

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
8 June 2006 (08.06.2006)

PCT

(10) International Publication Number
WO 2006/060713 A1

(51) International Patent Classification:

H02K 17/16 (2006.01) **F17C 7/02** (2006.01)
F04B 37/08 (2006.01)

(21) International Application Number:

PCT/US2005/043729

(22) International Filing Date:

2 December 2005 (02.12.2005)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

60/633,343 3 December 2004 (03.12.2004) US
11/023,760 22 December 2004 (22.12.2004) US

(71) Applicant (for all designated States except US): **EMERSON ELECTRIC CO.** [US/US]; 8000 West Florissant Avenue, St. Louis, MO 63136 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **BAILEY, Michael, R.** [US/US]; Emerson Motor Company, 500 Morrow Street, Mena, AR 71953 (US).

(74) Agents: **THOMAS, Michael, J.** et al.; Harness, Dickey & Pierce, P.L.C., 7700 Bonhomme Avenue, Suite 400, St. Louis, MO 63105 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

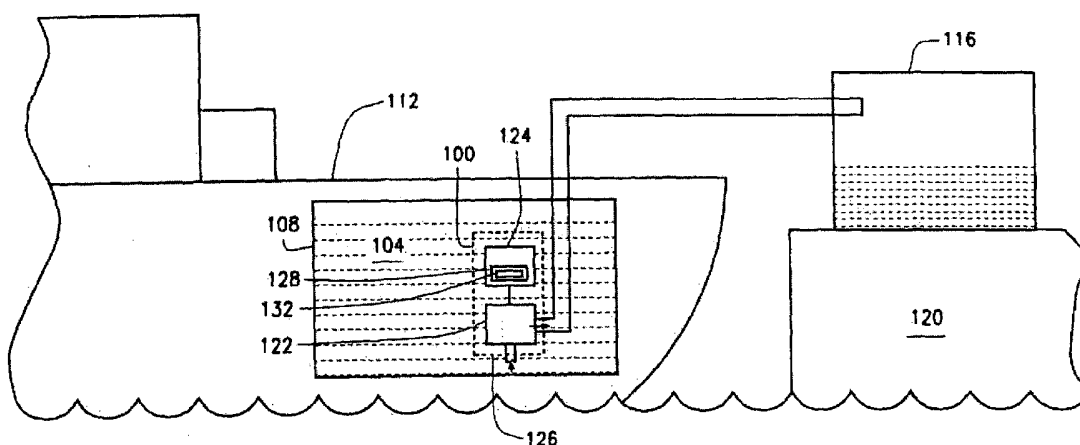
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: CRYOGENIC PUMPING SYSTEMS, ROTORS, AND METHODS FOR PUMPING CRYOGENIC FLUIDS



(57) Abstract: A cryogenic pumping system for pumping a cryogenic fluid generally includes a rotor having a plurality of slots. The rotor includes at least one endring defining a plurality of openings. Each opening is aligned with a different one of the slots. A plurality of rotor bars are each positioned within a different one of the slots. Each rotor bar includes an end portion received within a different one of the openings and welded to the endring. The cryogenic pumping system can be used to pump a cryogenic fluid from a first location to a second location.

CRYOGENIC PUMPING SYSTEMS, ROTORS, AND METHODS FOR PUMPING CRYOGENIC FLUIDS

FIELD

[0001] The present invention generally relates to cryogenic pumping systems, methods for pumping cryogenic fluids, and rotors suited for use in cryogenic pumps.

BACKGROUND

[0002] Fabricated rotor cores typically include three primary components, namely, a stack of laminations, rotor bars positioned within slots defined by the laminations, and two endrings positioned on opposite sides of the stack of laminations. Traditionally, the endrings have been formed by casting. To cast one of the endrings, a mold is positioned on top of the stack of laminations over ends of the rotor bars. Molten material is poured into the mold, and allowed to cool to form the endring. In order to mechanically bond and electrically connect the rotor bars to the endring, the endring is cast at a temperature sufficient to melt the ends of the rotor bars.

SUMMARY

[0003] According to one aspect of the present invention, a cryogenic pumping system for pumping a cryogenic fluid generally includes a rotor having a plurality of slots. The rotor includes at least one endring defining a plurality of openings. Each opening is aligned with a different one of the slots. A plurality of rotor bars are each positioned within a different one of the slots. Each rotor bar includes an end portion received within a different one of the openings and welded to the endring. The cryogenic pumping system can be used for pumping a cryogenic fluid from a first location to a second location.

