OPIC
OFFICE DE LA PROPRIÉTÉ INTELLECTUELLE DU CANADA

CIPO
CANADIAN INTELLECTUAL PROPERTY OFFICE

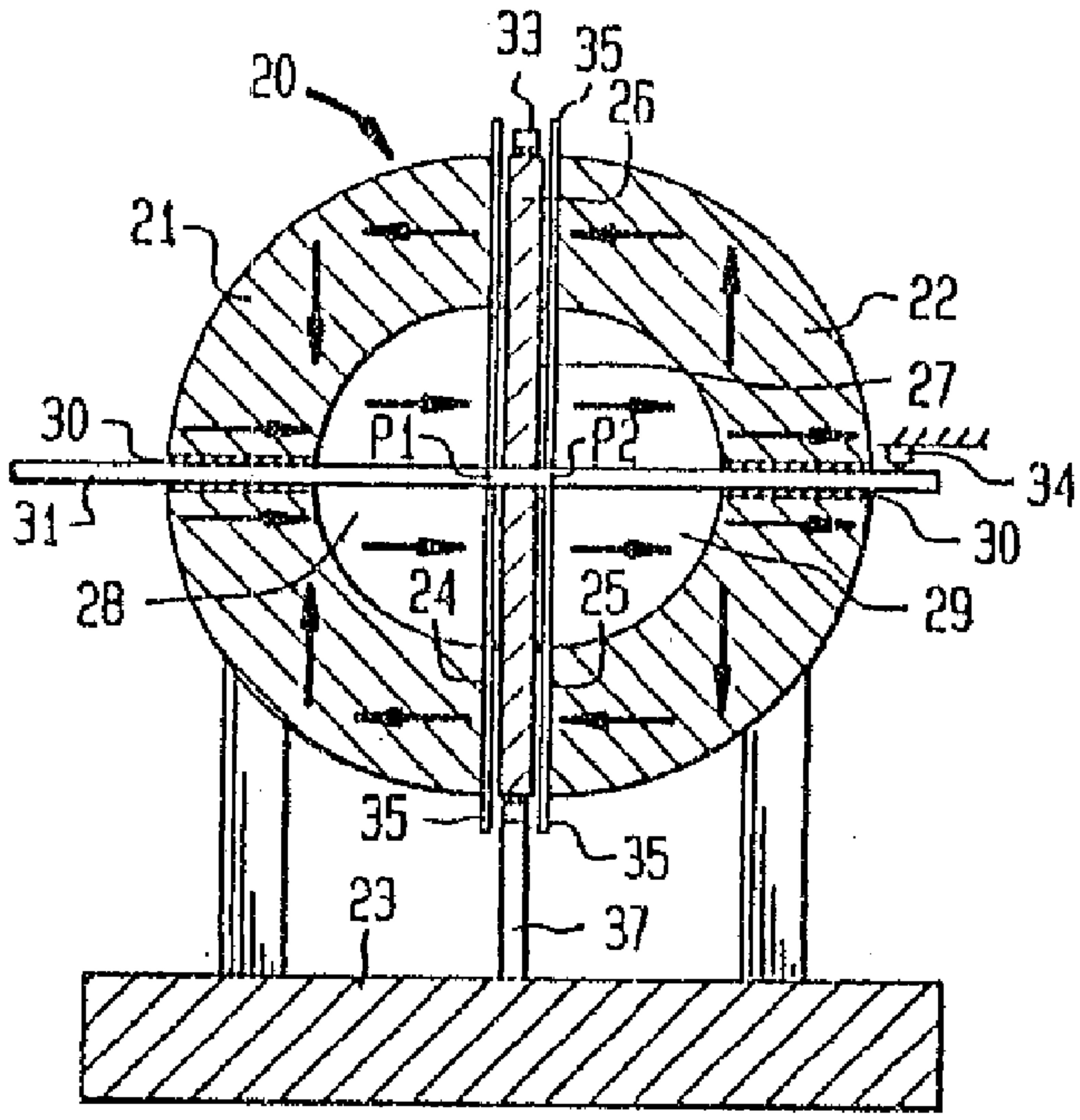
(12) (19) (CA) **Brevet-Patent**

(11) (21) (C) **2,059,579**
(22) 1992/01/17
(43) 1992/08/14
(45) 2000/04/11

(72) Leupold, Herbert A., US
(72) Rehberg, John T., US
(73) Government of the United States, as represented by the Secretary of the Army, US

(51) Int.Cl.^{5} H02K 21/36
(30) 1991/02/13 (07/654,476) US

(54) **MACHINE ELECTRIQUE A GRANDE PUISSANCE**
(54) **HIGH POWER ELECTRICAL MACHINERY**



(57) An electrical machine having a stator formed from a pair of cup-shaped permanent magnets symmetrically disposed on opposite sides of a conductive, disk-shaped rotor. The magnets are polarized such that a portion of their external magnetic flux passes in one direction through a short peripheral gap formed by the magnets in which the periphery of the rotor is disposed. The remainder of the external magnetic flux substantially passes in the opposite direction through a cavity defined by the inner volume of the cup-shaped magnets. The inner portion of the disk-shaped rotor is disposed in this cavity. One embodiment of the invention implements the cup-shaped magnets with modified "magic spheres" mounted on either side of the conductive disk-shaped rotor. Other embodiments use a magnetic plate on one side of the disk-shaped rotor to act as a magnetic mirror for a cup-shaped magnet mounted on the other side of the rotor. In still another embodiment, the magnets are mounted as rotors while the conductive disk is the stator. The machine may be used as a homopolar generator or a homopolar motor.

2059579

ABSTRACT

An electrical machine having a stator formed from a pair of cup-shaped permanent magnets symmetrically disposed on opposite sides of a conductive, disk-shaped rotor. The magnets are polarized such that a portion of their external magnetic flux passes in one direction through a short peripheral gap formed by the magnets in which the periphery of the rotor is disposed. The remainder of the external magnetic flux substantially passes in the opposite direction through a cavity defined by the inner volume of the cup-shaped magnets. The inner portion of the disk-shaped rotor is disposed in this cavity. One embodiment of the invention implements the cup-shaped magnets with modified "magic spheres" mounted on either side of the conductive disk-shaped rotor. Other embodiments use a magnetic plate on one side of the disk-shaped rotor to act as a magnetic mirror for a cup-shaped magnet mounted on the other side of the rotor. In still another embodiment, the magnets are mounted as rotors while the conductive disk is the stator. The machine may be used as a homopolar generator or a homopolar motor.

1. Field of the Invention

The present invention relates to electrical machinery and, more particularly, to homopolar, direct-current motors and generators capable of producing high output torques and high output currents, respectively.

2. Description of the Prior Art

One of the most critical problems confronting designers of high-power electrical machinery has been simplifying their construction while not adversely effecting their ability to produce high powers. In the recent past, those concerned with designing electrical generators having high output currents and motors having high output torques have turned to the use of superconducting magnets. For example, electrical motors having superconducting magnets are currently being considered for ship propulsion where high torque outputs are critical. Although superconducting machines can serve the purpose in many situations, they are not entirely satisfactory under all conditions of service because of the considerable expense involved in manufacturing and maintaining the superconducting magnets. Such magnets normally include electromagnetic coils made of a special superconductive material that must be kept at relatively low temperatures during machine operation. Further, the added bulk of most superconducting magnets and their power supplies makes their use undesirable in many environments, e.g. aboard ship, where space is critical. It has been recognized, therefore, that electrical motors and generators that employ superconducting magnets, while capable of producing the high magnetic fields required in high-power machines, are relatively more expensive and complicated to manufacture and maintain and more cumbersome to use than are their conventional counterparts.

Consequently, those concerned with the development of high-power electrical machinery have recognized the need for improved techniques of developing conventional-type electrical machinery capable of high-power operation that are not unduly complicated and expensive to manufacture and maintain. The present invention fulfills this need.

SUMMARY OF THE INVENTION

The general purpose of this invention is to provide an electrical machine capable of high-power outputs which embraces all the advantages of similarly employed machines, superconducting or otherwise, and possesses none of the aforedescribed disadvantages. To obtain this, the present invention contemplates a unique stator and rotor arrangement whereby a significant portion of the active magnetic field is coupled to the current-carrying conductors.

In general, the invention is directed to an electrical machine comprising a permanent magnet having a cup-shaped shell with an outer rim and a hollow cavity, and wherein the magnetic orientation in the shell varies over the shell to produce an external magnetic field in a first direction adjacent the rim and in a second direction opposite to the first direction in the cavity. An electrically conductive member is mounted adjacent the magnet and lies in the external magnetic field. Means is provided for causing relative rotation of the conductive member and the magnet with respect to each other.

More specifically, one embodiment of the invention comprises a stator formed from a pair of cup-shaped permanent magnets symmetrically disposed on opposite sides of a conductive, disk-shaped rotor. The magnets are polarized such that a portion of their external magnetic flux passes in one direction through a short peripheral gap formed by the magnets in which the periphery of the rotor is disposed. Further, the remainder of the external magnetic flux substantially passes in the opposite direction through a cavity defined by the inner volume of the cup-shaped magnets. The inner portion of the disk-shaped rotor is disposed in this cavity.

One embodiment of the invention implements the cup-shaped magnets with modified "magic spheres" mounted on either side of the conductive disk-shaped rotor. Other embodiments use a magnetic plate on one side of the disk-shaped rotor to act as a magnetic mirror for a cup-shaped magnet mounted on the other side of the rotor. The magnetic mirror produces an anti-image of the cup-shaped magnet. In still another embodiment, the magnets are mounted as rotors while the conductive disk is the stator.

The conductive disks of the various embodiments are connected by circuitry to an external utilization device. Depending on the nature of the utilization device and the circuit configuration, the electrical machine may operate as either a homopolar generator or a homopolar motor.

The exact nature of this invention, as well as other objects and advantages thereof, will be readily apparent from consideration of the following specification relating to the annexed drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation of a portion of the preferred embodiment.

FIG. 2 is a cross section of the preferred embodiment taken on the line 2-2 of FIG. 3, looking in the direction of the arrows.

