PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 3 : H02K 31/00, 39/00

A1

(11) International Publication Number: WO 82/ 02126

(43) International Publication Date: 24 June 1982 (24.06.82)

(21) International Application Number: PCT/US81/01588

(22) International Filing Date: 1 December 1981 (01.12.81)

(31) Priority Application Number: 215,463

(32) Priority Date: 11 December 1980 (11.12.80)

(33) Priority Country: US

(71) Applicant: THE ACME ENERGY COMPANY [US/US]; 25 Mitchell Boulevard, San Rafael, CA 94903 (US).

(72) Inventors: TROMBLY, Adam, Douglass ; KAHN, Joseph, Mardell ; 25 Mitchell Boulevard, San Rafael, CA 94903 (US).

(74) Agent: SLONE, David, N.; Townsend and Townsend, One Market Plaza, Steuart Street Tower, San Francisco, CA 94105 (US).

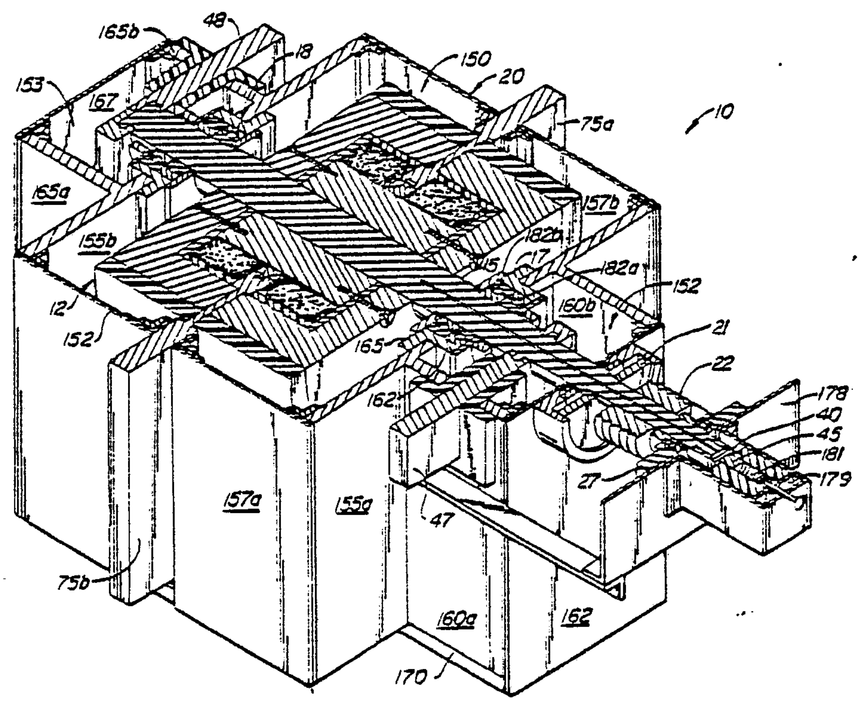
(81) Designated States: AT (European patent), AU, BR, CH (European patent), DE, DE (European patent), DK, FI, FR (European patent), GB, GB (European patent), JP, NL (European patent), NO, SE (European patent), SU.

Published
With international search report.

(54) Title: CLOSED PATH HOMOPOLAR MACHINE

(57) Abstract

A co-rotating homopolar generator has a rotor (12) comprising a disk conductor (30) and co-rotating coaxial electromagnets (32a and 32b) on either side, and achieves improved operation by utilizing a low reluctance magnetic return path for the magnetic flux that passes through the disk conductor (30). The low reluctance path permits the electromagnets (32a and 32b) to produce a high field with a relatively low value of coil excitation current. Thus overheating is avoided and the full potential of the homopolar generator is achieved. The low reluctance magnetic return path (220) is peferably provided by a relatively high permeablity co-rotating enclosure (having enclosure halves 37a and 37b) of sufficient radial and axial dimensions to enclose the electromagnets and disk conductor of the rotor. The disk conductor (30) is preferably constructed from a high permeability, low resistivity material such as iron, and can indeed be integral with the electromagnet cores (35a and 35b).



CLOSED PATH HOMOPOLAR MACHINE

FIELD OF THE INVENTION

The present invention relates generally to electric generation, and more particularly to a homopolar machine having a high efficiency.

BACKGROUND OF THE INVENTION

Electrical generation typically involves the conversion of mechanical work to electrical energy. In these energy conscious times, it is most important to achieve as high a conversion efficiency as possible.

It is well known that if a conducting disk is rotated about its axis in the field of a fixed magnet such that the magnetic flux lines intersect the plane of the disk, a voltage is induced between radially distinct portions of the disk. Such a device is known as a homopolar generator. Although less well known, it is also known that if the magnet is fastened to the disk, and the whole assembly co-rotated, a voltage is also induced between radially distinct portions of the disk. M. J. Crooks et al., in a recent article in the American Journal of Physics, No. 46(7), pp. 729-731 (1978), note with amusement that while the co-rotating type of homopolar generator seemed to the authors to be a brilliant new invention, it was "belatedly discovered that Faraday got there first." According to the published results of an experiment performed by Michael Faraday in 1832, "a copper disk was cemented upon the end of a cylinder magnet, with paper intervening; the magnet and disk were rotated together, and collectors (attached to the galvanometer) brought in contact with the circumference and the central part of the copper plate. The galvanometer needle moved as in former cases, and the direction of motion was the same as that which would have resulted, if the copper only had revolved, and the magnet had been fixed. Neither was there any apparent difference in the quantity of deflection. Hence, rotating the magnet causes no difference in the results; for a rotatory and a stationary magnet produces the same effect upon the moving copper."

Bruce E. DePalma, in an article in Energy Unlimited, The New Age Science Magazine, No. 5, pp. 16-23 (1980), makes the further statement that unlike a conventional generator which resists rotation when current is drawn, a homopolar generator having the magnet and disk conductor rigidly coupled to one another operates in a manner free of such rotational drag. More particularly, it is suggested that due to the fact that the torque is absorbed in the assembly, conversion efficiency beyond that normally achievable should be possible. To date, there have been attempts to build co-rotating homopolar generators, but the devices appear to have been troubled by overheating and other engineering difficulties that have tended to mask the potentially high efficiency.

SUMMARY OF THE INVENTION

The present invention provides a co-rotating homopolar generator that avoids the heating problems of prior machines and renders possible and convenient the generation of electricity at extremely high efficiency. The generator has a rotor comprising a disk conductor and co-rotating coaxial electromagnets on either side. The present invention achieves the improved operation by providing a low reluctance magnetic return path for the magnetic flux that passes through the disk conductor.

The low reluctance path permits the electromagnets to produce a high field (limited to 2.2 tesla by the saturation of iron) with a relatively low value of coil excitation current. Thus overheating is avoided and the full potential of the homopolar generator is achieved.

In the preferred embodiment, the low reluctance magnetic return path is provided by a relatively high permeability co-rotating enclosure (designated a "flux return enclosure") of sufficient radial and axial dimensions to enclose the magnets and disk conductor of the rotor. Additionally, the disk conductor itself is preferably constructed from a high permeability, low resistivity material such as iron, and can indeed be integral with the electromagnet cores.

