3 orthogonal receiver coils having multiple degrees of rotational freedom with respect to 3
15 orthogonal transmitter coils;
- Figures 3A** shows a coil arrangement in which several spiral coils are located on the surface of a sphere which moves relative to a single coil;
- Figures 3B** shows a coil arrangement in which several spiral coils are located on the surface of a first sphere which moves relative to a second
20 sphere having spiral coils on its surface;
- Figures 4A** shows a coil arrangement in which one or more receiver coils are arranged radially around a transmitting coil;
- Figures 4B** shows the coil arrangement of the type shown in Figure 4A wherein the transmitting coil has a central transmitter core;

Figures 4C shows the coil arrangement of the type shown in Figure 4A wherein the transmitting coil has a central transmitter core and the receiving coil includes an arcuate core;

5 **Figures 5A-5B** show a pot core type arrangement allowing rotation with multiple degrees of rotational freedom;

Figures 6A-6F show coil arrangements in which magnets are used to align the transmitter and receiver coils;

Figures 7A-7C show powered joints in which helical transmitting and receiving coils are located near the surface of a ball and socket; and

10 **Figure 8** is a diagram of an IPT system in which power is transmitted to a platform using tethers.

DETAILED DESCRIPTION

Figure 1A illustrates a coil arrangement 100 including a transmitter coil 101 that receives power from a source (not shown) to generate an alternating magnetic field. A receiving coil 102 is rotatable relative to transmitting coil 101 about its axis 103 and may be tilted as shown in Figure 1B. Optimum power transfer occurs when the coils have the highest coupling coefficient in the position shown in Figure 1A. However, coupling decreases as the receiving coil 102 is tilted with respect to the transmitting coil 101, as shown in Figure 1B. If the coils 101 and 102 are oriented such that the coupling coefficient is low, then the supplied power will be significantly reduced. While capable of transferring power, this arrangement is not particularly suitable for efficiently supplying constant power to moving components requiring a relatively large degree of rotational freedom.

25 The receiver coil arrangement 202 of Figure 2A has three orthogonal coils. This arrangement allows three degrees of rotational freedom with one receiving coil

having good coupling in any position. The arrangement shown in Figure 2B is suitable for use in a ball and socket joint with the transmitter coil housed in the socket and the receiving coil assembly 202 housed within the ball. The arrangement could also be employed in a universal joint. This arrangement ensures that at least one of the receiving coils is sufficiently coupled with the transmitter coil to effectively transfer power in all relative positions. However, to select the best coupled receiving coil may require measurement of the coupling between coils, which may take too long for real world applications. To enable rapid coil switching a sensor 203 may be provided to determine the orientation of the receiver coil arrangement 202 with respect to the transmitter coil 101. The orientation sensor may be any one of a gyroscope, accelerometer, magnetic field sensor, IMU, compass, gravity switch, or any other appropriate means of determining orientation. Based on the positional information from sensor 203 a controller 204 may selectively connect one of the receiver coils to a power flow controller supplying power to a load on the receiver side of the joint. The controller 204 may store in memory which coil to select based orientation information from the sensor. To improve transfer efficiency additional transmitter and/or receiver coils may also be provided at other angles.

A coil arrangement 205 including a three orthogonal transmitter coils 206 and 3 orthogonal receiver coils 207 is shown in Figure 2C. As in the previous topology, a suitable orientation sensor 208 may be used to selectively connect one transmitter coil with the best coupled receiver coil.

Another way to achieve improved coupling in a device having multiple degrees of rotational freedom is to position a series of spiral transmitter or receiver coils 305 on the surface of a spherical transmitter which is rotatable relative to a transmitter or receiver coil 303 as shown in Figure 3A. This type of arrangement may be suitable for a ball and socket joint. A transmitter and receiver pair may be selected or multiple transmitter coils may be driven with opposite polarity to

enhance power transfer to a single receiver coil. Figure 3B shows an arrangement where both the transmitter 301 and receiver 302 have an arrangement of helical coils 305 and 304 on their spherical surfaces to enable both rotation and orbiting about each other.

5 Figure 4A shows an arrangement that may be particularly suitable for a ball and socket joint where one or more receiver coils 402 are provided in the socket part of a joint and a central transmitter coil 401 is provided in the ball part of the joint. The one or more receiver coils 402 may be arranged in a ring around a central transmitter coil 401 or vice versa. This topology utilizes the fact that
10 transmitter coil 401 produces a generally toroidal magnetic flux (one flux line is indicated at 403) and each receiver coil moves generally along these flux lines. In the case of rotation about the axis of the joint the flux is substantially uniform. When the ball is tilted relative to the socket each receiver coil generally follows the flux lines and so remains well coupled to the transmitter coil. This topology
15 thus provides good coupling over a wide range of relative joint movements without requiring coil switching.

To further improve coupling a core having high magnetic permeability, such as a ferrite core 403 shown in Figure 4B, may be used to shape the magnetic field. The ferrite core 403 extends above and below the coil, and if used in a ball joint,
20 may extend to the periphery of the ball, as shown in Figure 4C. Additionally, a ferrite core 404 may extend through coil 402 and around the socket of the ball joint, as shown in Figure 4C, such as to maintain only a small air gap between transmitter and receiver ferrites 403 and 404 throughout the range of movement of the joint. The other receiver coils may also have similar ferrites which connect
25 at the top. The placement of the ferrites may be arranged to preferentially power different coils at different joint positions.

Another arrangement utilizing ferrites to improve the magnetic coupling is shown in 5A and 5B. In this embodiment a pot core type ferrite structure 500 is used including an upper ferrite consisting of a hemispherical part 501 and a central post 502 and a lower ferrite consisting of a hemispherical part 503 and a central post 504. A transmitter coil 506 is wound about post 504 and a receiver coil 505 is wound about post 502. In this arrangement the two ferrite sections are free to rotate and tilt with respect to each other, as shown in the tilted view in Figure 5B. This arrangement ensures that there is always only a small air gap between posts 502 and 504 and hemispheres 501 and 503 at all times ensuring a high magnetic permeability path in all orientations and thus efficient power transfer in all orientations without the need for any coil switching.