FIG. 3 is a cross section taken on the line 3-3 of FIG. 1, looking in the direction of the arrows.

FIG. 4 is an elevation partly in section of an alternate embodiment of the invention.

FIG. 5 is a cross section showing a detail of a further alternate embodiment.

FIG. 6 is a schematic circuit diagram illustrating current flow in the preferred embodiment.

FIG. 7 is a pictoral view with parts broken away of another alternate embodiment.

FIG. 8 is a pictoral view partly broken away and partly in section of a further alternate embodiment of the invention.

FIG. 9 is an elevation in cross section of still another alternate embodiment of the invention.

FIG. 10 is a cross section in elevation of a further modification of the invention.

FIG. 11 is a pictoral view with parts broken away of yet another embodiment of the invention.

FIG. 12 is an elevation of a still further embodiment of the invention.

FIG. 13 is a schematic circuit diagram illustrating current flow for the embodiment shown in FIG. 12.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, there is shown in FIGS. 1-3 an electrical machine 20 having two hemispherical, magnetic shells 21, 22 rigidly mounted on the upright arms of a supporting base 23. The magnetic shells 21, 22 have flat, ring-shaped faces 24, 25, respectively, that are spaced to form a short peripheral gap 27 in which a disk-shaped rotor 26 is rotatably mounted. The magnetic shells 21, 22 have hemispherical cavities 28, 29, respectively.

A shaft 31, rigidly attached to rotor 26, is mounted for rotation in bearings 30 that are fixed to and pass through the walls of the magnetic shells 21, 22. The rotor 26 is made of a non-magnetic electrically conductive material such as copper. The magnetic shells 21, 22 are preferably fabricated from magnetic materials having high coercivity such as alloys of cobalt and neodymium. The shells 21, 22 may be constructed in accordance with the principles disclosed in the U.S. Patent No. 4,837,542; the article entitled <u>Permanent Magnets for Production and Use of High Energy Particle Beams</u> by Klaus Halbach, "Proceedings of the Eighth

International Workshop on Rare Cobalt Permanent Magnets," (Univ. of Dayton, Dayton, OH 1985) pp. 123-136; the paper entitled A Catalogue of Novel Permanent Magnet Field Sources by H.A. Leupold, et al., Paper No. W3.2 at the 9th International Workshop on Rare-Earth Magnets and Their Applications, Bad Soden, FRG, 1987; and the Canadian Patent Application 2,059,085 by Herbert A. Leupold, entitled High-Power Electrical Machinery with Toroidal Permanent Magnets.

Ideally, the orientation of the magnetization of the shells 21, 22 varies continuously with and twice as fast as the polar angles wherein the longitudinal axis of shaft 31 defines the polar axis and the hemispherical centers P1, P2 (FIG. 2) of the respective shells 21, 22 define the poles. In general, the magnetizations in the respective shells 21, 22, shown by the arrows in FIG. 2, are antisymmetric in the sense that their shell orientation are reversed at corresponding locations in the shells 21, 22.

For example, in shell 22 along face 25, the magnetization is perpendicular to face 25 and points into gap 27. By contrast, the magnetization of shell 21 along the face 24 is such that the field is perpendicular to face 24 and points away from gap 27. Adjacent to the bearings 30, the magnetization of shell 21 is directed parallel to shaft 31 and points toward the cavity 28, while the magnetization in shell 22 is also directed parallel to shaft 31 but points away from cavity 29. Between these extremes, the magnetization direction varies gradually and continuously.

As indicated by the arrows in FIG. 2, the shells 21, 22 generate a ring-shaped or annular field across the gap 27 that is oriented perpendicular to the faces of rotor 26. Further, as illustrated by the arrows in the cavities 28, 29 (FIG. 2), the shells 21, 22 generate an external field over the broad surfaces of rotor 26 adjacent the cavities 28, 29 that is parallel to but oppositely directed to the field in gap 27.

The machine 20 may be used as a homopolar electric motor or a homopolar electric generator. When used as a homopolar generator, a torque is applied to the shaft 31 to cause the rotor 26 to rotate. The fields in gap 27 and cavities 28, 29 will interact with the conductive rotor 26 and cause currents to flow therein. More specifically, assuming that the shaft 31 is rotated by an external means (not shown) in the direction indicated by the arrows T in FIGS. 1 and 3, radial currents I will be induced on the rotor 26 in the directions indicated by the arrows I in FIG. 3. The induced currents I will flow radially but will reverse direction at the circular margin defined by the border between the gap 27 and the cavities 28, 29, i.e. along the circular margin where the magnetic field intercepted by the rotor 26 reverses direction.

The currents I that are induced when machine 20 is operated as a homopolar generator flow as direct currents from the rotor 26 via brushes 33, 34 and 35 (FIG. 2). Brush 33 may be a hoop-shaped structure that is in electrical contact with the entire outer edge of rotor 26, or brush 33 may comprise short brush segments spaced about the outer edge of rotor 26. Brush 33 is rigidly held in place by an arm 37 that forms a part of base 23.

Brush 34 is in electrical contact with the shaft 31 which may be made of conductive material for providing current flow from the center of rotor 26 to the brush 34. Brushes 35 include two flat, ring-shaped conductors fixed to the faces 24, 25 that have circular contacts in electrical contact with the faces of rotor 26 along the circular margin where the induced currents I change direction (FIG. 5).

FIG. 6 is a circuit diagram that illustrates a utilization device, load/source 36, joined by conductors 40 to brushes 33, 34, 35 via terminals 38, 39. When machine 20 is used as a homopolar generator, the electrical load (load/source 36) will utilize the direct current I via terminals 38, 39.

As indicated above, the machine 20 may also be used as a homopolar motor. When machine 20 is used as a motor, a source of power (load/source 36) is connected across the terminals 38, 39, causing direct currents I to flow on rotor 26 in the directions indicated by the arrows in FIG. 6. The interaction between the direct currents I and the fields residing in gap 27 and cavities 28, 29 will create a torque T on rotor 26 in the direction indicated in FIGS. 1, 3, thereby causing the shaft 31 to rotate.

Under most applications, the magnets 21, 22 will each be of greater mass than the mass of rotor 26. As such, it is usually more efficient to use the magnets 21, 22 as the stators. However, in some applications, it may be desirable to rotate the magnets 21, 22 and hold the rotor 26 stationary.

FIG. 4 illustrates an electrical machine 20′ having magnets 21′, 22′ that are rotated and a conductive member that is fixed. Magnets 21', 22' are mounted on a rotatable shaft 31'. A conductive disk-shaped stator 26'is supported on base 23'. Stator 26' has a bearing 30' rotatably mounting shaft 31'. Conductors 40' are joined to the stator 26' at the indicated locations, i.e. the outer edge, the center and the point where the external magnetic fields of magnets 21', 22' reverses direction. The current distribution on the stator 26' will be the same as the current I on rotor 26 (FIG. 3) for situations where the magnetization of magnets 21', 22' and the rotation of shaft 31' are the same as that indicated by the arrows in FIGS. 2 and 3. The elimination of the need for brushes in the FIG. 4 embodiment is an obvious mechanical simplification over the FIGS. 1-3 embodiment.

Of course, the structures are shown in FIGS. 1-4 in a simplified diagrammatic form to represent an ideal case. Using presently available technology it would be difficult to form the magnets 21, 22, 21', 22', i.e. wherein the direction of magnetization varies continuously and smoothly in the manner indicated. However, as disclosed in the '542 patent and the above-cited publications, a segmented approximation (FIG. 5) is readily achievable.

The FIG. 5 embodiment shows magnetic segments 21A-21C and 22A-22C which are joined to approximate the magnets 21, 22, respectively, of FIGS. 1-3. Each segment 21A-21C and 22A-22C is uniformly magnetized in the directions illustrated by the arrows in FIG. 5. The segments 21A-21C and 22A-22C have cone-shaped surfaces that mate with each other to form the overall hemispheres. As indicated in the cited publications, a FIG. 5 structure using as few as five segments per great circle of longitude could produce a ninety percent approximation of the ideal structures as seen in FIGS. 1-3.

FIG. 7 illustrates a machine 49 constructed of cylindrically shaped magnets 41, 42, having a plurality of pie-shaped cuts each with four segments 45A, 45B, 45C and 45D. Each segment 45A-45D has a triangular cross section. A bearing 43 is fixed in segments 45B to rotably support a shaft 44 that is joined to the center of a conductive, disk-shaped rotor 46. Magnets 41 and 42 are supported to form a gap 47 and cavities (only cavity 48 is shown) similar to gap 27 and cavities 28, 29 (FIG. 2). The rotor 46 is free to rotate in gap 47.

The magnetization of each segment 45A-45D is uniform and together they generate an external field that approximates the field of the structure shown in FIG. 2. In general, the field across the gap 47 is parallel to the axis of shaft 44 and is directed downwardly (FIG. 7). The field in cavity 48 is parallel to the field in gap 47 but directed in the opposite direction, i.e. upwardly as viewed in FIG. 7. The rotor currents I will be distributed radially in the directions indicated by the arrows in FIG. 7 when the rotor 46 is turned in the direction indicated by arrow T. The machine 49 will employ appropriate brushes similar to brushes 33, 34 and 35 of FIG. 2 for applying currents to the rotor 46 when machine 49 is used in the motor mode, or for drawing currents from rotor 46 when machine 49 is used in the generator mode. The segments 45A-45D will in general be easier to manufacture then the segments 21A-21C and 22A-22B of the FIG. 5 embodiment.

Regardless of the selected configuration for a particular application, it is important only that the magnets be cup-shaped and have a cavity and an annular rim. The cup-shaped configuration will confine most of the external magnetic field to the cavity and the annular rim. A conductive plate is mounted adjacent the rim and the cavity. Either the conductive plate or the magnets may be rotated. When the magnets are rotated the brushes are not necessary. Also, the machine may be used as a homopolar motor or a homopolar generator. Because most of the external magnetic field is confined to the cavity and the rim, the power output will be higher than it is in conventional machines of the same size.