Output power is drawn between the periphery of the disk conductor (within the flux return enclosure) and the rotor shaft through fixed disk and shaft brushes. The disk brush protrudes through an annular slot in the flux return enclosure, and is geometrically configured so as not to add a large amount of reluctance to the flux return path. To this end, the disk brush is formed with a relatively thin web portion that passes through the enclosure gap. The web portion still has sufficient thickness so that the mechanical strength of the brush is not compromised. Moreover, the web portion has sufficient thickness, and hence conductance, that the saving in magnet power is not offset by excessive ohmic heating in the web portion.

For a further understanding of the nature and advantages of the present invention, reference should be made to the remaining portions of the specification and to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectioned isometric view of a homopolar machine according to the present invention;

Fig. 2 is an electrical/mechanical schematic view of the homopolar generator;

Fig. 3 is a sectioned oblique view of the rotor and shaft;

Fig. 4A is an isometric view showing the construction of the disk brush;

Fig. 4B is a fragmentary enlarged view showing a portion of the disk brush;

Figs. 5A and 5B are exploded isometric views of the shaft brushes;

Fig. 5C is an isometric view of a shaft brush support;

Fig. 6 is a sectioned isometric view of the magnet brush;

Fig. 7 is a sectioned oblique side view showing the brushes, bearings, and casing, with the rotor shown in phantom; and

Fig. 8 is a sectioned isometric view of the shaft end seal.

DETAILED DESCRIPTION OF THE DRAWINGS

Overview

Fig. 1 is a sectioned isometric view showing a homopolar generator 10 according to the present invention. Fig. 2 is an electrical and mechanical schematic of the generator system incorporating generator 10. Generator 10 comprises a rotor 12 mounted to a shaft 15 journalled in bearing assemblies 17 and 18 for rotation within a casing 20. The casing maintains rotor 12 within a controlled atmosphere (slightly pressurized nitrogen). One end of shaft 15 protrudes outside casing 20 through a shaft seal assembly 21 and is provided a drive sheave 22 to communicate mechanical energy from a drive motor 25 of any conventional desired type. A shaft end bearing 27 takes up radial loading on drive sheave 22 due to the coupling with motor 25.

Broadly, rotor 12 comprises a central disk conductor portion 30, flanking electromagnet coils 32a and 32b with respective associated iron core portions 35a and 35b, and a flux return enclosure having enclosure halves 37a and 37b. When high currents are involved, the disk may more closely resemble a cylinder. However, the term "disk" will still be used for the conductor that corresponds to the disk of Faraday's experimental device. Electromagnet coils 32a and 32b are series connected between shaft 15 and an electrically isolated shaft portion 40. Excitation current is provided by a magnet excitation power supply 42 which is coupled between a magnet brush 45 which rubs on electrically isolated shaft portion 40, and a pair of parallel connected shaft brushes 47 and 48. An outer portion of disk conductor 35 engages a disk brush 50 and output power is drawn between disk brush 50 and shaft brushes 47 and 48. As will be described more fully below, generator 10 has the capability of operating at extremely high efficiency.

Rotor and Shaft

Referring to the sectioned oblique view of Fig. 3, the detailed construction of rotor 12 and shaft 15 may be seen. While there is no particular significance to absolute dimensions, the description that follows will be in terms of an illustrative generator whose rotor has an outer diameter of 14.0 inches and an axial length of 9.25 inches, with the rotor being carried on a shaft of diameter 2.0 inches. Where practical, suitable proportions will be maintained in isometric and oblique views so that other dimensions may be ascertained from the drawings. Disk conductor portion 30 and electromagnet core portions 35a and 35b are constructed of high permeability, low resistivity material such as iron, and may be integrally formed as a single iron rotor core, designated 55. Rotor core 55 is brazed to shaft 15 which is preferably made of a copper-beryllium alloy. A suitable shaft material may be obtained from Brush Wellman Company under the name Brush 3 Alloy. This is an alloy characterized by a high electrical conductivity (50% of copper standard) and a high modulus of elasticity. A circumferentially extending copper contact 57 is brazed to the outer surface of rotor core 55 at the axial midpoint thereof and contacts disk brush as will be described below.

Electromagnet coils 32a and 32b are wound with epoxy-impregnated wire which may be No. 12 size in the illustrative embodiment. Iron annuli 60a and 60b are bolted to opposite ends of rotor core 55 to define therewith a spool which axially confines the coils. The series connection between isolated shaft portion 40 and shaft 15 is defined by first, second, and third magnet conductors 62, 63, and 64.

First magnet conductor 62 runs from shaft portion 40 along the axis of shaft 15, and then radially outward to coil 32b. Second magnet conductor 63 runs between coils 32a and 32b, passing through brush contact 57. Third magnet conductor passes radially outward from coil 32a to shaft 15. Electromagnet coils 32a and 32b are provided with respective high tensile strength wrappings 65a and 65b, preferably fiberglass-epoxy tape, to prevent centrifugal destruction of the coils.

The flux return enclosure provides a low reluctance magnetic path for the magnetic flux lines passing through rotor core 55 and should therefore be made of relatively high permeability material. For example, enclosure halves 37a and 37b may be constructed of medium-high permeability, high tensile strength, forged silicon steel. Enclosure halves 37a and 37b are bolted to rotor core 55, and together define a cylindrical enclosure within which are located electromagnet coils 32a and 32b, rotor core 55, copper brush contact 57, and magnet coil wrappings 65a and 65b. Facing portions of enclosure halves 37a and 37b are spaced apart to define a circumferentially extending slot 66 that permits disk brush 50 to engage copper contact 57. Slot 66 is approximately 9/32-inch thick in the region between enclosure halves 37a and 37b, but broadens to approximately 1.0 inch thick in the region between electromagnet coils 32a and 32b. Enclosure halves 37a and 37b are provided with respective high tensile strength wrappings 67a and 67b.

As stated above, shaft 15 is characterized by a 2-inch diameter in the rotor region. Axially away from rotor 12, shaft 15 is of lesser diameter, being reduced to 45 millimeters in the region of bearing assemblies 16 and 17. Proceeding axially away from rotor 12 in a first direction toward isolated shaft portion 40, shaft 15 is formed with radially relieved portions 68 and 69 to define therebetween a first annular collar 70 for engagement with shaft brush 47. Proceeding axially in the other direction, shaft 15 is formed with an annular groove 71 spaced from the shaft end to define a second annular collar 72 for engagement with shaft brush 48.

Brushes

Fig. 4A is an isometric view showing the construction of disk brush 50. Disk brush 50 comprises symmetrical halves 75a and 75b which, when bolted together in coplanar relationship, completely encircle rotor 12. Disk brush half 75b is shown only in phantom. Since disk brush halves 75a and 75b are similarly constructed, brush half 75a only will be described. Brush half 75a is in the form of a 1-inch thick rigid copper plate with a semicircular opening 77 along an edge thereof, opening 77 being adapted to cooperate with a similar opening in brush half 75b to form a circular aperture. A semi-annular web portion 80 of reduced thickness surrounds opening 77 in a spaced concentric relation thereto, and defines an inner brush portion 82 between opening 77 and web portion 80. Web portion 80 is approximately 1/4-inch thick while inner brush portion 82 is approximately 13/16-inch thick. Web portion 80 has a radial extent that is only slightly greater than the radial extent of the facing portions of flux return enclosure halves 37a and 37b and their associated wrappings 72a and 72b. At the same time, web portion 80 is sized to fit within slot 66 of rotor 12 with a small clearance (for example 1/64th inch on either side). Inner brush portion 82 is sized to fit within the broadened slot portion between electromagnet colis 32a and 32b, and engages brush contact 57. Axial clearances are somewhat broader than those surrounding web portion 80. A clearance of 3/32-inch on either side is suitable.