An alternative means of maintaining alignment of transmitter and receiver coils may be provided by magnets of opposite polarity associated with transmitting and receiving coils as shown in Figure 6A. In this embodiment coil 601 is wound about permanent magnet 603 and coil 602 is wound about permanent magnet 604. The opposing faces of the permanent magnets have opposite magnetic polarity so that they attract to each other to align the coils. The permanent magnets also provide a high magnetic permeability path for the magnetic flux to improve power transfer. Whilst centralized coil alignment is shown any suitable alignment that assists with power transfer may be employed.

This general method of coil alignment is shown in a ball and socket joint in Figures 6B and 6C. In this embodiment coil 602 is mounted in fixed relation to socket 611 near to ball 612. Coil 601 is provided within a cavity in ball 612 and is free to move relative to ball 612. The cavity may be empty or filled with a fluid or some other medium. Alternatively coil 601 may be supported by resilient elements which return coil 601 to a centralized position when no external magnetic force is present but allow movement within the cavity. Flexible conductive wires 613 convey power to or from coil 601 whilst allowing relatively

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free movement of coil 601 within the cavity. Due to magnetic attraction between magnets 603 and 604 coils 601 and 602 are held close and in alignment when ball 612 moves with respect to socket 611, as illustrated in Figure 6C where coil 601 has moved within the cavity relative to its original position shown in Figure 6B.

Figures 6D and 6E show an alternate embodiment in which the moveable coil is located in the socket. In this case the arrangement is generally the same as for that shown in Figures 6B and 6C except that coil 601 is located in a cavity within the socket 611 instead of being within a cavity in the ball. Figure 6F shows a variant of the design shown in Figure 6D and 6E including resilient elements 614 that act to centralize coil 601 but which stretch to allow coil 601 to follow coil 602 due to the magnetic attraction between magnets.

Figures 7A to 7C show a further coil arrangement for a ball and socket joint utilizing helical coils 701 and 702 wound close to the surface of each of the ball 712 and socket 711. A cutaway view of the socket with the ball inserted is shown in Figures 7A and 7B (i.e. a similar helically hound winding is provided in the socket but only the cross-sections of the windings are visible). A top view of a helical coil 701 is shown in Figure 7C. Due to the distribution of the helical windings over the ball and socket effective power transfer may be achieved over a relatively large range of movement as shown in Figure 7B.

Figure 8 shows a system to provide power wirelessly through tethers 815 to a hanging device or platform 816, allowing the device or platform 816 to rotate with respect to the tethers 815. A pair of IPT ball connectors 801 and 802, such as those shown in Figure 2C, are held in place by a joint (not shown) that maintains a fixed separation while allowing the ball connectors 801 and 802 to rotate with multiple degrees of rotational freedom. One example of a suitable application for this arrangement is a delta robot, commonly used in 3D printers,

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where a heated nozzle is positioned typically using three tethers moving up and down on belts attached to fixed support poles. The heated nozzle requires power to heat it, and the use of such an inductive power transfer system 800 may reduce wear on electronic components.

5 The described coil arrangements provide good inductive coupling in mechanical joints. While embodiments have been described with reference to a particular joint configuration, they could also be applied to other systems having multiple degrees of rotational freedom that would benefit from the simplicity of wireless power transfer. These applications include, but are not limited to robotics,
10 prosthetics, industrial automation, household and industrial appliances and toys.

While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in detail, it is not the intention of the Applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and
15 modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departure from the spirit or scope of the Applicant's general inventive concept.

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CLAIMS:

1. A powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the
5 powered joint including:
 - i. one or more power transmission coils associated with the first component;
 - ii. a plurality of power receiving coils associated with the second component;
 - 10 iii. a sensor which determines the orientation of the second component with respect to the first component; and
 - iv. a control circuit for selectively connecting one of the plurality of power receiving coils to a power receiving circuit based on information received from the sensor.
- 15 2. A powered joint as claimed in claim 1 wherein the sensor is a gyroscope.
3. A powered joint as claimed in claim 1 wherein the sensor is an accelerometer.
4. A powered joint as claimed in claim 1 wherein the sensor is a magnetic field sensor.
- 20 5. A powered joint as claimed in claim 1 wherein the sensor is an IMU.
6. A powered joint as claimed in claim 1 wherein the sensor is a compass.
7. A powered joint as claimed in claim 1 wherein the sensor is a gravity switch.

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8. A powered joint as claimed in any one of the preceding claims including a single transmission coil.
9. A powered joint as claimed in any one of the preceding claims including 2 orthogonal power receiving coils.
- 5 10. A powered joint as claimed in any one of the preceding claims including 3 orthogonal power receiving coils.
11. A powered joint as claimed in any one of the preceding claims wherein the joint is a ball and socket joint.
- 10 12. A powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:
 - i. a plurality of power transmission coils associated with the first component;
 - 15 ii. one or more power receiving coils associated with the second component;
 - iii. a sensor which determines the orientation of the second component with respect to the first component; and
 - 20 iv. a control circuit for selectively connecting one of the plurality of power transmitting coils to a coil drive circuit based on information received from the sensor.
13. A powered joint as claimed in claim 12 wherein the sensor is a gyroscope.
14. A powered joint as claimed in claim 12 wherein the sensor is an accelerometer.