FIG. 8 illustrates a system 50 constructed from a plurality of identical electrical machines 50A, 50B and 50C mounted on a common shaft 51 that passes through the hemispherical magnets 52A-53C. Disk-shaped rotors 56A-56C are fixed to the shaft 51 for freely rotating in the cavities and gaps formed by magnets 52A-53C. Peripheral brushes 57A-57C and inner brushes 58A-58C are mounted in sliding contact with rotors 56A-56C, respectively. The brushes 57A-57C would be connected in common as would the brushes 58A-58C. A brush (not shown) would contact the conductive shaft 51 in the same manner as the brush 34 contacts the conductive shaft 31 (FIGS. 2, 6). A similar assembly having any number of tandem machines may be constructed to increase the output power. The machine 49 of FIG. 7 may be ganged in tandem in a similar fashion.

With the use of a magnetic mirror, also referred to as an anti-mirror, the size and mass of the machine may be reduced significantly by eliminating the need for one of the shells. FIG.

9 shows a machine 80 having only one permanent magnet, namely hemispherical shell 81. A magnetic mirror 82, in the form of a flat plate of magnetic material such as iron, is spaced from the peripheral faces of shell 81 to form a gap 83. The shell 81, magnetized in the directions indicated by the arrows, together with the mirror 82 will produce an external field in the cavity 89 and the gap 83 identical to that produced by a similar machine having two shells. The mirror 82 will provide a flux path such that the shell 81 will in effect see an anti-image 81', i.e. the shell 81 and its anti-image 81' will both have the same geometric shape while the shell orientation of their magnetizations will be reversed or antisymmetric as indicated by the arrows.

A disk-shaped conductive rotor 84 is mounted in the gap 83 for rotation with respect to the shell 81 and mirror 82 via shaft 85. Brushes 86, 87, 88 make contact with the rotor 84 and shaft 85 in the same fashion as described earlier for brushes 33, 34, 35 (FIG. 6). The machine 80 may be operated as a homopolar motor or generator in the same manner as the earlier-described machines operate. The current distributions on the rotor 84 will also be similar to the current distributions on the earlier-described machines.

FIG. 10 shows a machine 90 formed from a tandem arrangement of the two machines 80 of FIG. 9. The rotors 84 are fixed to the common shaft 85 which is mounted for rotation in bearings located in the fixed shells 81 and the fixed mirrors 82. Each of the mirrors 82 will produce an anti-image of its corresponding shell 81. Each shell 81 and its corresponding mirror 82 is in effect an independent machine. The brushes 86, 87, 88 are omitted in FIG. 10 for clarity.

In addition to reducing the size and mass of the machines, magnetic mirrors may also be used to simplify machine fabrication. The cup-shaped magnets (magnets 21, 22; 41, 42; 52A, 53A) so far described, must be magnetized in an antisymmetric fashion as described above. However, with the use of magnetic mirrors, machines having magnets which are magnetized with only one type of polarity may be fabricated.

FIG. 11 illustrates an electrical machine 60 having two identical hemispherical magnets 61. FIG. 12 illustrates an assembly 70 wherein two identical machines 60 are ganged in tandem. The opposed magnets 61 are spaced to form gaps 62. Two identical disk-shaped conductive rotors 63 are mounted in each gap 62. Sandwiched between each rotor 63 is a magnetic mirror 64.

The rotors 63 are fixed at their centers to the shaft 66 that is mounted in bearings that pass through the magnets 61. The mirrors 64 are spaced from the rotors 63 and may or may not be mounted to rotate with shaft 66.

As indicated by the arrows in FIG. 11, the currents I1 on the upper rotor 63 will flow in the opposite direction to the currents I2 on the lower rotor 63. Because of this, it will be necessary to connect the various points on the rotors 63 appropriately. FIG. 13 is a circuit diagram showing the two pairs of rotors 63 and the shaft 66 of the FIG. 12 embodiment.

It is first noted that the shaft 66 has two separate conductive paths 90, 91 leading to two brushes 72, 73. The centers of the upper rotors 63 are connected to brush 72 via path 90 while the centers of the lower rotors 63 are connected to brush 73 via path 91. Connected in common are the edge brushes 79 and the inner brushes 78. The edge brushes 77 and the inner brushes 76 are also connected in common. Terminal 93 is connected to brushes 73, 76, 77. Terminal 94 is connected to brushes 72, 78, 79. The electrical load, in the case of a generator, or the electrical power source, in the case of an electrical motor, is connected across the terminals 93, 94. The circuit of FIG. 13 illustrates a parallel connection of the rotors 63 and the terminals 93, 94. It will be evident to those skilled in these arts that a series connection of these elements would also be an appropriate alternative.

The machine 60 and assembly 70 may be cheaper and easier to manufacture because the cup-shaped magnets 61 are identical. However, it is noted that the magnetic mirror 64 in some applications may be a limiting factor. The amount of power output from a machine 60 will depend on the amount of magnetic flux that the mirror 64 can conduct. However, such mirrors 64 may become saturated at a level that may limit the power.

Various other modifications and alterations are contemplated and may obviously be resorted to by those skilled in the art in the light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A homopolar electrical machine comprising:

a permanent magnet having a hemispherical cup-shaped shell with an outer rim and a hollow cavity, and a magnetic orientation in said shell that varies over said shell to produce an external magnetic field in a first direction adjacent said rim and in a second direction opposite to said first direction in said cavity;

means for returning the external magnetic field adjacent said rim to said cavity to complete a magnetic flux path, which means is separated from said rim by a gap;

an electrically conductive member mounted adjacent said magnet and lying in said gap; and

means for causing relative rotation of said conductive member and said magnet with respect to each other, the machine including conductor means connected to said member for electrically connecting a utilization device to said member.

2. The machine of claim 1 wherein said conductor means includes sliding contacts.

3. The machine of claim 1 wherein said utilization device is a direct current source and said machine is an electrical motor.

4. The machine of claim 1 wherein said utilization device is a load and said machine is an electrical generator.

B

5. The machine of claim 1 wherein said means for returning the external magnetic field is a second permanent magnet similar in shape to and fixed with respect to said first-mentioned permanent magnet, said magnets being antisymmetrically polarized and being symmetrically disposed on opposite sides of said conductive member.

6. The machine of claim 1 wherein said means for returning the external magnetic field is a magnetic mirror mounted adjacent to said conductive member such that said conductive member lies between said mirror and said magnet.

7. The machine of claim 1 further comprising:

a second permanent magnet similar in shape and magnetic polarization to said first-mentioned magnet, said magnets being symmetrically fixed with respect to each other on opposite sides of said conductive member; and

a second conductive member mounted between said first-mentioned conductive member and said second permanent magnet; and wherein said means for returning the external magnetic field is a magnetic mirror mounted between said conductive members.

8. An electrical machine assembly comprising:

a plurality of homopolar electrical machines mounted in tandem on a common axle, each said machine comprising:

a permanent magnet having a hemispherical cup-shaped shell with an outer rim and a hollow cavity, and a magnetic

B

orientation in said shell that varies over said shell to produce an external magnetic field in a first direction adjacent said rim and in a second direction opposite to said first direction in said cavity;

means for returning the external magnetic field adjacent said rim to said cavity to complete a magnetic flux path, which means is separated from said rim by a gap;

an electrically conductive member mounted adjacent said magnet and lying in said gap; and

means for rotatably mounting said conductive member and said magnet about said axle with respect to each other, the machine assembly further including a conductor means connected to said members for connecting a utilization device to said members.

9. The machine assembly of claim 8 wherein said magnets are held stationary, said conductor means includes sliding contacts, and said conductor members are fixed on said axle for rotation therewith.

10. The machine assembly of claim 8 wherein said utilization device is a direct current source and said assembly is an electrical motor wherein said axle is rotated to produce mechanical energy.

11. The machine assembly of claim 8 wherein said utilization device is an electrical load and said axle is rotated by an external force.

B

12. The assembly of claim 8 wherein each said electrical machine's said means for returning the external magnetic field is a second permanent magnet similar in shape to and fixed with respect to said first-mentioned permanent magnet, said magnets being antisymmetrically polarized and being symmetrically disposed on opposite sides of said conductive member.

13. The assembly of claim 8 wherein said means for returning the external magnetic field is a magnetic mirror mounted adjacent to said conductive member such that said conductive member lies between said mirror and said magnet.

14. The assembly of claim 8 wherein each said electrical machine further comprises:

a second permanent magnet similar in shape and magnetic polarization to said first-mentioned magnet, said magnets being symmetrically fixed with respect to each other on opposite sides of said conductive member; and

a second conductive member mounted between said first-mentioned conductive member and said second permanent magnet; and wherein said means for returning the external magnetic field is a magnetic mirror mounted between said conductive members.

15. A homopolar electrical machine comprising:

a permanent magnet having a cup-shaped shell with a planar, ring-shaped peripheral surface and a hollow cavity, said magnet having a magnetic orientation in said shell that varies to produce an external magnetic field adjacent to said surface in a first direction perpendicular to said surface and in said cavity in a second direction opposite to said first direction;

means for returning the external magnetic field adjacent said rim to said cavity to complete a magnetic flux path, which means is separated from said rim by a gap;

an electrically conductive disk mounted adjacent to said magnet and lying in said gap in a plane that is parallel to and spaced from said surface; and

axle means for rotatably mounting said conductive disk and said magnet with respect to each other, the machine including conductor means for electrically connecting a utilization device to said disk.

16. The machine of claim 15 wherein said cavity has a hemispherical wall.

17. The machine of claim 15 wherein said cavity has a cylindrical wall.

18. The machine of claim 15 wherein said means for returning the external magnetic is a second permanent magnet similar in shape to and fixed with respect to said first-mentioned permanent magnet, said magnets being antisymmetrically polarized and being symmetrically disposed on opposite sides of said conductive disk to form a gap having a magnetic field therein.

19. The machine of claim 18 further including mounting means for supporting said machine and for fixing said magnets with respect to each other.

20. The machine of claim 19 wherein said axle means includes an axle fixed to said disk, means mounting said axle for rotation with respect to said magnets and for rotating said disk in said gap.