The outside dimensions of disk brush halves 75a and 75b are not critical, nor are the particular outside configurations. However, it is important that the brush halves have portions that extend sufficiently beyond the outside surface of rotor 12 to permit proper mechnical support with respect to casing 20. A height of 18 inches and a width of 10.5 inches (total brush width of 21 inches) is suitable.

As will be described below, generator 10 is operated under conditions of very high current so that brush resistance must be minimized. This is accomplished by wetting the brush contact areas with liquid metal, and providing a structure to hold the liquid metal in place. To this end, inner brush portion 82 carries a fixed contact assembly 85, which may be seen with reference to the fragmentary oblique sectional view of Fig. 4B. More particularly, inner brush portion is formed with an inwardly opening recess 87 which broadens beneath the surface to define opposing lips 90 and 91 spaced to receive copper contact 57 therebetween. Lips 90 and 91 confine fixed contact assembly 85 which comprises a strip of ground braid material 92 (1/2-inch x 1/16-inch cross-section is suitable) and a copper strap 95 that is crimped around it to provide structural integrity. Strap 95 surrounds ground braid strip 92 to the same extent as lips 90 and 91, so that the inwardly facing portion between the lips is exposed ground braid material which engages contact 57. In use, ground braid strip 92 is wetted with a liquid metal such as a sodium/potassium eutectic (NaK-78). Operation is optimum with a small and precisely controlled clearance (e.g., 0.002 inches) between braid strip 92 and contact 57. This may be achieved by a break-in run that is carried out prior to wetting braid strip 92 with the liquid metal. The purpose of braid strip 92 is to hold the liquid metal in place and to alter its velocity characteristics so that it does not experience dynamic turbulent flow phenomena or migrate away from the surface of brush contact 57. While the use of ground braid material is a useful expedient, fixed contact assembly may utilize any construction that provides a finely convoluted surface. For example, screen material could be used.

Figs. 5A and 5B are exploded isometric views of shaft brushes 47 and 48. Turning first to Fig. 5A, shaft brush 47 is of two-piece construction including an elongated rectangular bar member 100 (1-inch x 4-inch cross-section) and an abutting short member 102, members 100 and 102 having respective semicircular openings 105 and 107 along facing, abutting edges thereof. Thus, when brush members 100 and 102 are bolted together, as for example by bolts 110, they define a circular bore of a diameter corresponding to that of radially relieved shaft portions 68 and 69. The surface of the circular bore is recessed and houses a contact assembly 112 (which may comprise eutectic wetted braid) in the same manner as inner brush portion 82 houses contact assembly 85. If braid material is used, a 3/4-inch x 1/16-inch cross-section is suitable. Contact assembly 112 engages annular collar 70 to conduct current between shaft 15 and shaft brush 47. The outside dimensions of brush members 100 and 102 are not critical, but brush member 100 is preferably of sufficient length to extend outside casing 20.

Turning next to Fig. 5B, shaft brush 48 includes cooperating brush members 120 and 125 which are generally the same as brush members 100 and 105 with the exception that the semicircular bores do not extend all the way through, but rather terminate within the brush members. A contact assembly 127 engages annular collar 72.

Fig. 5C is an isometric view of one of two identical support elements 130 for shaft brushes 47 and 48. Support element 130 is formed of insulative material and provides an electrically insulated mounting of the shaft brushes to housing 20. Support element 130 includes a rectangular channel section 131 for receiving and supporting a respective shaft brush and a flange section 132 for mounting to housing 20.

Fig. 6 is an isometric sectional view illustrating the construction of isolated shaft portion 40 and magnet brush 45. Magnet brush 45 is a cylindrical element of sintered copper-graphite or equivalent material. As described above, conductor 62 runs in an axial bore along shaft 15. The end of shaft 15 is formed with a cylindrical recess into which is epoxied an undersized metal cylinder 135 which is bored to receive an uninsulated end of magnet conductor 62. Isolated shaft portion 40 is a circular plate of the same diameter as the adjacent portion of shaft 15, and is soldered to cylinder 135 to form a mechanical and electrical coupling thereto.

Housing

Fig. 7 is a side oblique view, sectioned vertically along the axis of rotor 12, with the shaft and rotor shown only in phantom. Figs. 1 and 7, taken together, show the construction of housing 20, bearing assemblies 17 and 18, and the mechanical support of the disk, shaft, and magnet brushes. Housing 20 comprises a central rotor chamber 150 and axially outboard shaft brush chambers 152 and 153. Rotor chamber 150 includes a pair of end walls 155a and 155b, and a pair of side panels 157a and 157b. Shaft brush chamber 152 includes a pair of side walls 160a and 160b, and an end panel 162, while shaft brush chamber 153 includes a pair of side walls 165a and 165b, and an end panel 167. Housing 20 further comprises a floor 170 and a roof 172. End walls 155a and 155b, side walls 160a and 160b, side walls 165a and 165b, and floor 170 are preferably 1/2-inch stainless steel plate and are welded together to provide a rigid load-bearing assembly. Side panels 157a and 157b, end panels 162 and 167, and roof 172 are of lighter material such as 1/8-inch stainless steel, and are bolted in place so as to be removable. Bolted connections are gasketed, using, for example, 1/8-inch thick cloth-impregnated butyl rubber gasketing material, chosen for its minimal outgassing characteristics. Disk brush halves 75a and 75b are supported between a lower brush support channel 175 and an upper brush support channel 177, both of which are fabricated from a fiber reinforced thermosetting plastic material. Lower brush support channel 175 sits on floor 170 while upper brush support channel 177 is bolted to appropriate structural angle members, not shown. Shaft end bearing 27 is mounted to a housing extension 178 which carries a magnet brush support bracket 179. Magnet brush 45 is held in a cylindrical bore within an insulating brush support block 180, and is kept in contact with isolated shaft portion 40 by a spring 181.

Bearing assemblies 17 and 18 are mounted into, and supported by respective end walls 155a and 155b. Since the bearing assemblies are generally identical, only one will be described. Bearing assembly 17 includes a lightly preloaded duplex pair of angular contact ball bearings 180a and 180b mounted within a rectangular housing 183 having a mounting flange 185 on three sides thereof. Suitable bearings may be obtained from Fafnir Company under the designation 2MM209 WI CR DUL. These are very high precision grade (ABEC-7) bearings characterized by a 1.7717-inch bore, a 3.3465-inch outer diameter, and a 1.4960-inch width. These bearings are able to run at 8,000 r.p.m. in grease under the loading imposed by rotor 12 and shaft 15. The bearings are held in place by opposed retaining plates 187a and 187b and a retaining collar 190. Shaft end bearing 27 may be a pre-housed two-bolt flanged unit such as that obtainable from SKF under the designation FYTP-100. This is a bearing having a 1.0000 inch bore and capable of operation at 8700 r.p.m. in grease. Such a bearing has labyrinth seals which do not actually touch, thus avoiding problems of excessive wear and heating at high speeds.