[0004] According to another aspect of the present invention, a rotor has a plurality of slots and includes at least one endring defining a plurality of openings.

Each opening is aligned with a different one of the slots. A plurality of rotor bars are each positioned within a different one of the slots. Each rotor bar includes an end portion received within a different one of the openings and welded to the endring. Each slot can also include a relief portion to allow the rotor bar within that slot to deflect into the relief portion.

[0005] Further aspects and features of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0007] FIG. 1 is a block diagram representation of a cryogenic pumping system used to pump a cryogenic fluid according to one exemplary embodiment of the invention;

[0008] FIG. 2 is an exploded perspective view of a rotor core according to one exemplary embodiment of the invention;

[0009] FIG. 3 is a perspective view of the rotor core shown in FIG. 2 after it has been assembled but before the endrings have been welded to the rotor bars;

[0010] FIG. 4 is a partial view of an endring shown in FIG. 3 and further illustrating a weld between the endring and an end portion of a rotor bar;

[0011] FIGS. 5A and 5B are perspective views of the rotor core shown in FIG. 3 and illustrating one of the endrings welded to end portions of the rotor bars;

[0012] FIG. 6 is a perspective view of the rotor core shown in FIGS. 5A and 5B after machining has been performed in order to provide an attractively smooth surface finish;

[0013] FIG. 7 is a longitudinal cross-sectional view of the rotor core shown in FIG. 6;

[0014] FIG. 8 is a perspective view of an endring according to an exemplary embodiment of the invention;

[0015] FIG. 9 is an upper plan view of the endring shown in FIG. 8;

[0016] FIG. 10 is a partial longitudinal cross-sectional view of a rotor core according to another exemplary embodiment and illustrating a relief portion positioned on an interior side of a slot that allows the rotor bar within that slot to deflect into the relief portion; and

[0017] FIG. 11 is a partial longitudinal cross-sectional view of the rotor core shown in FIG. 10 and illustrating the rotor bar deflected generally radially inward into the relief portion.

[0018] Corresponding reference numerals indicate corresponding features throughout the several views of the drawings.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0019] The following description of exemplary embodiments is merely exemplary in nature and is in no way intended to limit the invention, its applications, or uses.

[0020] A method according to one aspect of the present invention generally includes pumping a cryogenic fluid from a first location to a second location. By way of example only, FIG. 1 illustrates a cryogenic pumping system or assembly 100 being used to pump liquefied natural gas 104 from a storage vessel 108 onboard a tanker ship 112 to an onshore storage vessel 116 located at a sea port 120. As shown in FIG. 1, the cryogenic pumping system 100 includes a pump 122 and an electric motor 124 that generates the mechanical power for operating the pump 122. In the illustrated embodiment, the pump 122 and electric motor 124 are positioned within housing 126 of the cryogenic pumping system 100, although this is not required. Also shown in FIG. 1, the electric motor 124 includes a rotor 128, which, in turn, includes a rotor core 132.

[0021] An exemplary embodiment of a rotor core suitable for use in rotor 128, cryogenic pumping system 100 and/or cryogenic environment is shown in the

figures. As shown in FIG. 2, a rotor core 132 includes a stack of laminations 136, a pair of endrings 140 positioned on opposite sides of the lamination stack 136, and a plurality of rotor bars 144.

[0022] The laminations 136 define a plurality of slots 148 each sized to receive one of the rotor bars 144 therein. The laminations 136 also define a generally central opening 152 sized to receive a shaft (not shown) to which the rotor core 132 can ultimately be coupled for common rotation therewith.

[0023] Each endring 140 defines a plurality of openings 156. Each opening 156 is aligned with a different one of the slots 148. Each endring 140 also defines a generally central opening 160 sized to receive the shaft to which the rotor core 132 can ultimately be coupled.

[0024] Each rotor bar 144 is positioned within a different one of the slots 148. As shown in FIG. 3, each rotor bar 144 includes an end portion 164 received within a different one of the openings 156 and welded to the endring 140, as described in detail below.

[0025] In the illustrated embodiment of FIGS. 2 through 10, the rotor bars 144 each have a generally oval-shaped cross section. The lamination slots 148 and the endring openings 156 also have generally oval-shaped cross sections. Alternatively, other shapes can be used for the rotor bars, the lamination slots, and/or the openings in the endrings. Further, the number, size, and shape of the rotor bars 144, lamination slots 148, and/or endring openings 156 can vary depending, for example, on the particular application in which the rotor core 132 will be used.