21. The machine of claim 18 further including mounting means for supporting said machine and for fixing said disk.

22. The machine of claim 21 wherein said magnets are mounted on said axle means for rotation therewith such that said magnetic field in said gap rotates in the plane of said disk and extends perpendicular to said disk.

2059579

FIG. 1

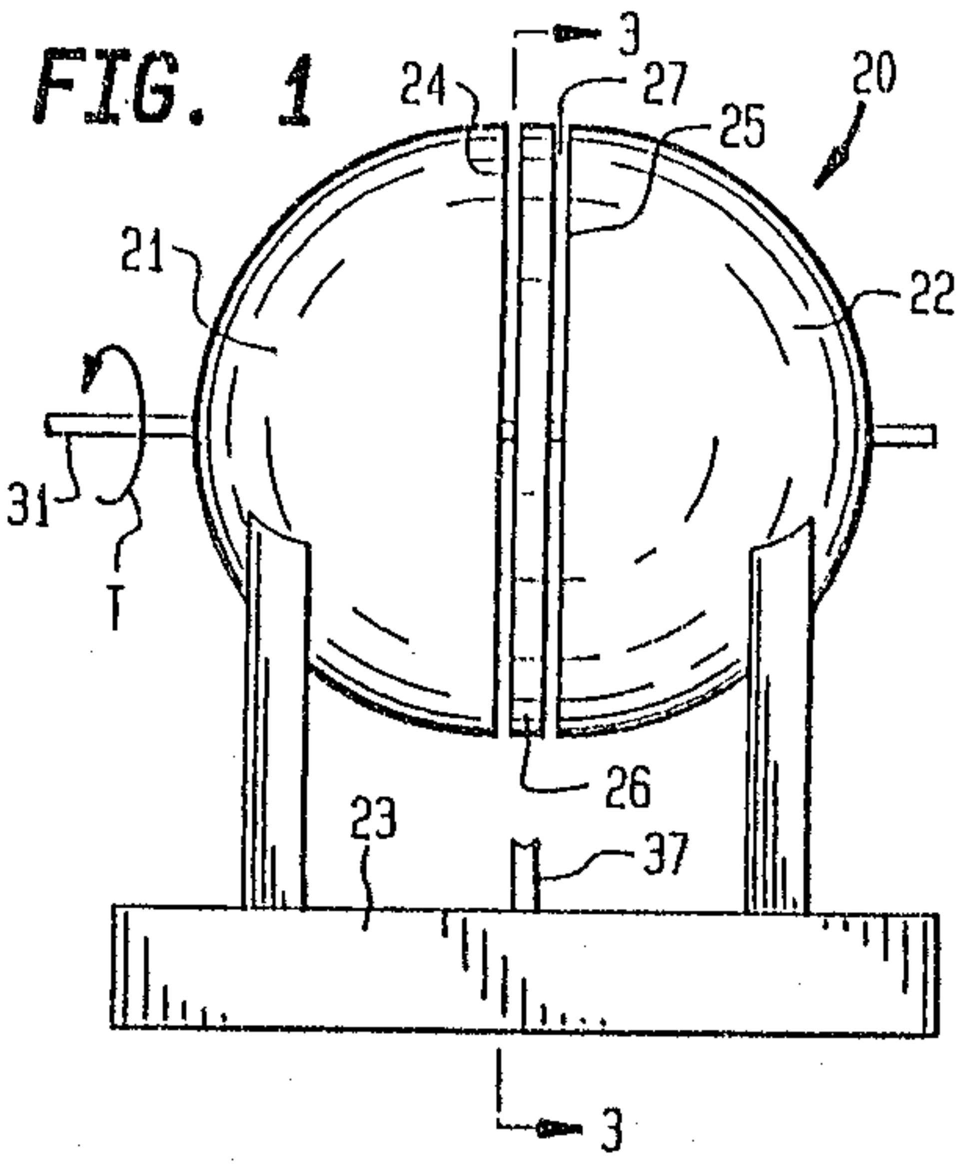


FIG. 2

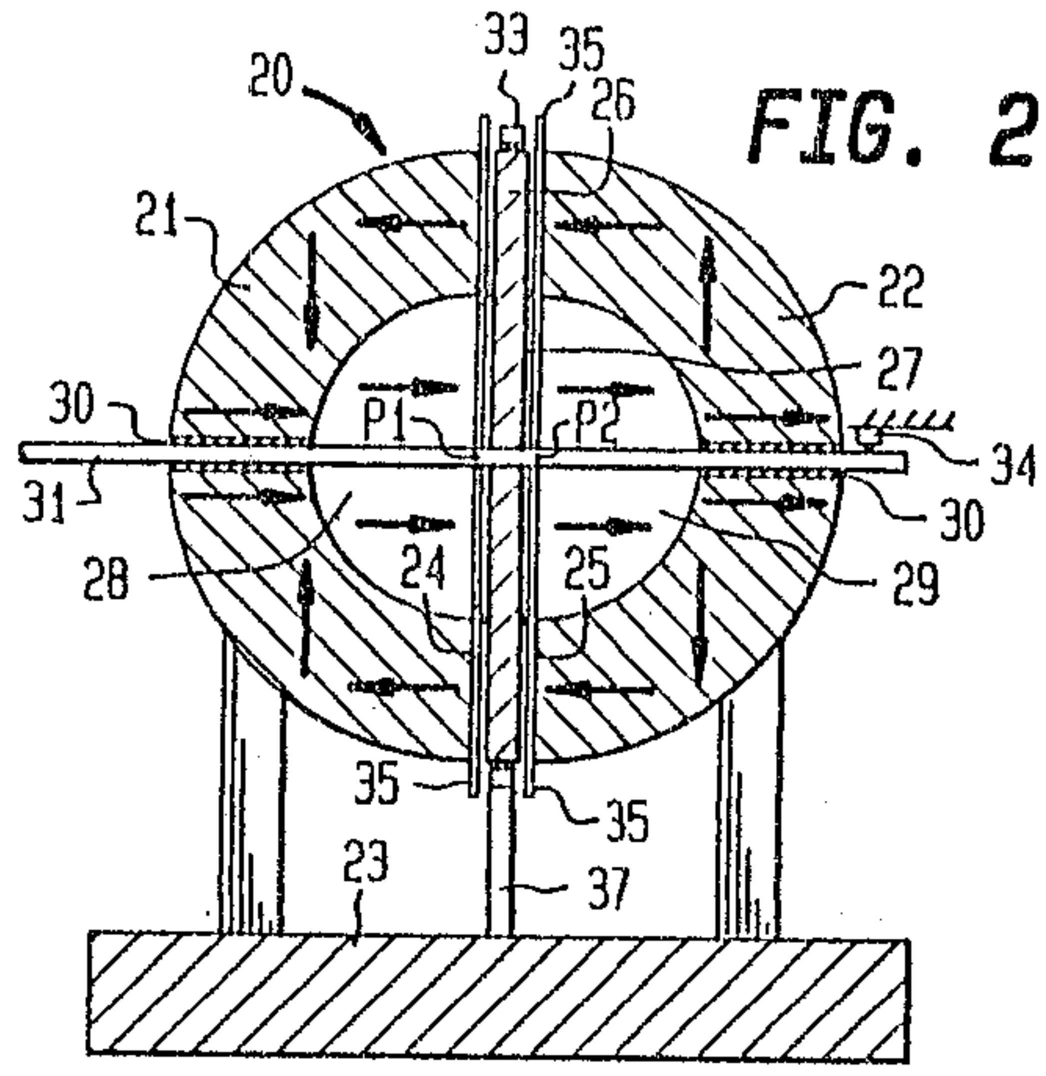
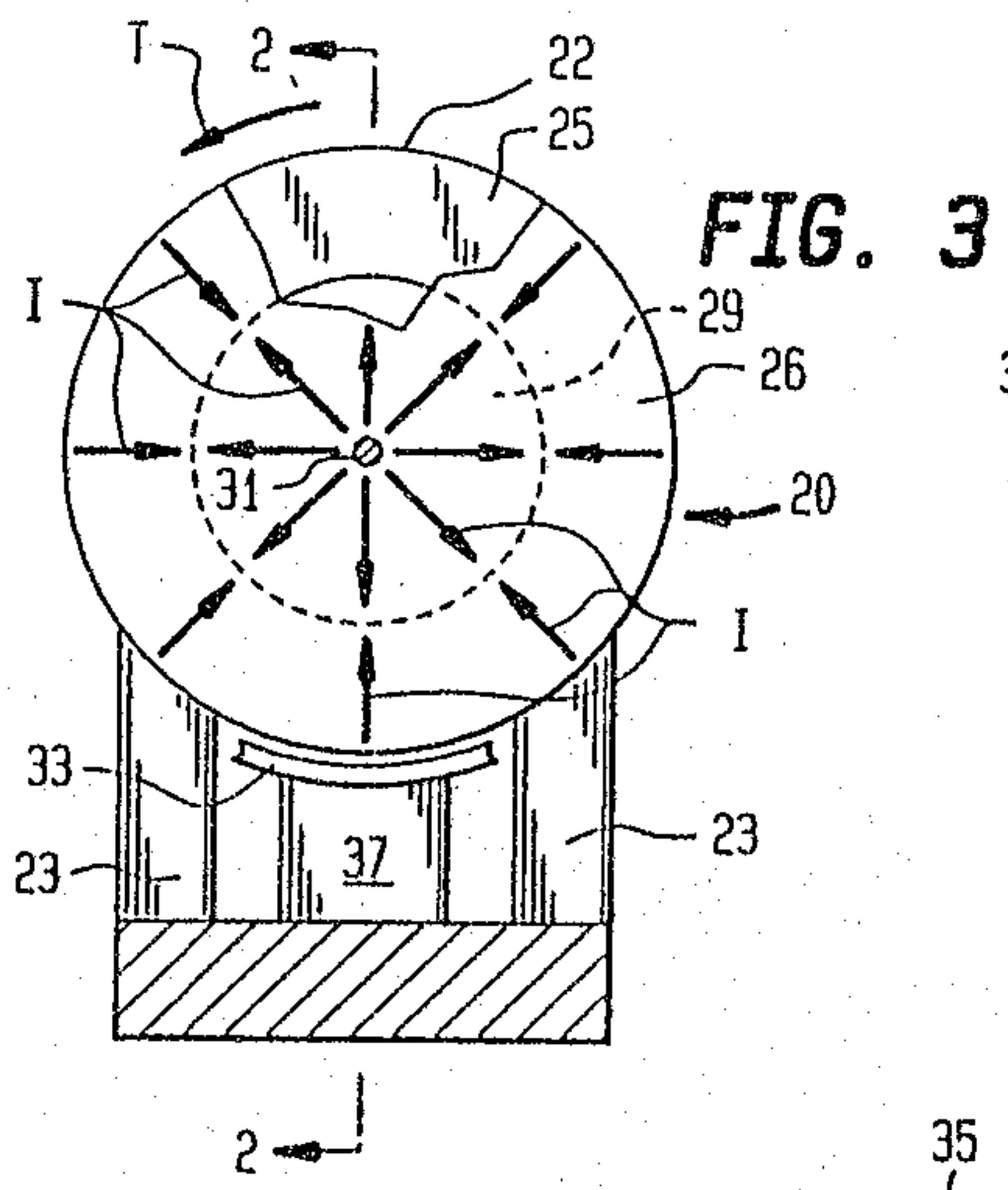