Fig. 8 is a partially cut away isometric view showing the details of shaft seal assembly 21 which maintains a seal during operation when casing 20 is filled with slightly pressurized nitrogen. Shaft seal assembly 21 comprises an elastomeric seal 195 held in place within a shaft seal housing 196 by a retaining plate 197. A suitable elastomeric seal may be obtained from Johns-Manville Company under the designation 10058LUP, which signifies a seal fabricated from buna-N material and characterized by a 2.0000-inch outer diameter, a 1.2500-inch bore, and a 0.3750-inch width. At the high angular velocity of operation, the elastomeric seal would rapidly wear away portions of the beryllium-copper material of shaft 15. Accordingly, shaft 15 is provided with a stainless sleeve 198, such as that obtainable from Chicago Rawhide under the designation 99125 Speedi-Sleeve. This is a sleeve characterized by 1.250-inch bore, and a 0.010-inch wall thickness with a special outer finish designed expressly for efficient sealing action.

However, in order to fill housing 20 with pressurized nitrogen, the housing must first be evacuated and purged. Elastomeric seal 195 is incapable of maintaining a vacuum, so an O-ring sealing mechanism utilizing an axially movable gland 202 is provided. Moving gland 202, shown in its sealing position, has a frustoconical bore 205 adapted to engage a corresponding frustoconical portion 207 of shaft 15 (also see Fig. 3). Movable gland 202 is grooved within its frustoconical bore to carry a first O-ring 210 for sealing to shaft 15, and is grooved on its face to carry a second O-ring 212 for sealing to shaft seal housing 197. After housing 20 is filled with nitrogen, gland 202 is moved away from shaft seal housing 197 so that O-ring 210 does not engage the shaft during operation.

Operation

Having described the structure of the present invention, suitable operating parameters may be set forth by way of example. By way of background, for a machine of the type described, it is readily shown that the voltage, V, generated between the shaft and the outer circumference of the rotor core is given by the following equation:

$$V = \frac{B \omega (r_2^2 - r_1^2)}{2} \quad \text{(in mks units)}$$

where B is the magnetic field strength, ω is the angular velocity of the rotor, r_2 is the rotor core radius, and r_1 is the shaft radius. For rotation at 7200 r.p.m. (754 radians per second), a 1-inch radius shaft, a 3-inch radius rotor core, and a magnetic field of 1.5 tesla, the voltage may be shown to be equal to approximately 2.9 volts. In order to render the pattern of output current relatively symmetrical within the device, it is preferred to couple the load to both disk brush halves and both shaft brushes. If two similar loads are used, one may be coupled between disk brush half 75a and shaft brush 48 (which protrude through the casing on the same side) and the other between disk brush half 75b and shaft brush 47.

Due to the brush design, the total internal resistance of the generator is in the neighborhood of 6-10 micro-ohms. Assuming that the machine is capable of dissipating no more than 2.25 kilowatts of internal heating, the maximum test load current is about 15 kiloamperes. At this current, the power output is 43.7 kilowatts. However, the anticipated load current permissible for continuous operation may be more realistically in the neighborhood of as low as 8 kiloamperes, which corresponds to a power output of 23.3 kilowatts. As stated above, motor 25 may be any suitable prime mover, and for the operating conditions described herein, should be capable of developing approximately 15 horsepower.

In view of of the present invention and the operation of generator 10, the advantages of the configuration of rotor 12 may be understood. In particular, it will be noted that enclosure halves 37a and 37b cooperate with rotor core 55 to provide a low reluctance magnetic circuit. That is, energization of coils 32a and 32b causes magnet flux lines, denoted schematically by loops 220 in Fig. 3, that are contained within a low reluctance magnet circuit comprising a substantially closed path of high permeability material. The only high reluctance portion is slot 66 which is kept as narrow as possible consistent with web portion 80 of brush halves 75a and 75b having sufficient mechanical strength and electrical conductance. With this configuration, a total excitation input power of approximately 150 watts is sufficient to produce a 1.5 tesla field in portion 30 of rotor core 55. The excessive consumption of power in producing a high magnetic field level is eliminated, making possible sustained operation at high levels of magnetic induction (and therefore of output voltage).

In summary, it can be seen that a generator according to the present invention is characterized by high efficiency and low magnet power requirements, achieved by the use of a rotor configuration having a low reluctance path. While the above provides a full and complete disclosure of the preferred embodiments of the invention, various modifications, alternate constructions, and equivalents may be employed without departing from the true spirit and scope of the invention. For example, housing 20 could be constructed with a cylindrical configuration to minimize the internal volume. Moreover, while a brush geometry that encircles the rotor and shaft is desirable, other configurations could be used. Therefore, the above description and illustration should not be construed as limiting the scope of the invention which is defined by the appended claims.

IN THE CLAIMS:

1. In a homopolar machine having a disk conductor mounted coaxially to a shaft, magnetic means mounted to said shaft for rotation with said disk conductor for inducing a generally axially directed magnetic field in said disk conductor, and first and second fixed brush means coupled to said disk conductor at radially outer and inner locations, respectively, the improvement comprising return means defining a low reluctance magnetic return path for magnetic flux induced by said magnetic means.

2. The invention of claim 1 wherein said magnetic means comprises at least one electromagnetic coil and an associated core, and wherein said return means comprises a relatively low reluctance enclosure mounted to said shaft for rotation therewith and extending radially outward of said electromagnetic coil and covering substantially the entire axial extent of said coil, said core, and said disk conductor.

3. The invention of claim 2 wherein said enclosure is provided with a narrow annular opening to allow said first fixed brush means to pass therethrough.

4. The invention of claim 3 wherein said first fixed brush means is formed with a thin web portion in the portion of said first fixed brush means that passes through said opening.

5. The invention of claim 2 wherein said disk conductor is fabricated from a relatively high permeability material.

6. The invention of claim 5 wherein said disk conductor and said core are of integral construction.

7. The invention of claim 1 wherein said first fixed brush means comprises a highly conductive brush member extending circumferentially around said disk conductor and a finely convoluted conductive member held by said highly conductive brush member, said finely convoluted member being wetted with liquid eutectic alloy, and wherein said disk conductor carries a copper contact member for engaging said eutectic wetted finely convoluted member.

8. The invention of claim 1 wherein said disk conductor is electrically coupled to said shaft, and wherein said second fixed brush means engages said shaft directly.

9. A homopolar generator comprising:

a shaft;

a coaxial disk conductor mounted to said shaft, said disk conductor being fabricated from a relatively high permeability material;

first and second electromagnets flanking said central conductor, each said electromagnet including a respective coaxial relatively low reluctance core and a coil;

a fixed disk brush surrounding said disk conductor and engaging the periphery thereof;

a shaft brush surrounding a portion of said shaft for engagement therewith; and

a relatively low reluctance flux return enclosure mounted to said shaft and surrounding said electromagnets and said disk conductor, said enclosure having a narrow annular opening to accommodate said disk brush;

said disk conductor, said cores of said first and second electromagnets, and said flux return enclosure defining a low reluctance magnetic path for magnetic flux, thus permitting a high magnetic field to be induced through said disk conductor with a relatively low level of power required for said coils of said first and second electromagnets.