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15. A powered joint as claimed in claim 12 wherein the sensor is a magnetic field sensor.
16. A powered joint as claimed in claim 12 wherein the sensor is an IMU.
17. A powered joint as claimed in claim 12 wherein the sensor is a compass.
- 5 18. A powered joint as claimed in claim 12 wherein the sensor is a gravity switch.
19. A powered joint as claimed in any one of claims 12 to 18 including a single power receiving coil.
- 10 20. A powered joint as claimed in any one of the preceding claims including two orthogonal power transmitting coils.
21. A powered joint as claimed in any one of claims 12 to 20 including 3 orthogonal power transmitting coils.
22. A powered joint as claimed in any one of claims 12 to 21 wherein the joint is a ball and socket joint.
- 15 23. A powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:
 - 20 i. one or more power transmission coil associated with the first component; and
 - ii. one or more power receiving coil associated with the second component,

wherein the receiving coil is spaced away from the transmitting coil and remains generally aligned with a radial line from the center of the transmitting coil throughout the range of movement of the joint.

- 5 24. A powered joint as claimed in claim 23 including a single power transmitting coil and a single power receiving coil.
25. A powered joint as claimed in claim 23 including a single power transmitting coil and a plurality of power receiving coils.
26. A powered joint as claimed in claim 25 wherein the power receiving coils are aligned in a common plane.
- 10 27. A powered joint as claimed in claim 26 wherein the power receiving coils are arranged around the power transmitting coil.
28. A powered joint as claimed in any one of claims 23 to 27 wherein the joint is a ball and socket joint.
- 15 29. A powered joint as claimed in claim 28 wherein a first core formed of a magnetically permeable material is provided within the power transmitting coil and is located within the ball of the ball and socket joint.
30. A powered joint as claimed in claim 29 wherein the first core extends above and/or below the power transmitting coil so as to enhance coupling with each power receiving coil.
- 20 31. A powered joint as claimed in claim 30 wherein the first core extends to or near to the distal end of the ball.
32. A powered joint as claimed in any one of claims 28 to 31 wherein a second core formed of a magnetically permeable material is provided within each receiving coil.

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33. A powered joint as claimed in claim 32 wherein the second core extends to or near the first core,
34. A core formed of a magnetically permeable material comprising an outer partial hemisphere having a central post projecting from the hemisphere towards the center of the hemisphere.
35. A powered joint comprising first and second cores as claimed in claim 34 wherein one core is smaller than the other and is mounted so that the hemispheres are relatively rotatable in an overlapping manner with a transmission coil wound around one post and a receiving coil wound around the other.
36. A powered joint having a first joint component and second joint component in which the first joint component has multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:
- i. one or more power transmission coils associated with the first component; and
 - ii. one or more power receiving coil associated with the second component;
- wherein each coil has an associated magnet so that proximate transmitter and receiver coil pairs are maintained in alignment due to magnetic attraction between the magnets.
37. A powered joint as claimed in claim 36 wherein each magnet associated with a transmitter coil has a pole facing the magnet associated with a receiver coil that is of opposite magnetic polarity.

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38. An arrangement for powering a device having free spatial movement in two or more dimensions including a powered support connected to two or more relatively moveable elements by a powered joint having a first joint component and a second joint component, the first joint component having multiple degrees of rotational freedom with respect to the second joint component, the powered joint including:

- i. a plurality of power transmission coils associated with the first component; and
- ii. a plurality of power receiving coils associated with the second component;

wherein the transmission and receiving coils are spaced apart and are rotatably movable relative to each other.

39. An arrangement as claimed in claim 38 wherein the powered joint includes at least two orthogonally arranged power transmission coils and at least two orthogonally arranged power receiving coils.

40. An arrangement as claimed in claim 38 wherein the powered joint includes three orthogonally arranged power transmission coils and three orthogonally arranged power receiving coils.

41. An arrangement as claimed in claim 38 wherein the powered joint has transmission coils arranged on a curved surface.

42. An arrangement as claimed in claim 38 or 41 wherein the powered joint has receiving coils arranged on a curved surface.

43. An arrangement as claimed in any one of claims 38 to 42 wherein the powered joint includes permanent magnets located within each coil having

polarities that maintain respective transmission and receiving coil pairs in alignment.

5 44. An arrangement as claimed in any one of claims 38 to 43 wherein the powered joint includes a pair of transmission coils driven with opposite polarity.

45. An arrangement as claimed in any one of claims 38 to 44 wherein the powered joint includes an orientation sensor to power appropriate transmission coils based on the relative orientation of the transmission and receiving coils.

10 46. An arrangement as claimed in claim 38 including three relatively movable elements.

15 47. A powered joint having a first joint component and second joint component in which the first joint component has one or more degrees of rotational freedom with respect to the second joint component, the powered joint including:

- i. a power transmission coil associated with the first component; and
- ii. a power receiving coil associated with the second component

20 wherein the power receiving coil is moveable with respect to the second component so that it can be maintained in a desired alignment with the power transmission coil.

48. A powered joint as claimed in claim 47 wherein magnets associated with each transmission and receiving coil maintain them in alignment.

49. A powered joint as claimed in claim 48 wherein a permanent magnet is provided within each coil.

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50. A powered joint as claimed in any one of claims 47 to 49 wherein the receiving coil is suspended in fluid.
51. A powered joint as claimed in any one of claims 47 to 50 wherein the receiving coil is suspended by elastic elements.
- 5 52. A powered joint as claimed in claim 47 wherein the receiving coil is moved relative to the second component by actuators.
53. A powered joint having a first joint component and second joint component in which the first joint component has one or more degrees of rotational freedom with respect to the second joint component, the
10 powered joint including:
- i. a power transmission coil associated with the first component; and
 - ii. a power receiving coil associated with the second component
 - iii. wherein the power transmitting coil is moveable with respect to the first component so that it can be maintained in a desired alignment
15 with the power receiving coil.
54. A powered ball and socket joint having a ball having multiple degrees of rotational freedom with respect to socket, the powered joint including:
- i. a helically wound power transmission coil provided in the ball; and
 - ii. a helically wound power receiving coil provided in the socket.