FIG. 3



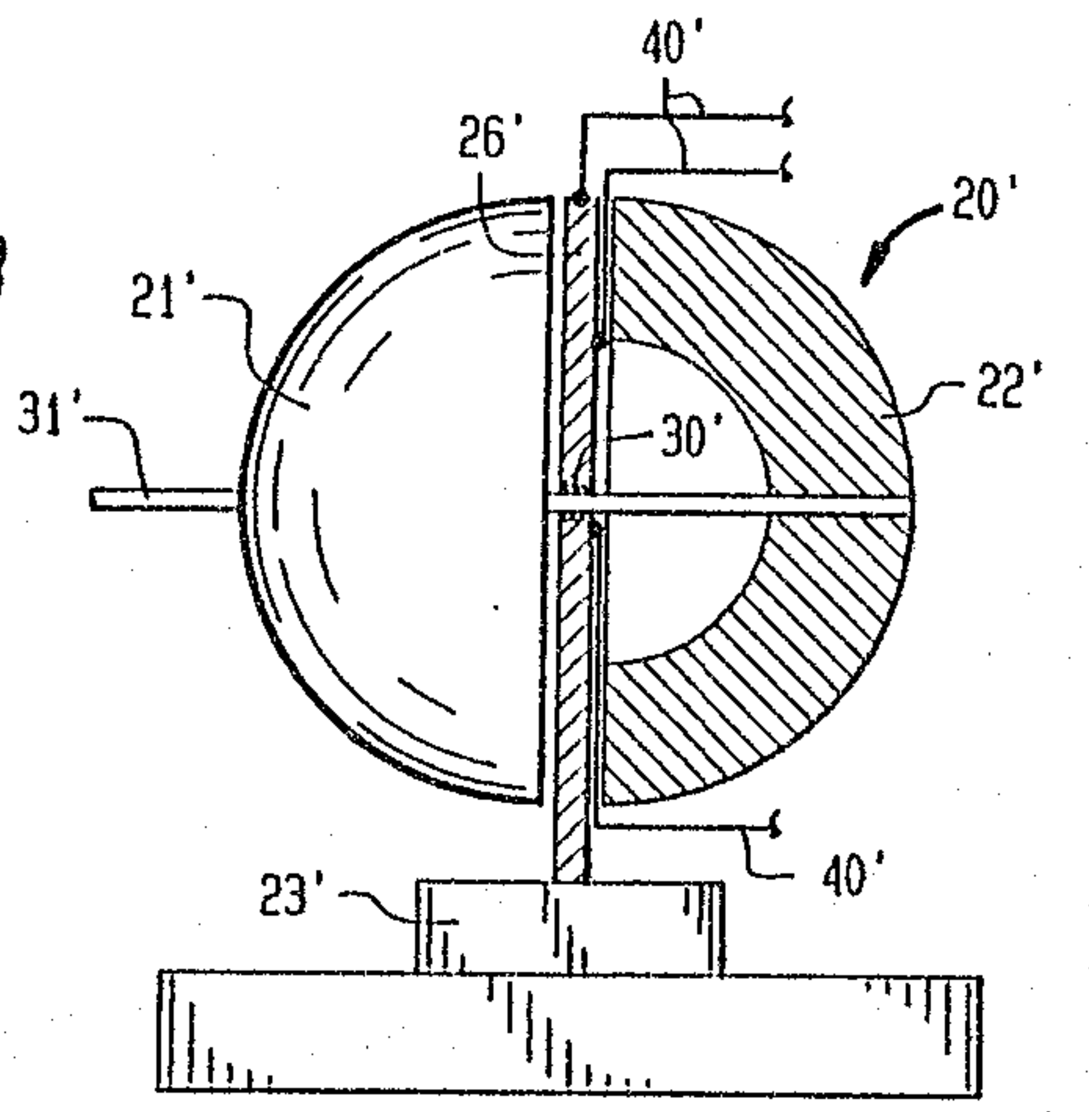
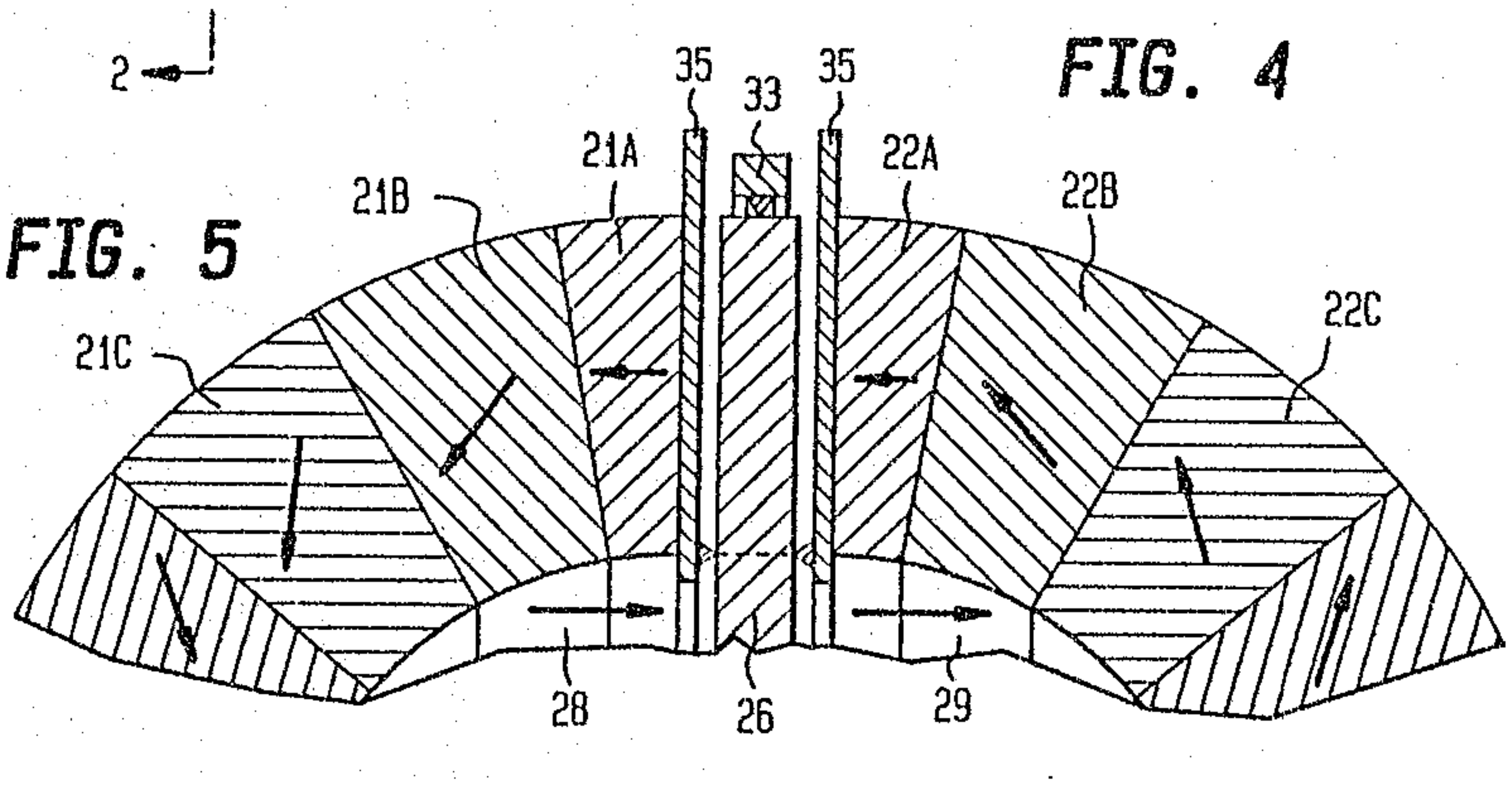