10. The invention of claim 9 wherein said disk brush is formed with a thin web portion in the portion of said disk brush that passes through said opening.

11. The invention of claim 9 wherein said disk conductor and said cores of said first and second electromagnets are of integral construction.

12. The invention of claim 9 wherein said disk brush comprises a highly conductive brush member extending circumferentially around said disk conductor and a finely convoluted conductive member held by said highly conductive brush member, said finely convoluted member being wetted with liquid eutectic alloy, and wherein said disk conductor carries a copper contact member for engaging said eutectic wetted finely convoluted member.

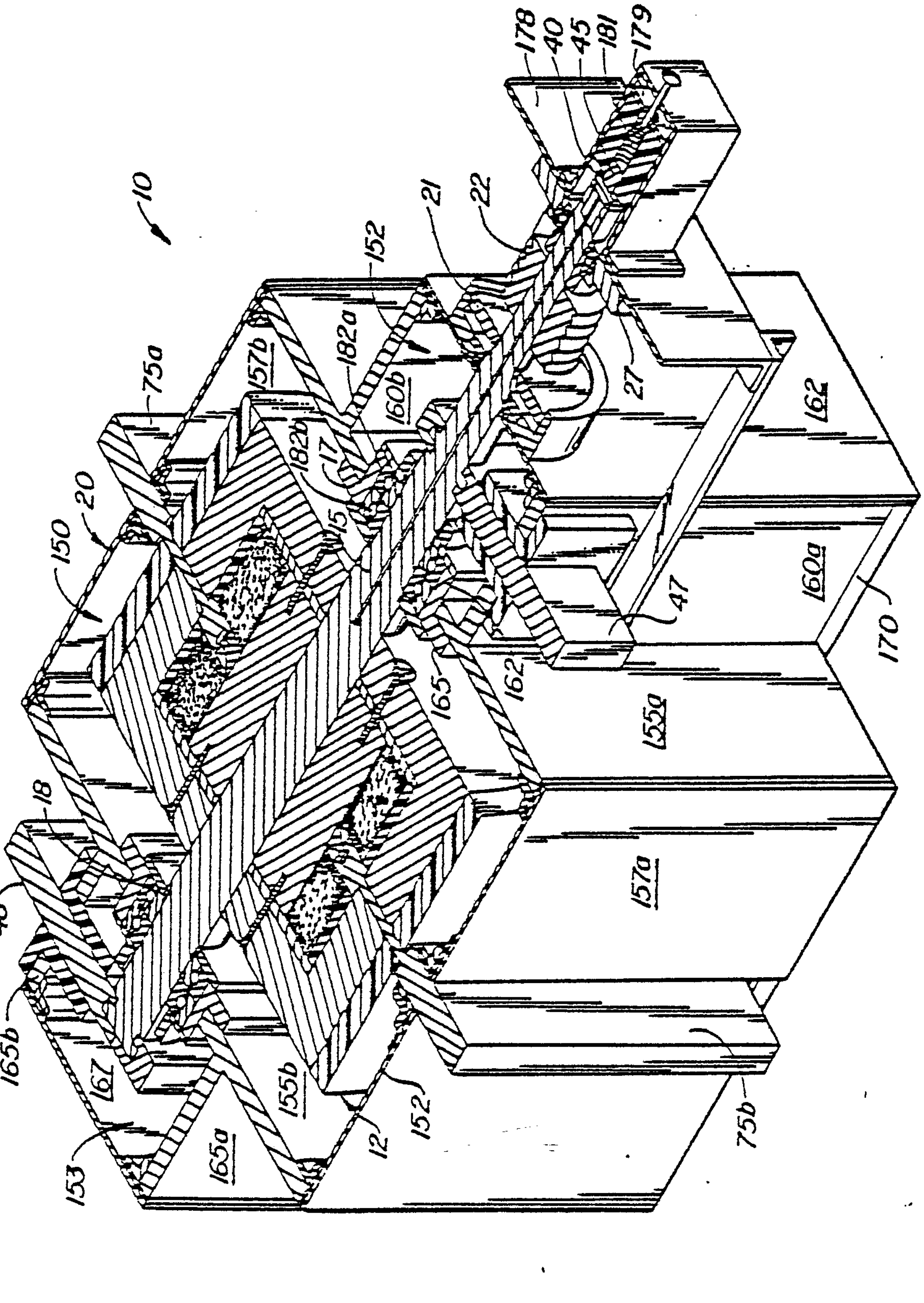

10
178
40
45
181
179
21
22
152
75a
157b
182a
160b
27
162
150
20
182b
17
15
160a
47
170
165
162
155a
18
48
157a
165b
167
155b
153
165a
12
152
75b

FIG._1.

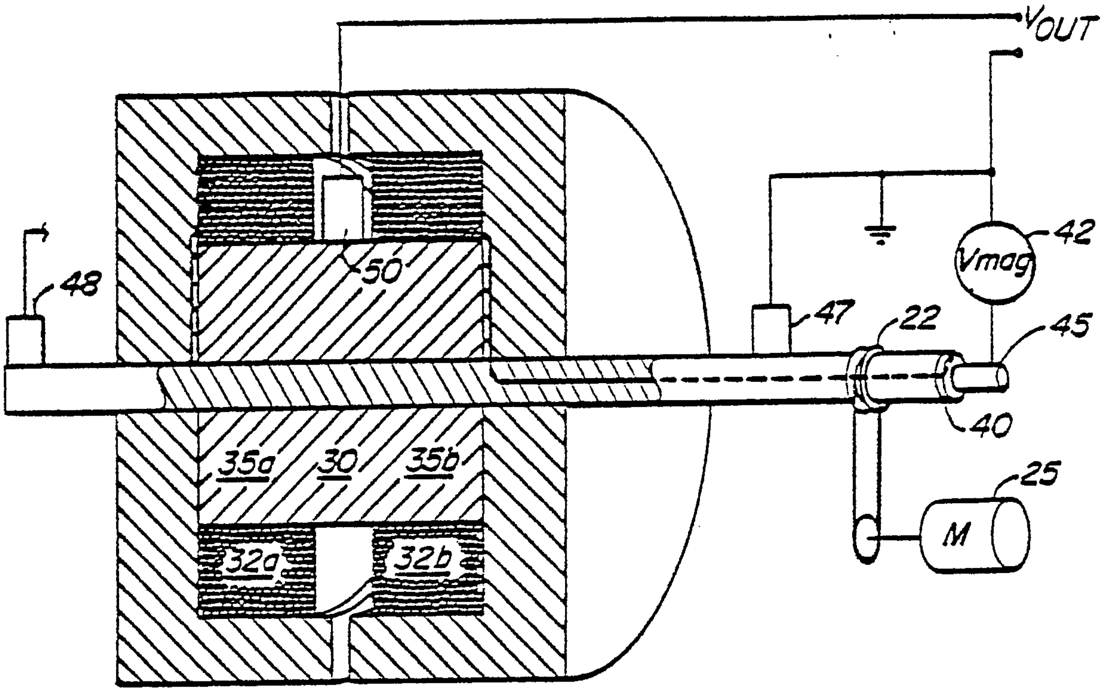


FIG._2.