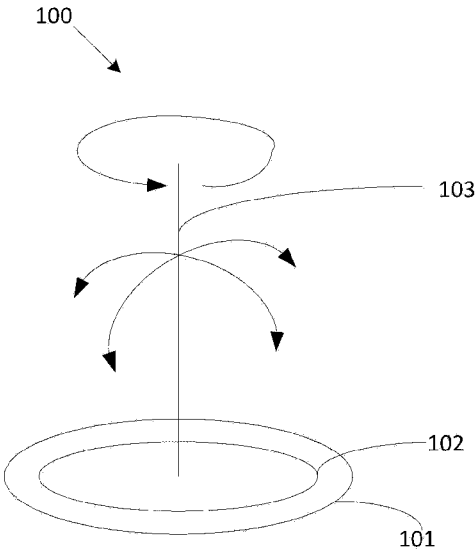


Figure 1A

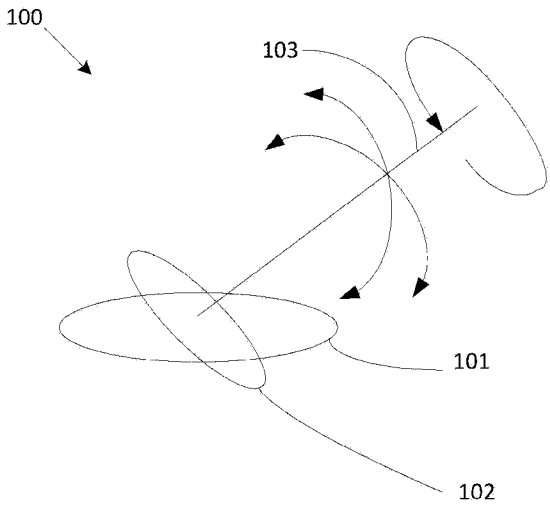


Figure 1B

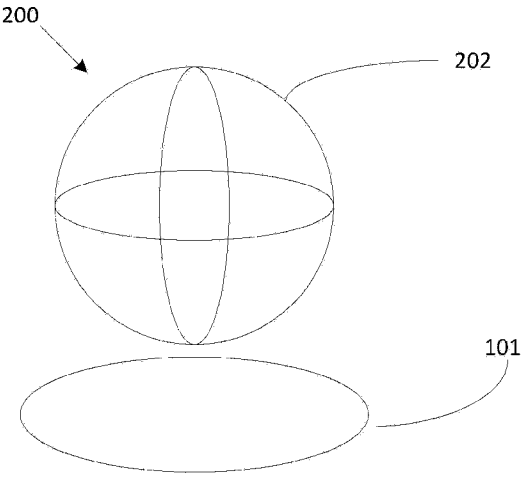


Figure 2A

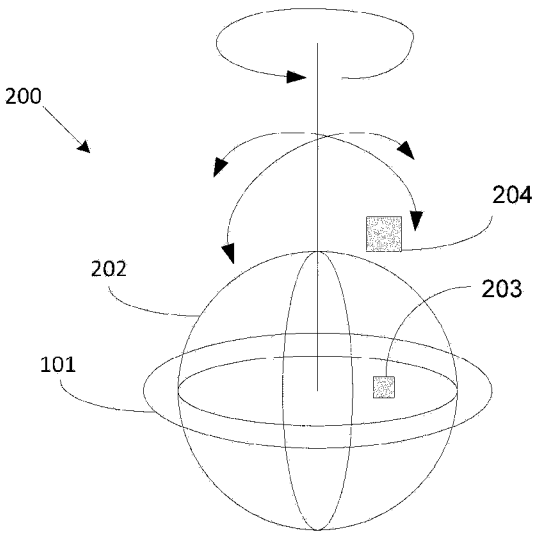


Figure 2B

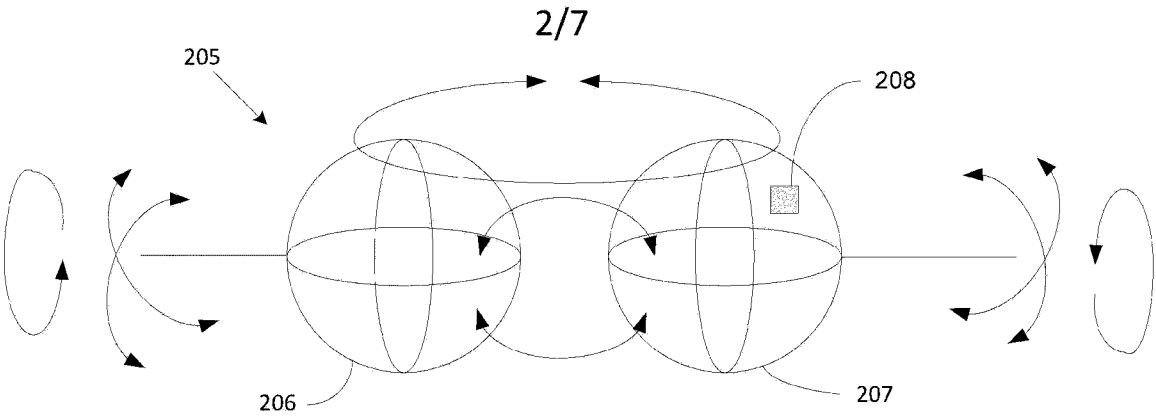


Figure 2C