FIG. 4

FIG. 5



K. P. Aspila
Patent Agent for Applicant

2059579

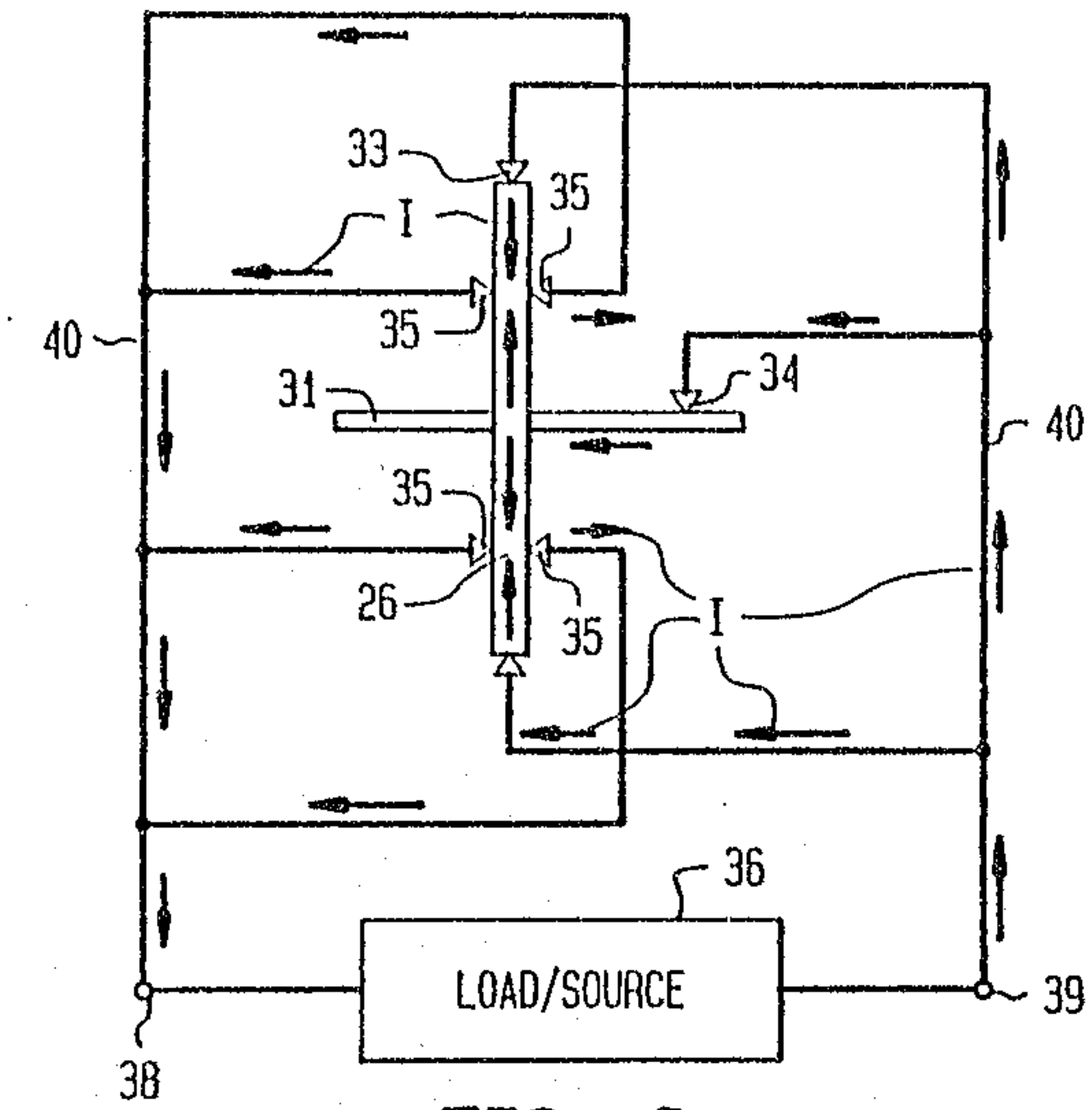


FIG. 6

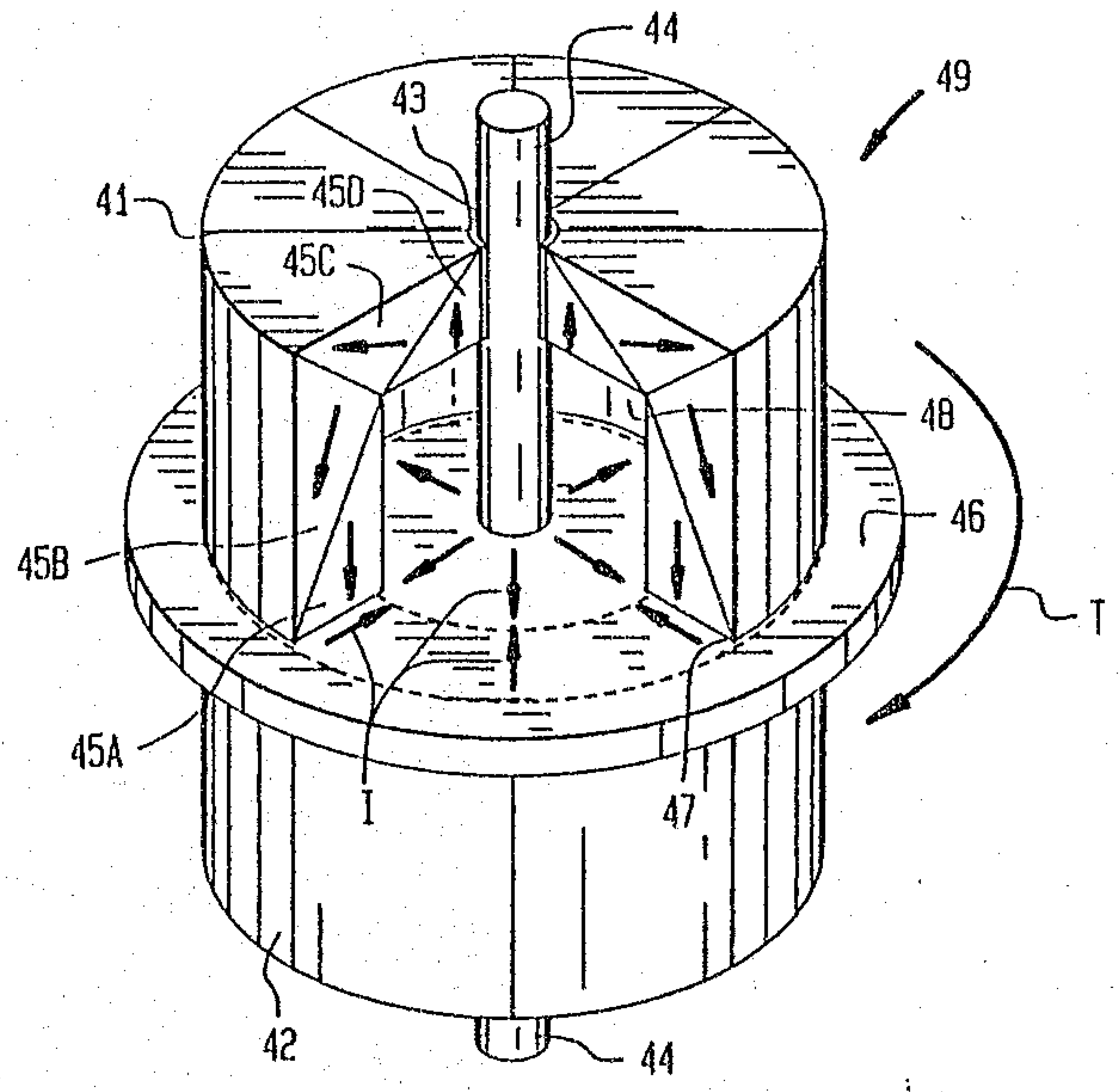


FIG. 7

K. P. Aspila
Patent Agent for Applicant

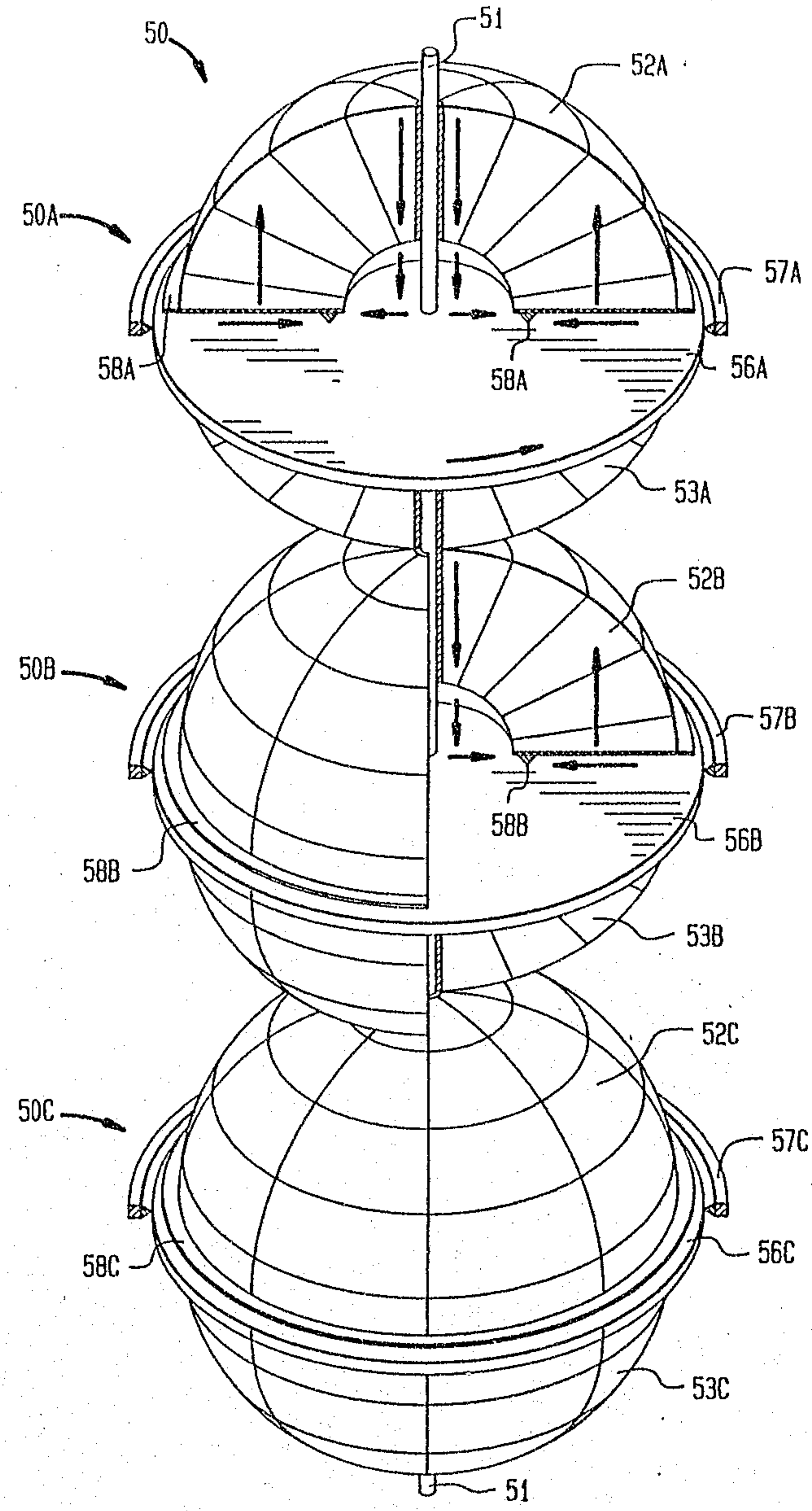