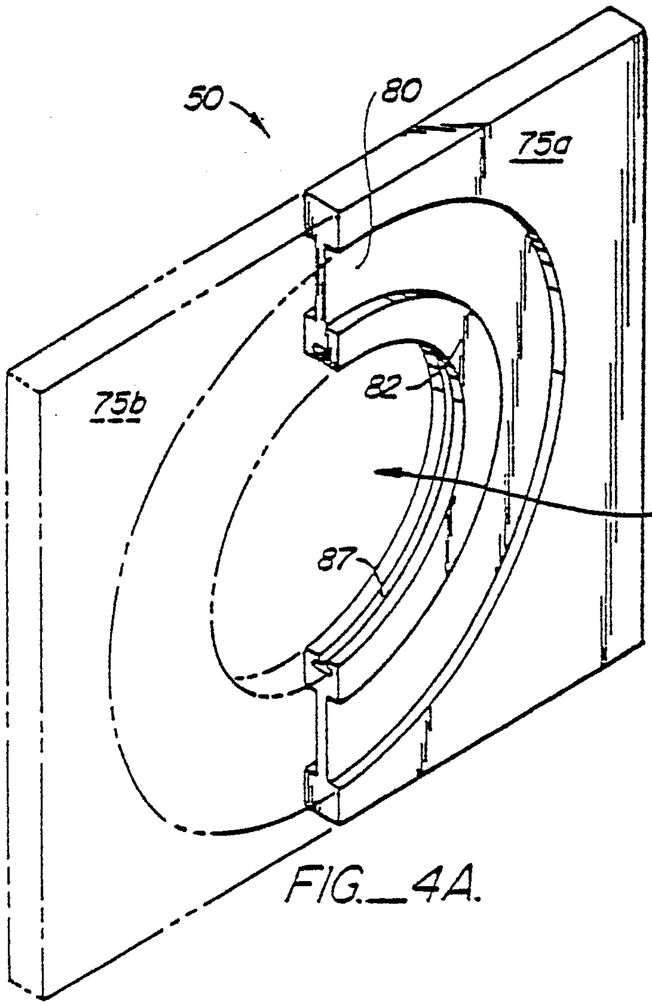


FIG._4A.

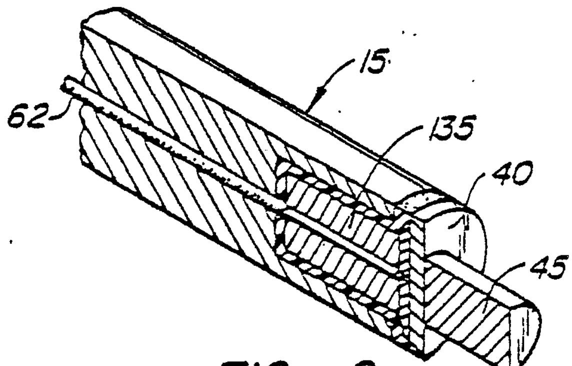


FIG._6.

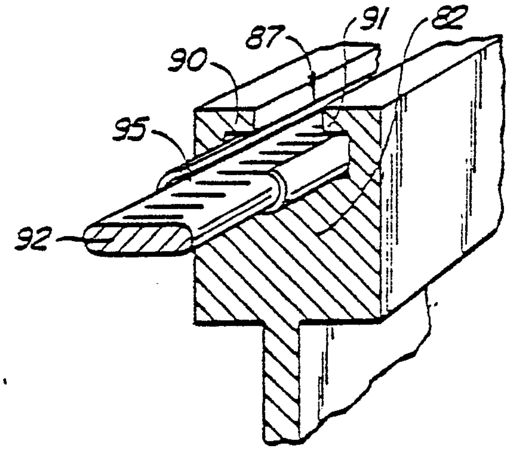


FIG._4B.

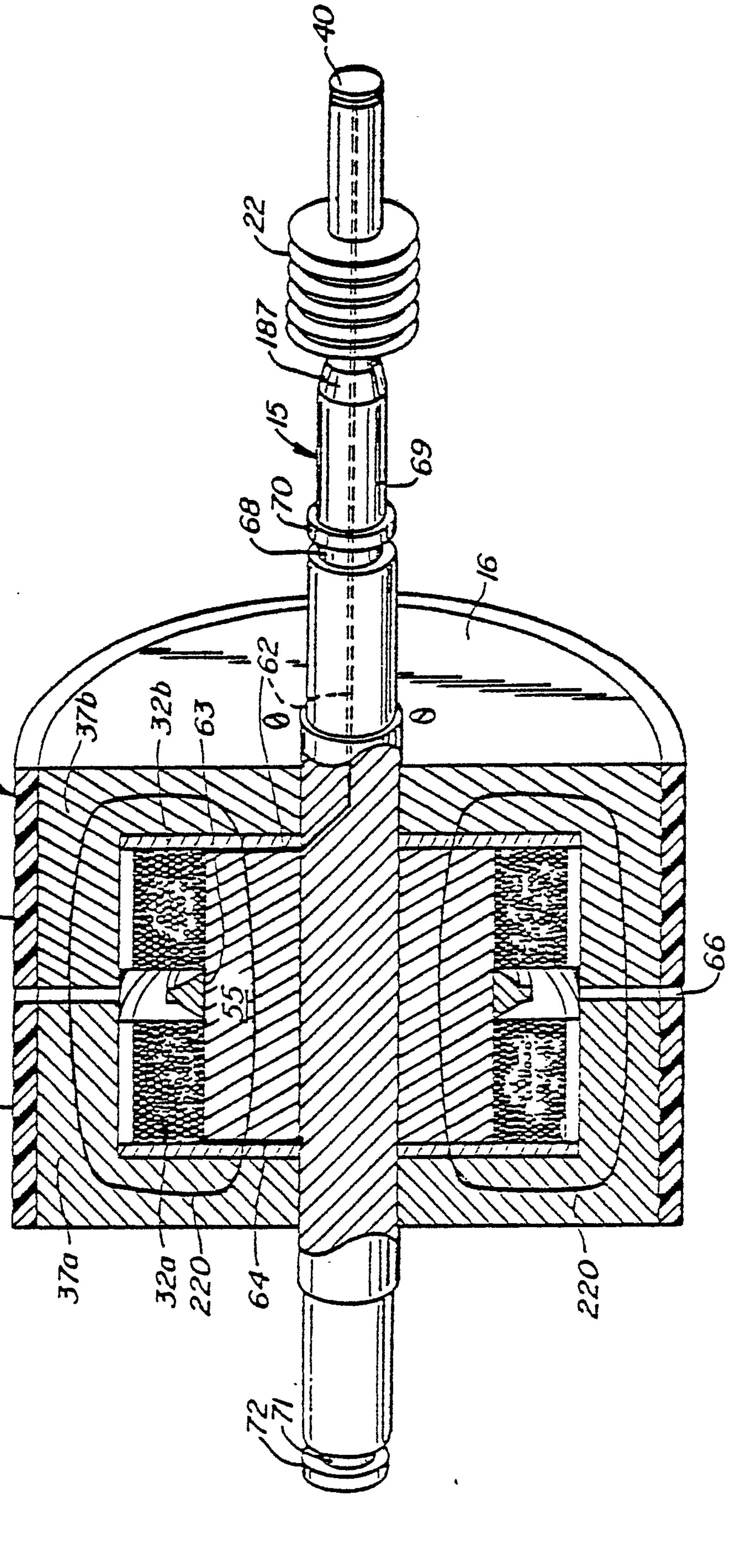

40
22
187
15
69
70
68
16
62
θ
θ
12
37b
32b
63
67b
55
66
67a
37a
32a
220
64
220
72
71

FIG. 3.