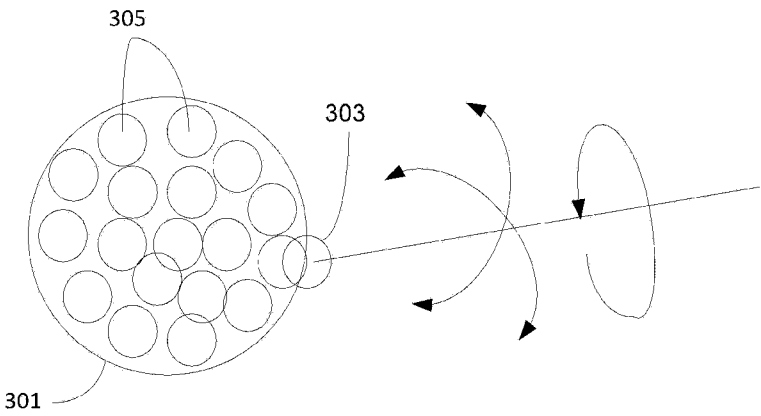


Figure 3A

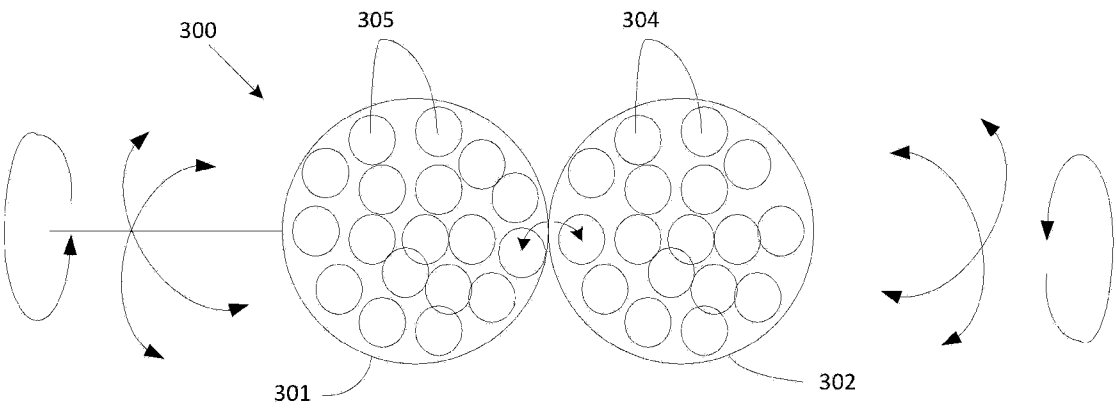


Figure 3B

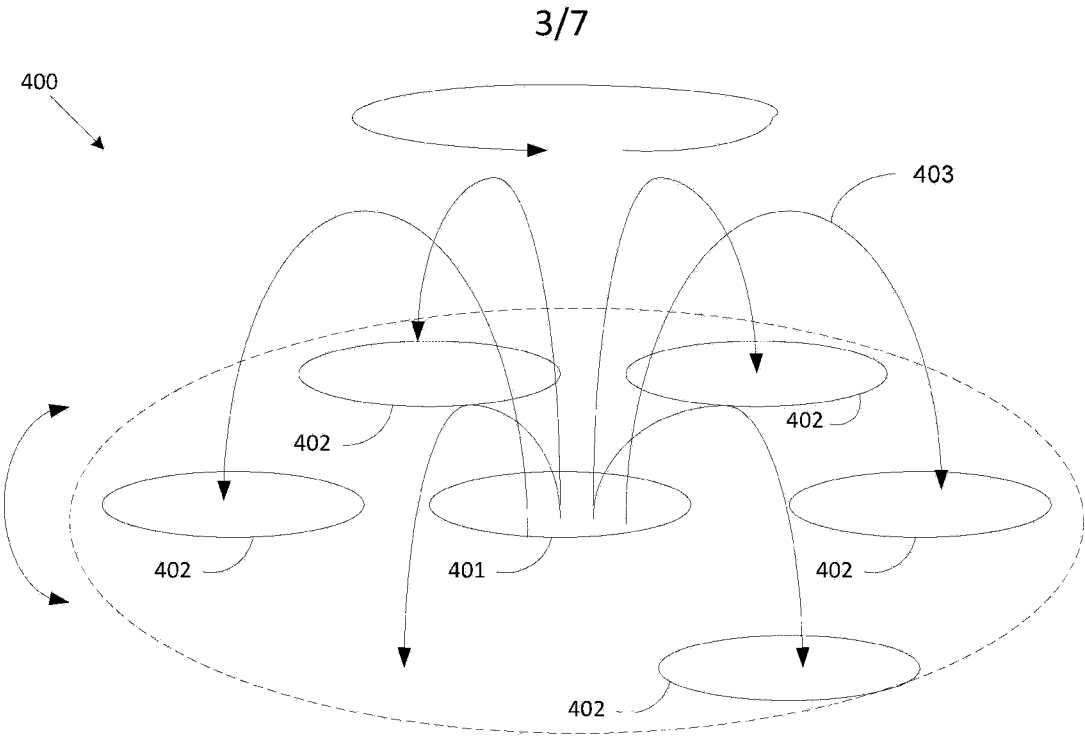


Figure 4A

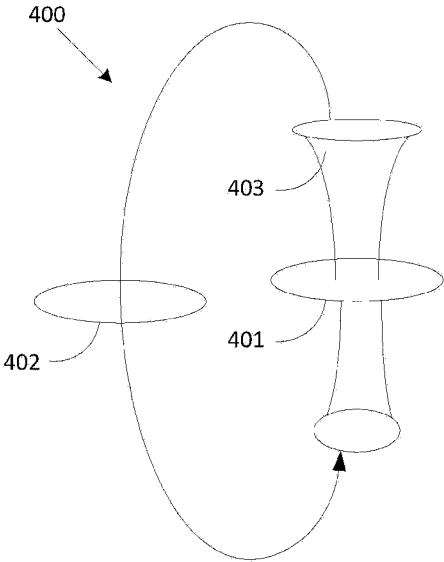


Figure 4B

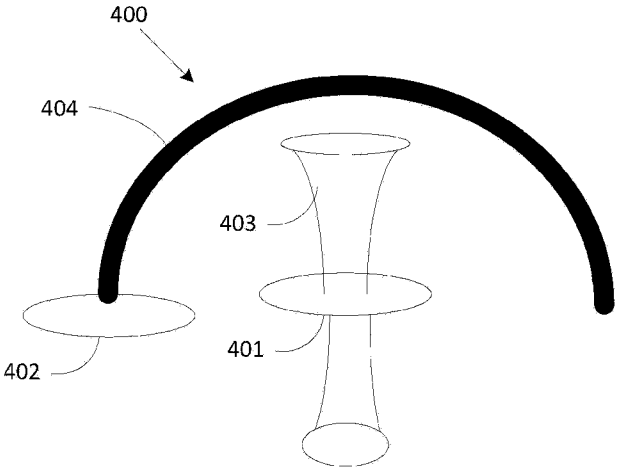