FIG. 8

K. P. Aspila
Patent Agent for Applicant

2059579

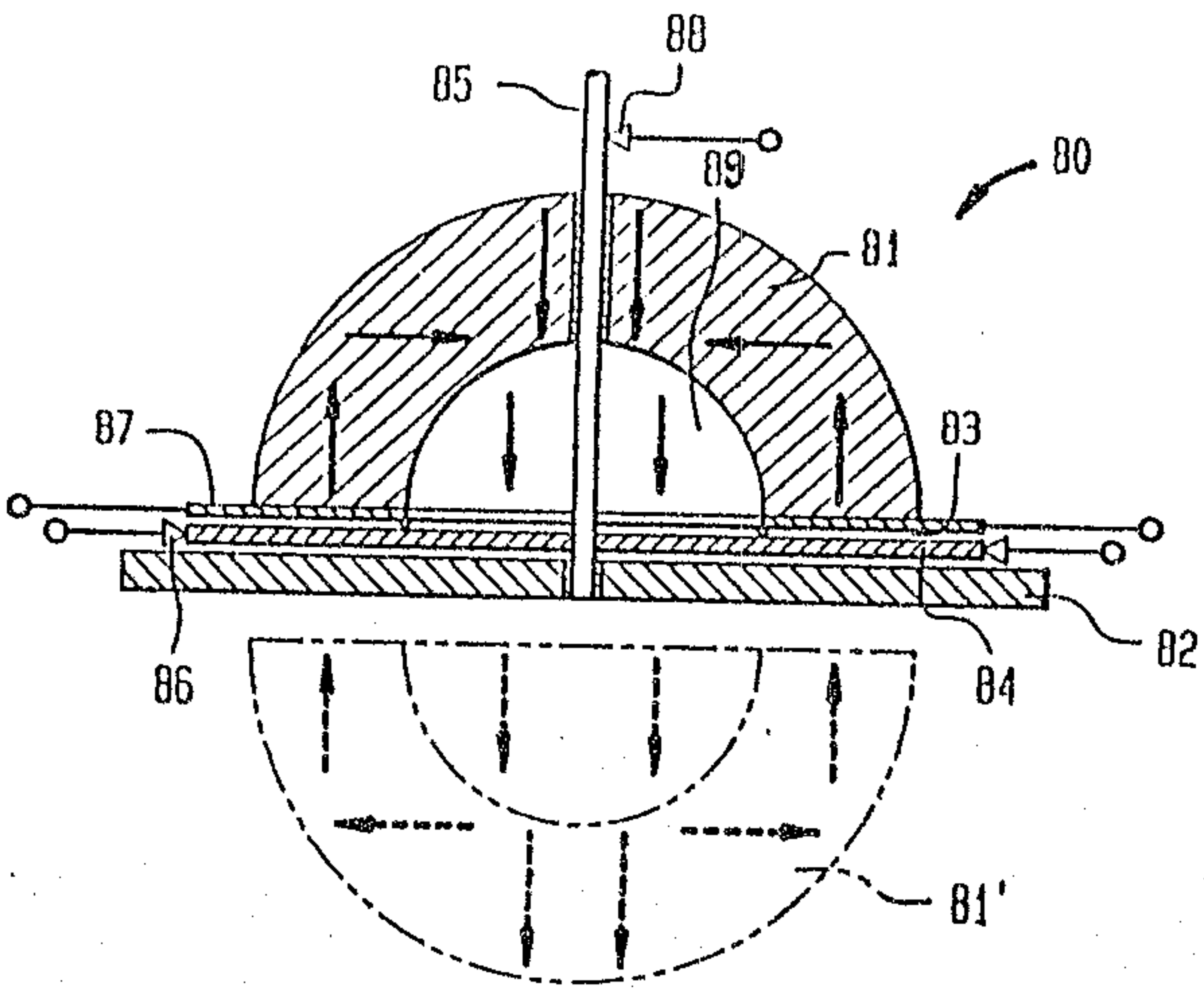


FIG. 9

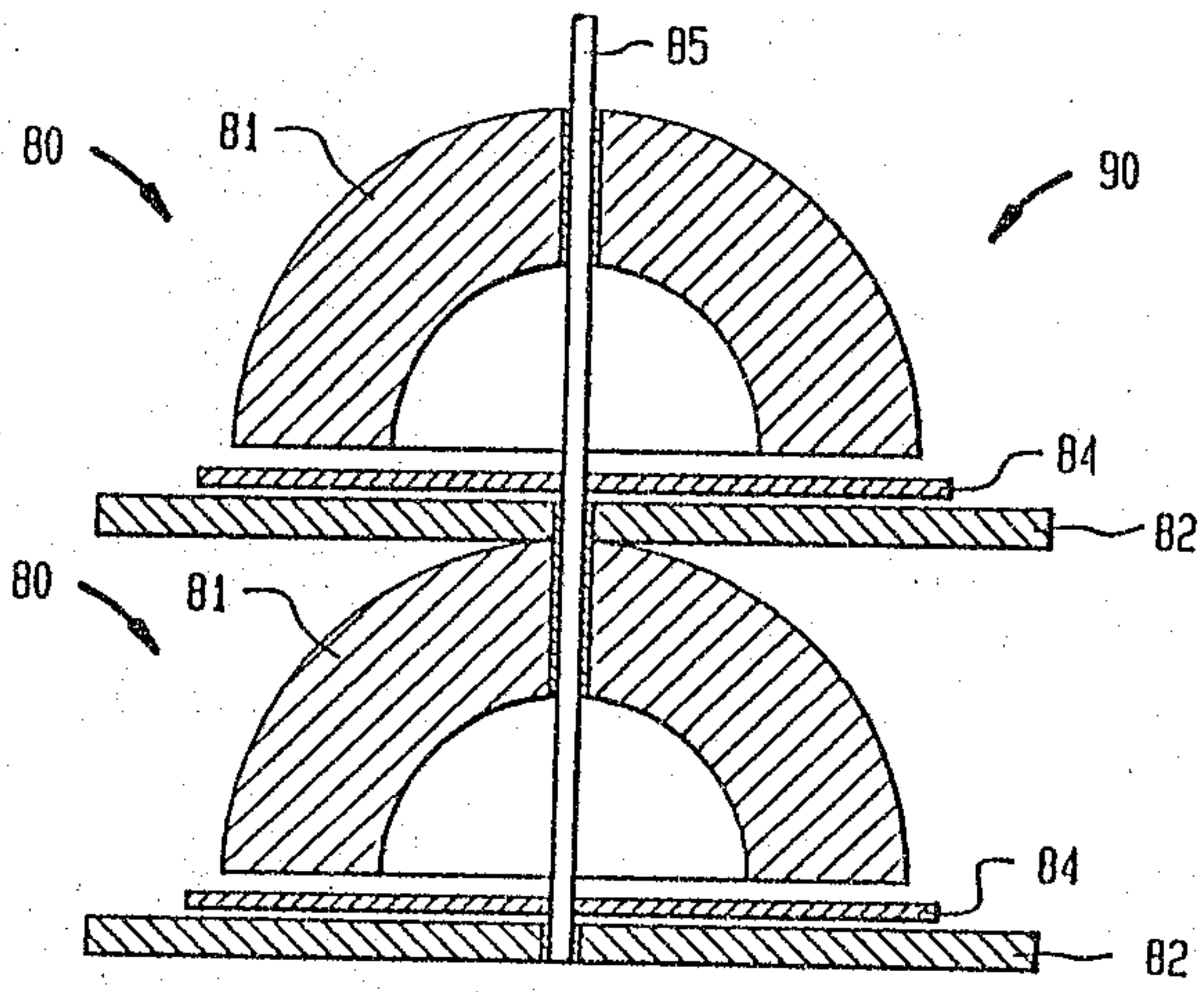


FIG. 10

K. P. Aspila
Patent Agent for Applicant

2059579