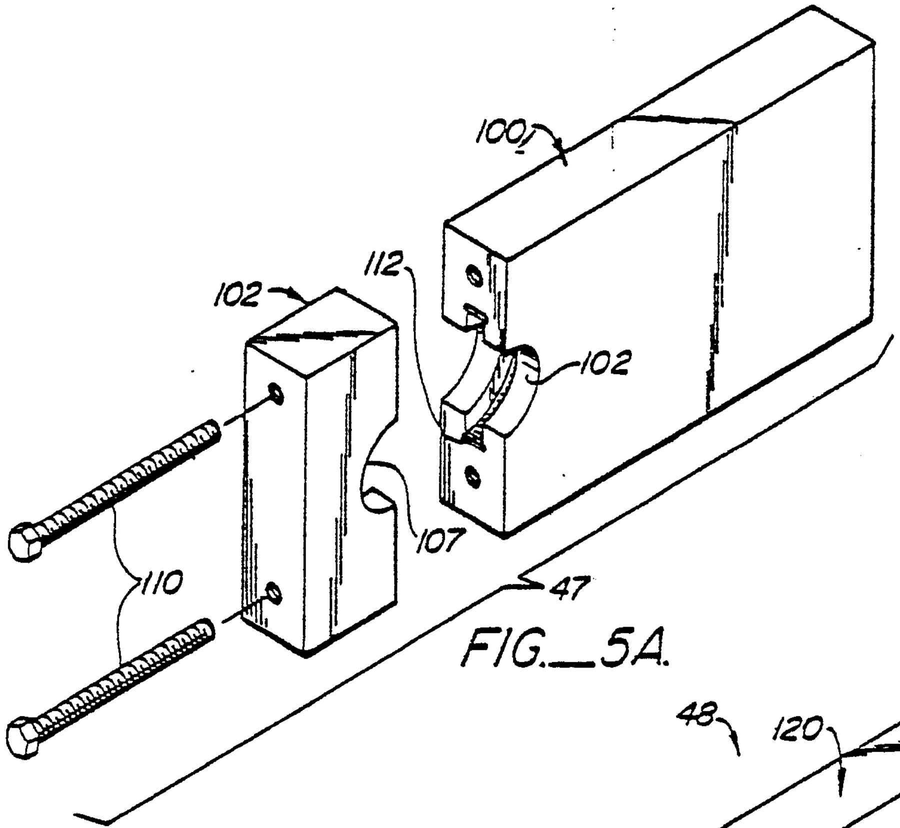


FIG._5A.

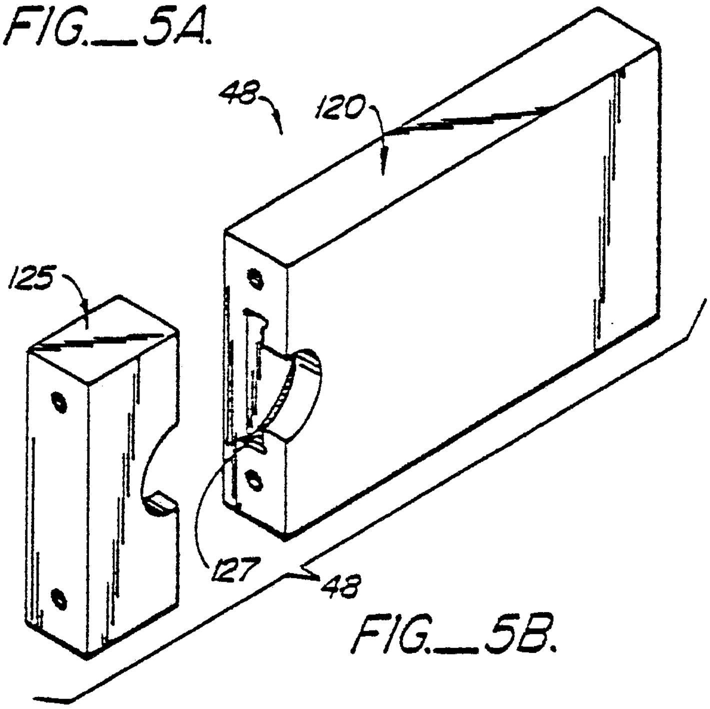


FIG._5B.

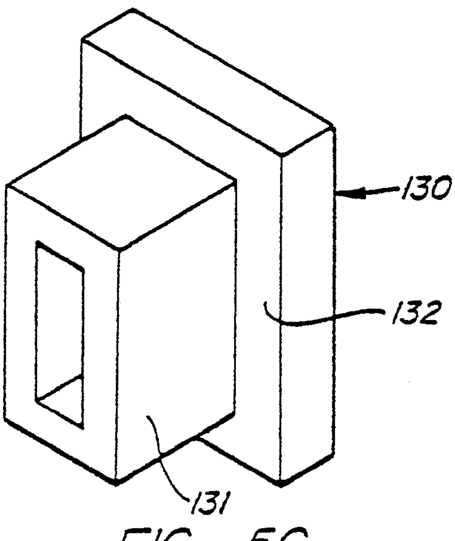


FIG._5C.