Figure 4C

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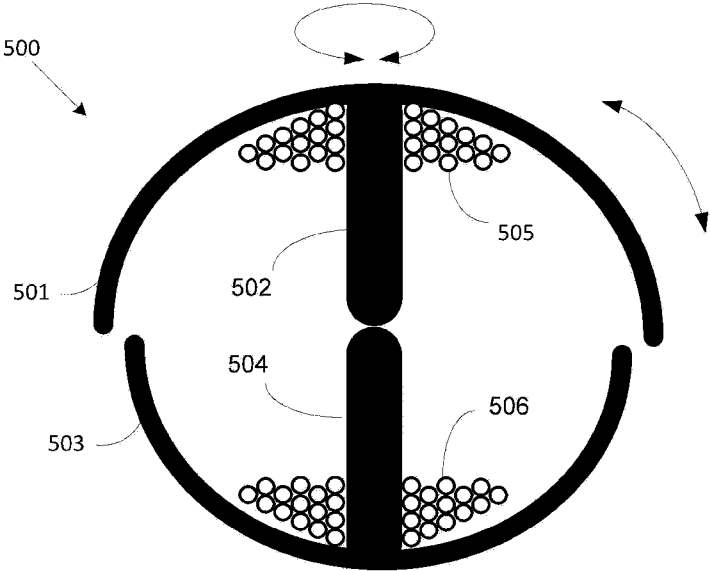


Figure 5A

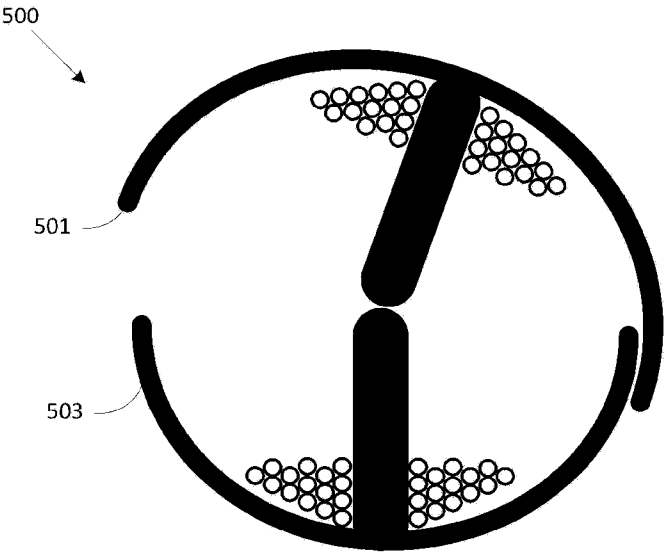


Figure 5B

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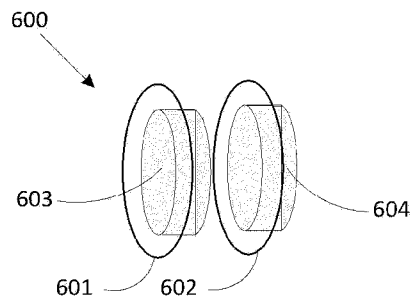