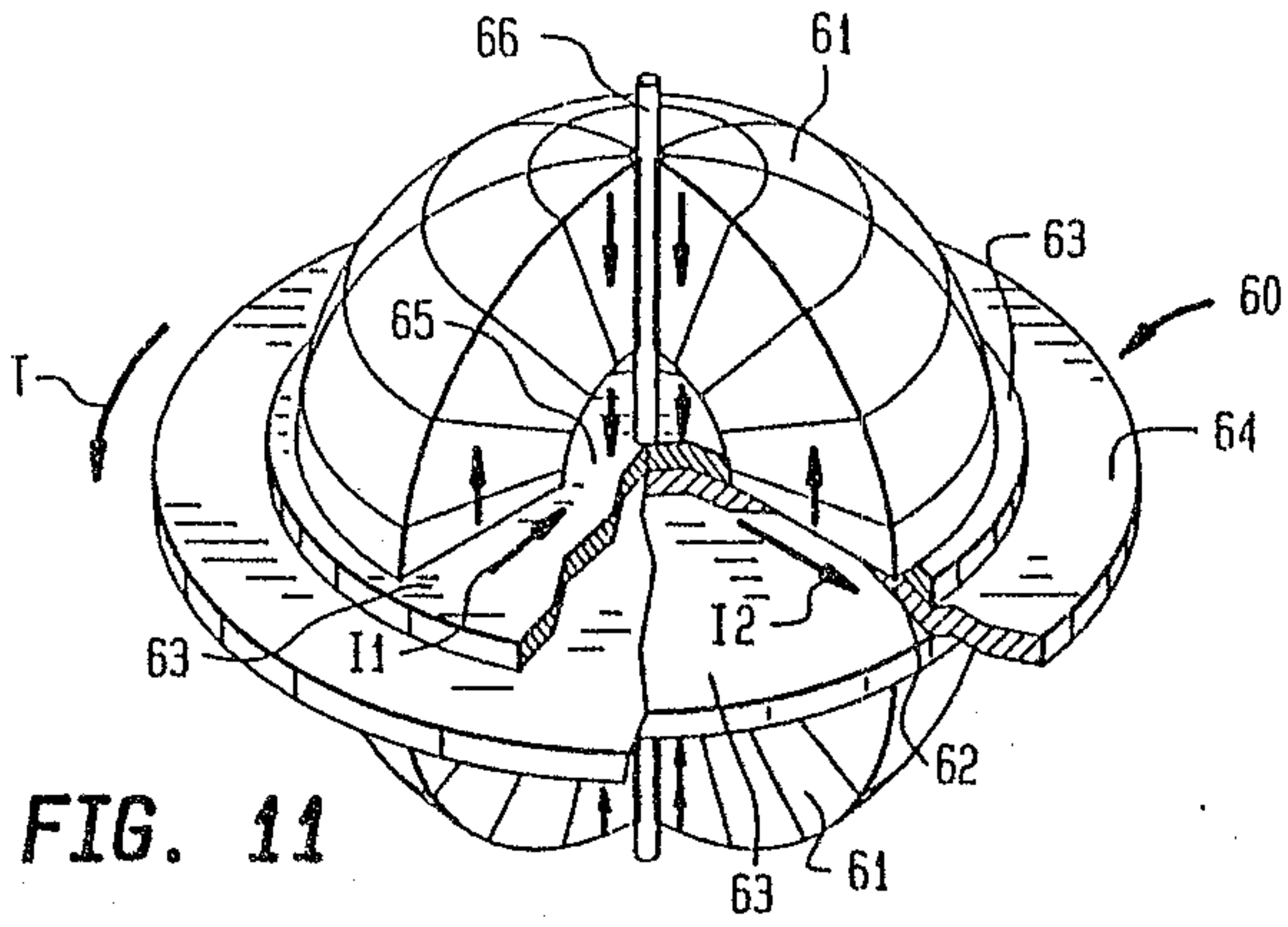


FIG. 11

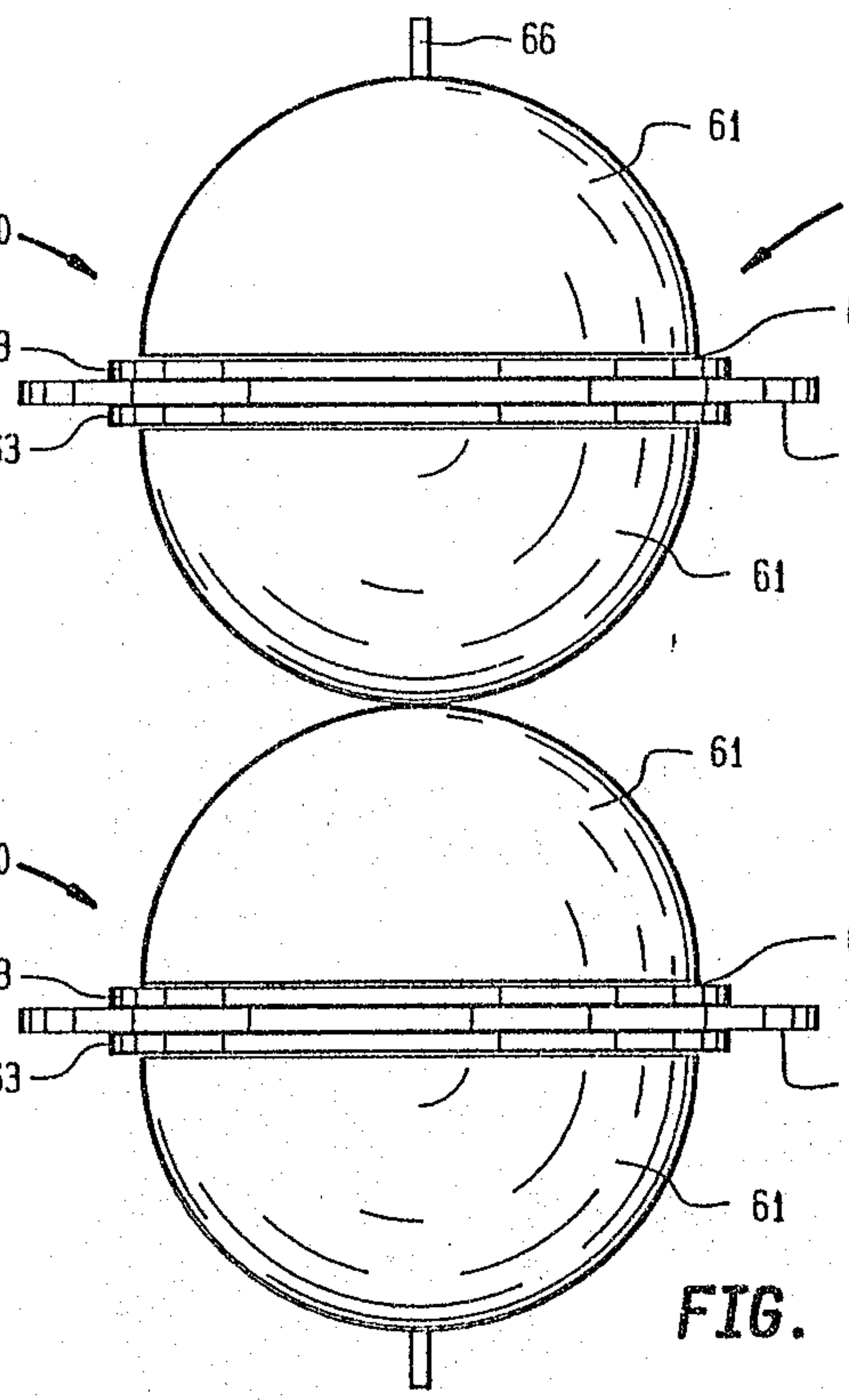


FIG. 12

R. P. Aspila
Patent Agent for Applicant

2059579

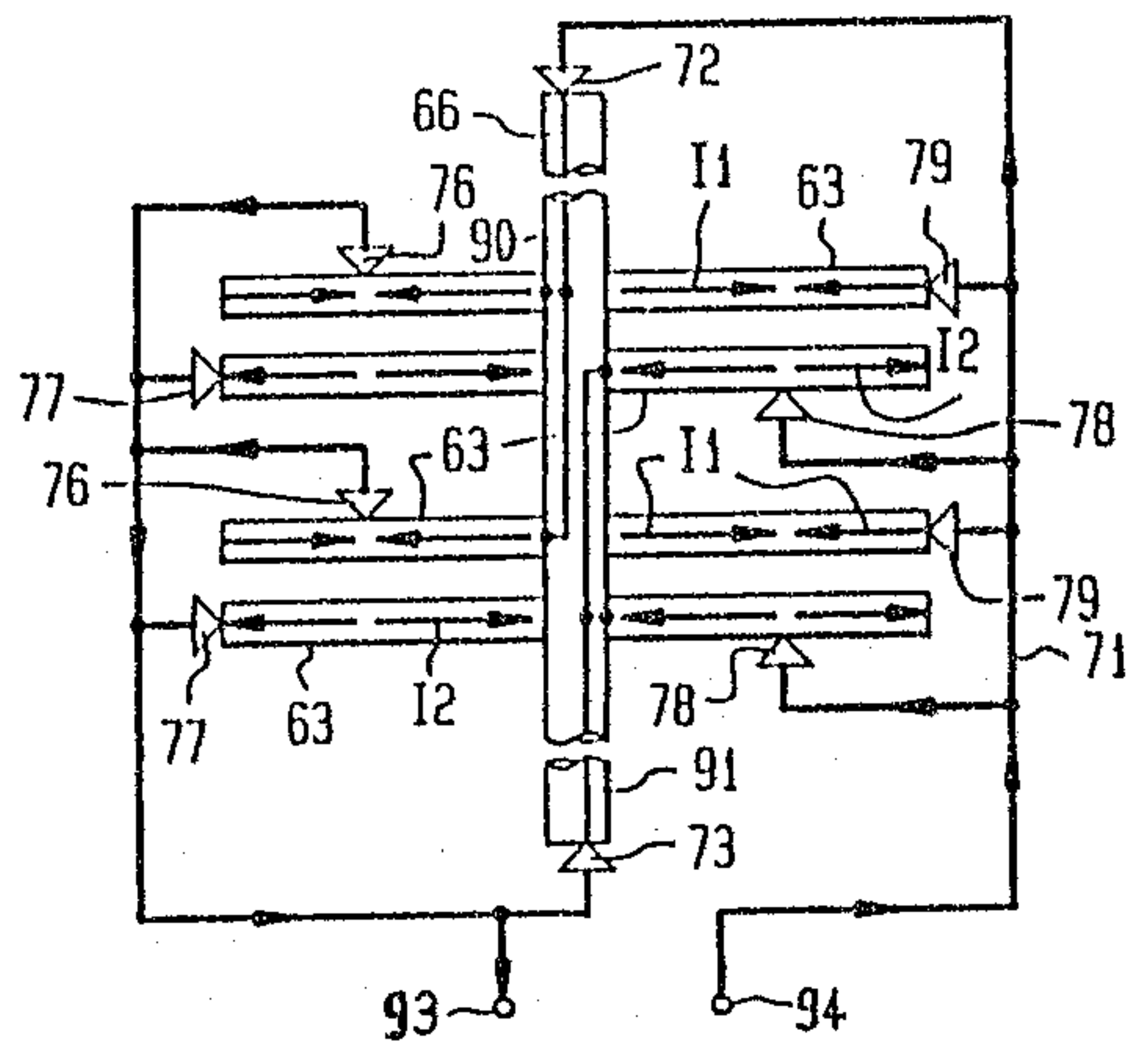


FIG. 13

K.P. Aspila
Patent Agent for Applicant