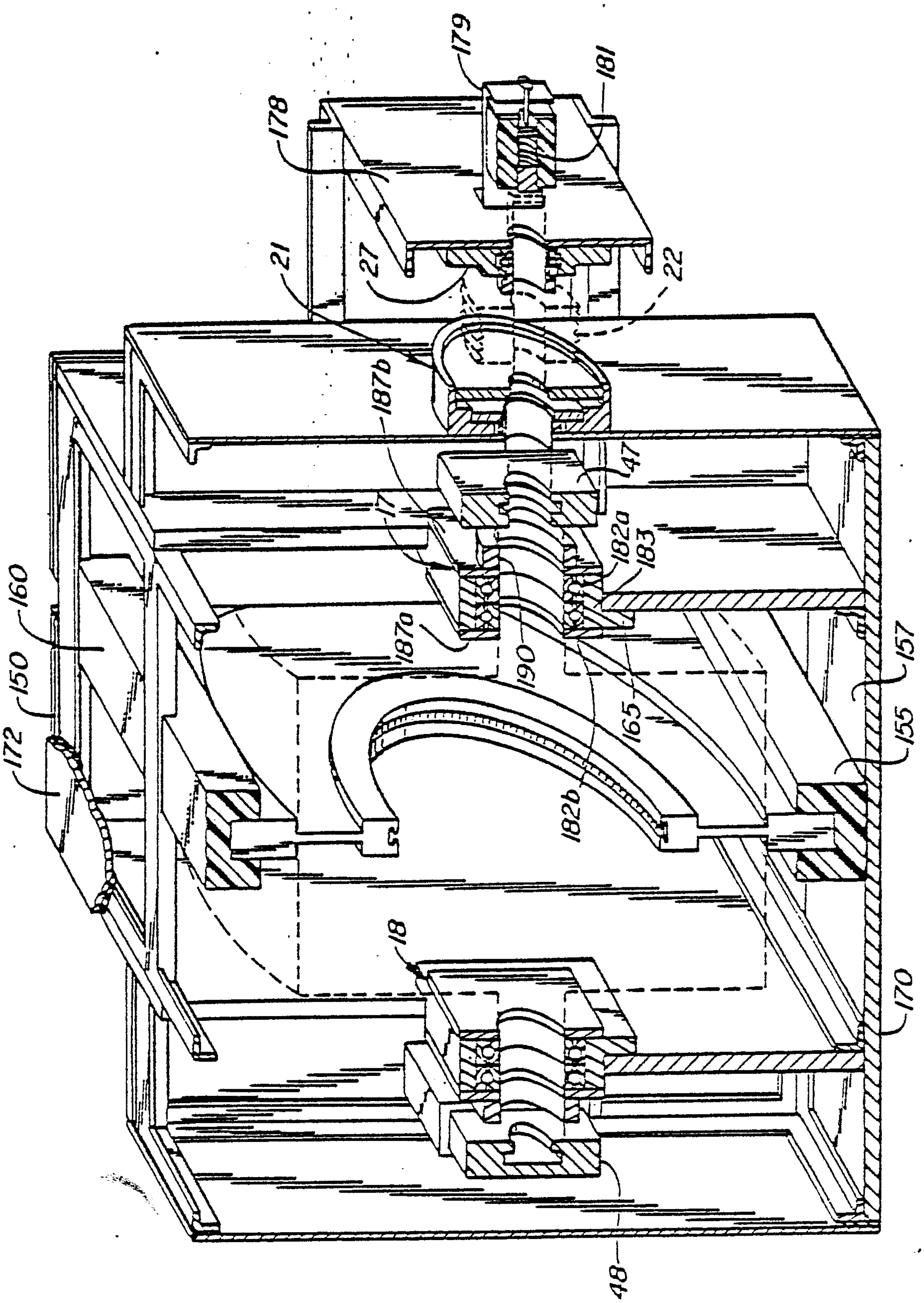

179
181
178
21
27
22
187b
47
17
182a
183
160
150
187a
190
172
165
157
155
182b
18
170
48

FIG. 7.

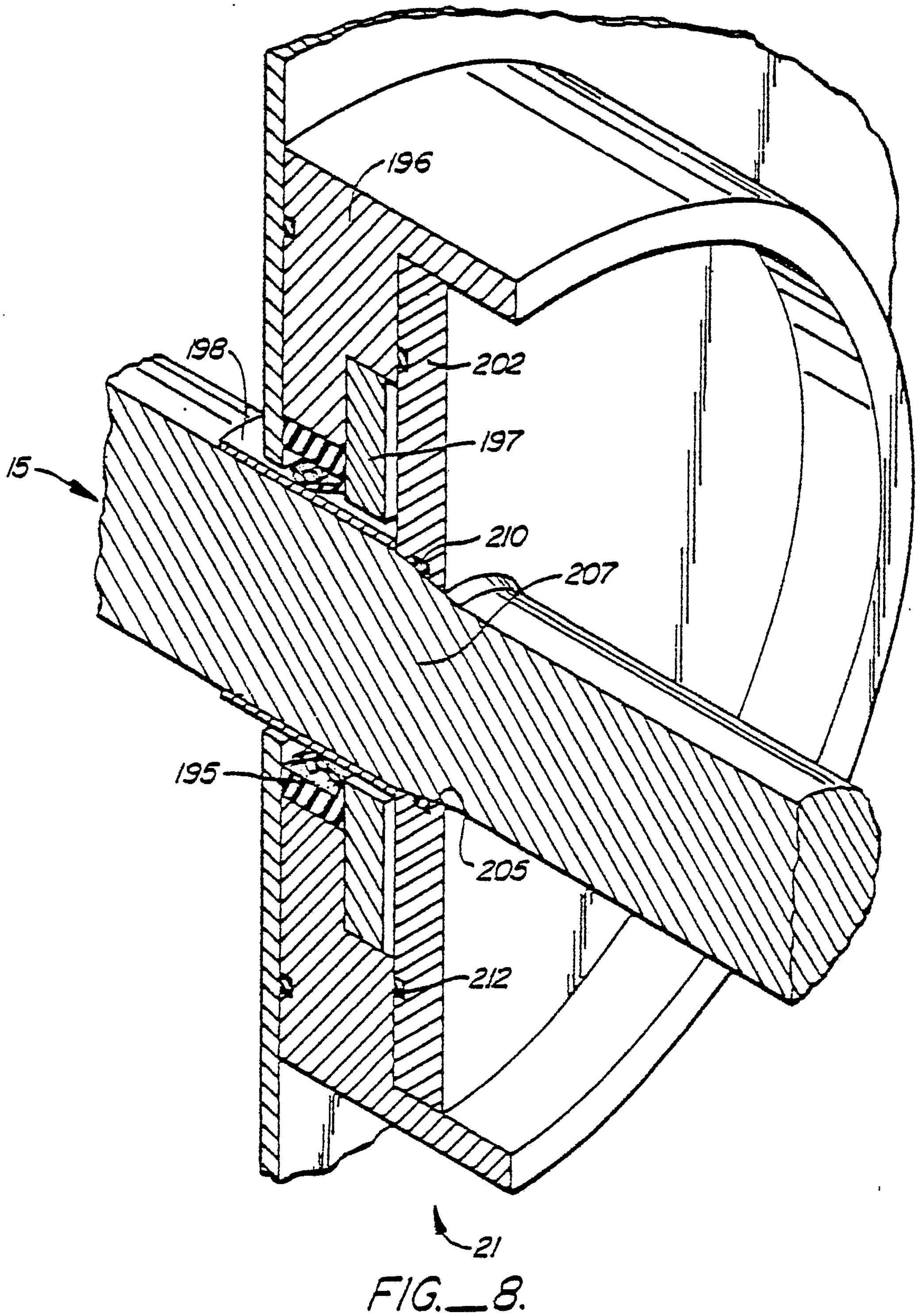


FIG._8.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 81/01588

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC 3

H02K 31/00, 39/00

310 /178,219

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	310/178,219,102R,102A,112-114

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US,A, 3,185,877 PUBLISHED 25 May 1965, Sears	1-12
A	US,A, 3,736,450 PUBLISHED 29 May 1973, EMALDI	1-12
A	US,A, 3,944,865 PUBLISHED 16 MARCH 1976, JEWITT	1-12
A	US,A, 2,408,080 PUBLISHED 24 SEPTEMBER 1946, LLOYD	
A	US,A, 2,845,554 PUBLISHED 29 JULY 1958, SCHWAB et al	
A	US,A, 3,270,228 PUBLISHED 30 August 1966, RIOUX	
A	US,A, 3,513,340 PUBLISHED 19 May 1970, APPLETON	

* Special categories of cited documents: [15]

"A" document defining the general state of the art

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

"L" document cited for special reason other than those referred to in the other categories

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

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or 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

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
13 JANUARY 1981	01 FEB 1982
International Searching Authority [1]	**Signature of Authorized Officer** [20]
ISA/US	Robert Skudy