Figure 6A

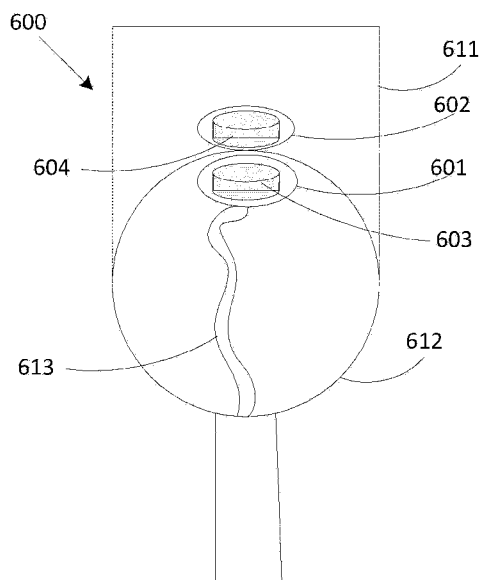


Figure 6B

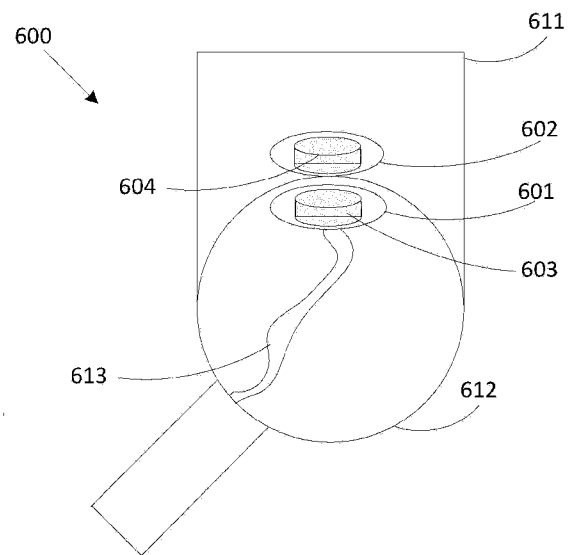


Figure 6C

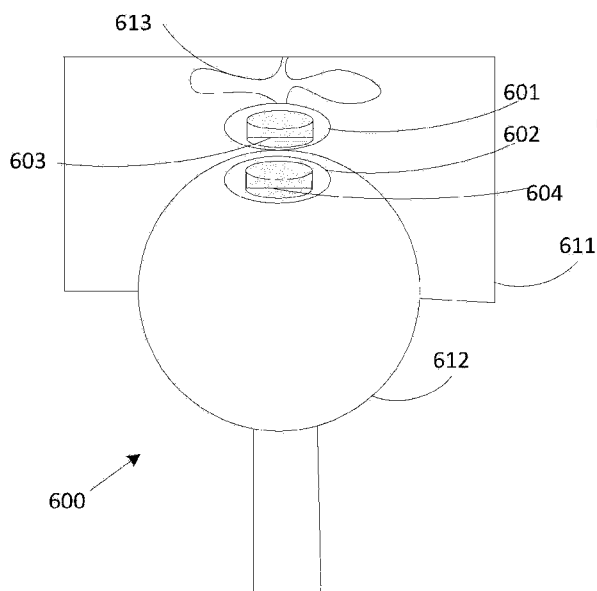


Figure 6D

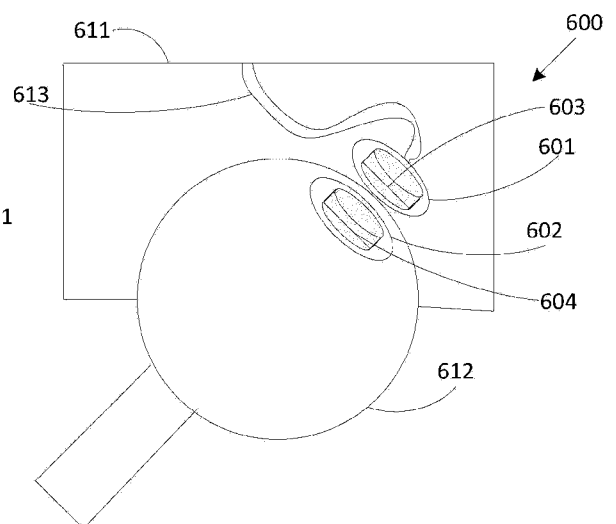


Figure 6E

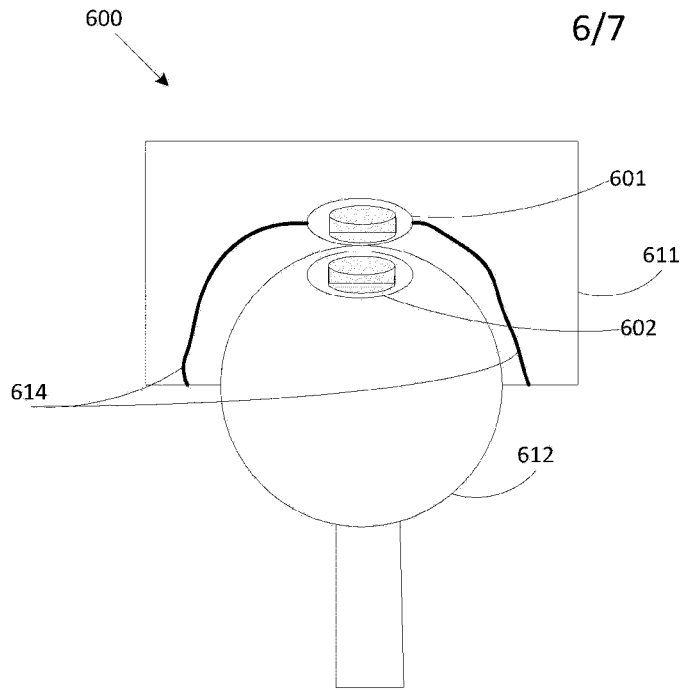


Figure 6F

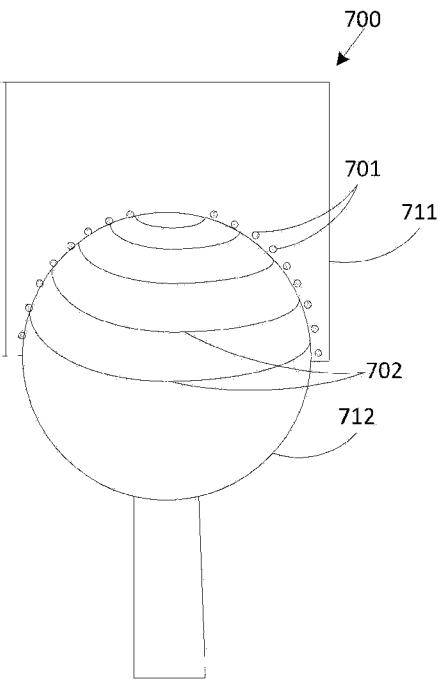


Figure 7A

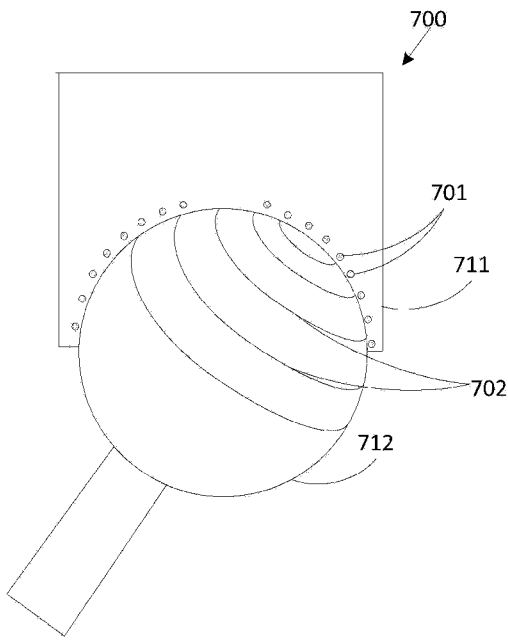


Figure 7B

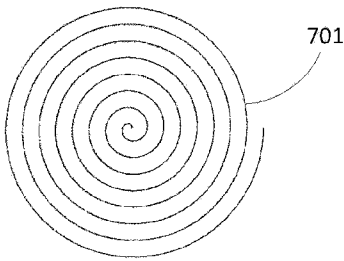


Figure 7C

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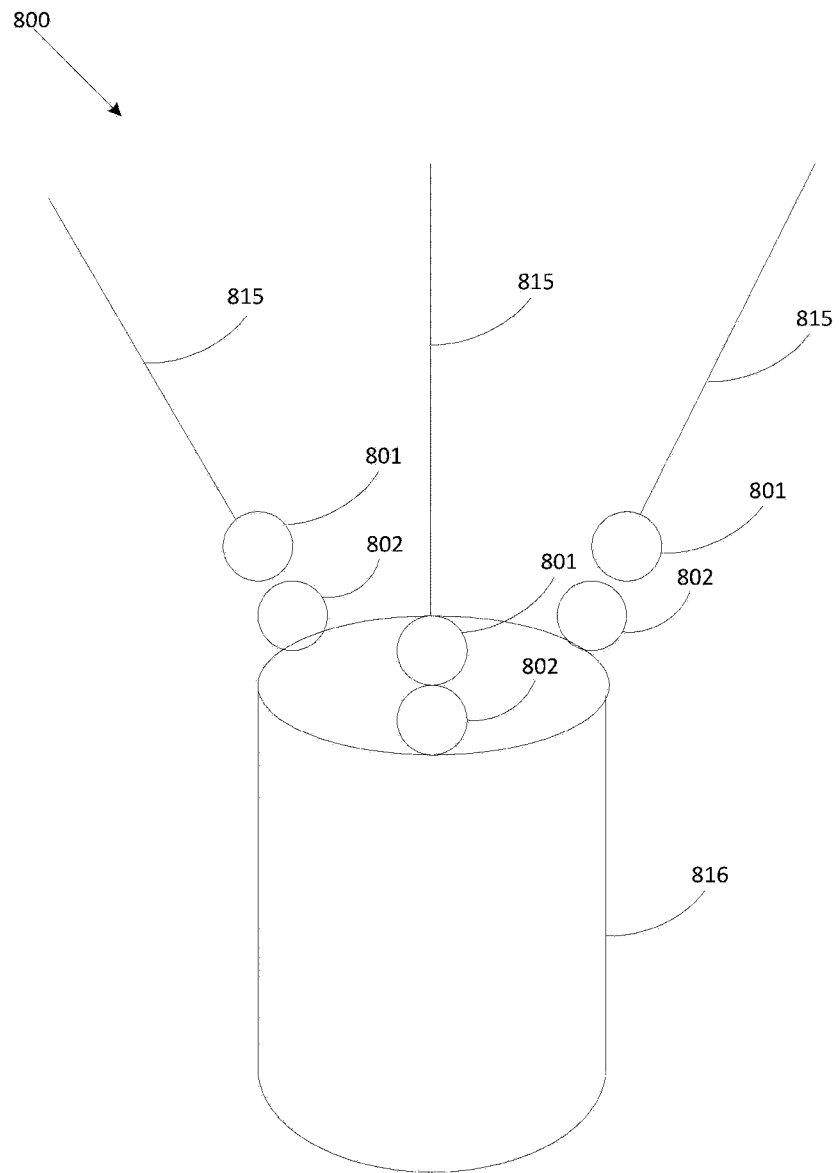


Figure 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ2017/050071

A. CLASSIFICATION OF SUBJECT MATTER

H02J 7/00 (2006.01) H04B 5/00 (2006.01)

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)

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)

PATENW, Google Web, Google Patents, Google Scholar and IEEE Xplore: Keywords (multidimension, degrees of freedom, orthogonal, coil, ball, socket, joint, robots, wireless power transfer, multiple, control, align, magnet, orient, sensor, flux, transmitter, receiver, energise) and like terms; IPC/CPC marks: H04B5/0037, H04B5/0075; H01F38/14, H02J5/005; H02J50/90; H04B5/0037; H04B5/0075, H04B5/0087, H02J50/40.

Applicant and Inventor name search in Espacenet, Auspat and internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	



Further documents are listed in the continuation of Box C



See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
9 August 2017

Date of mailing of the international search report
09 August 2017

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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/NZ2017/050071
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/0204928 A1 (HOOVER) 23 July 2015 Figs. 1 - 4, 7; Paragraphs [0016], [0021], [0022], [0024] - [0026], [0030], [0047]	1 - 54
A	WAI MAN NG et. al "Two- and Three-Dimensional Omnidirectional Wireless Power Transfer"; IEEE transactions on Power Electronics, Vol. 29, No. 9, September 2014 Entire Document	9, 10, 20, 21, 27, 39 and 40
A	US 2009/0096413 A1 (PARTOVI et. al) 16 April 2009 Entire Document	26, 36 - 37
A	US 6686823 B2 (ARNTZ et. al) 03 February 2004 Entire Document	34 - 35, 41 - 42

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INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/NZ2017/050071	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
US 2015/0204928 A1	23 July 2015	US 2015204928 A1	23 Jul 2015
		US 9577449 B2	21 Feb 2017
		JP 2015136286 A	27 Jul 2015
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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.			

INTERNATIONAL SEARCH REPORT Information on patent family members		International application No. PCT/NZ2017/050071	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
Patent Document/s Cited in Search Report		Patent Family Member/s	
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		US 2017025896 A1	26 Jan 2017
		US 2017194809 A1	06 Jul 2017
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		WO 2010129369 A2	11 Nov 2010
US 6686823 B2	03 February 2004	US 2003201862 A1	30 Oct 2003
		US 6686823 B2	03 Feb 2004
End of Annex			
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001. Form PCT/ISA/210 (Family Annex) (July 2009)			