[0026] Various processes can be used to form the endrings 140 and/or other rotor components. In one exemplary embodiment, the endrings 140 are formed by machining. This can be advantageous in that machining generally allows a higher yield strength material to be used as compared to casting and forging processes. For example, one particular embodiment includes machining the endrings 140 entirely from 6061 T-6 aluminum alloy, which has a higher yield strength than pure aluminum (a material commonly used for casting endrings).

[0027] In some embodiments, only the end portions 164 of the rotor bars 144 are welded to the endring 140, and the endrings 140 are not bonded directly to the laminations 136. In these embodiments, the endrings 140 are able to slide or move relatively freely in the radial direction relative to the laminations 136. This can be advantageous in cryogenic applications where the cryogenic temperatures can cause significant differential thermal contraction between the endrings 140 and the laminations 136. For such embodiments, machining is typically better than casting for forming the endrings. This is because casting processes are typically performed at such a high temperature that portions of the endring and/or laminations melt. In which case, upon cooling the endring is bonded directly to the laminations. With machining, however, the endrings can be formed at lower temperatures such that in some embodiments the endrings 140 are not directly bonded to the laminations 136 themselves.

[0028] Further, forming the endrings at the lower temperatures associated with machining can also allow improvements in the straightness of the rotor core as compared to rotors cores in which the endrings are formed by forging or casting. The relatively high temperatures associated with such forging or casting processes can cause at least some movement and/or distortion of the rotor core components.

[0029] A wide range of materials can be used for the various components of the rotor core. In some embodiments, the endrings 140 and rotor bars 144 are formed entirely from the same material(s). In a particular embodiment, the endrings 140 and rotor bars 144 are formed entirely from 6061 T-6 aluminum alloy.

[0030] In some embodiments, only the end portions 164 of the rotor bars 144 are welded to the endrings 140, as shown in FIGS. 4, 5, and 7. In such embodiments, the welds 168 between each endring 140 and the rotor bar end portions 164 are a spaced distance from the laminations 136. Further, the endrings 140 are not directly bonded by welding or otherwise to the laminations 136 themselves. In these embodiments, the endrings 140 are thus able to slide or move relatively freely in the radial direction relative to the laminations 136. This feature can help eliminate or at least inhibit the stress riser and stress concentration that can

typically occur at the lamination-to-endering interface or joint with traditional rotor core constructions.

[0031] In addition, welding the rotor bars 144 to the endrings 140 can also create higher strength joints than that produced with traditional rotor core constructions.

[0032] A wide range of materials can be used to form the welds between the endring 140 and the rotor bars 144. In various embodiments, the weld or fill material has properties similar to the properties of the material(s) forming the endring and/or rotor bars are formed.

[0033] In one embodiment, a 5356 aluminum alloy electrode is used to form the welds between the endrings 140 and the rotor bar end portions 164. This can be beneficial when the endring 140 and rotor bars 144 are formed entirely from 6061 T-6 aluminum alloy because the weld wire of the 5356 aluminum alloy electrode has substantially similar material properties to the 6061 T-6 aluminum alloy. Alternatively, other materials can be used for the welding wire, filler metals, rotor bars, and/or endring.

[0034] After each rotor bar end portion 164 has been welded to the endrings 140, some embodiments can also include capping the weld area on each endring 140 with a cap weld, and then machining to cleanup the cap weld. This machining can provide a substantially smooth surface 170 having a high or production-wise quality surface finish that is cosmetically pleasing to the user, as shown in FIG. 6.

[0035] In some embodiments, each slot includes a relief portion or clearance to allow the rotor bar within that slot to deflect into the relief portion. As shown in FIGS. 10 and 11, a relief portion 272 is positioned on an interior side of the slot 248 to allow the rotor bar 244 within that slot 248 to deflect generally radially inward into the relief portion 272 (as shown in FIG. 11). In this particular embodiment, FIG. 10 depicts the rotor core 232 at an ambient room temperature, and FIG. 11 depicts the rotor core 232 at a cryogenic temperature.

[0036] During operation, the rotor core 232 can be disposed within (e.g., submerged, etc.) a cryogenic fluid. Due to the extremely cold or cryogenic

temperatures, the endrings 240 may contract in the radial direction to a greater extent than that of the laminations 236. The relief portions 272 allow the rotor bars 244 to deflect or flex radially inward as the endring 240 contracts. This, in turn, can significantly reduce stress concentrations and shearing forces (and possible crack formation and propagation caused thereby) between the endring 240 and rotor bars 244.

[0037] By increasing the size of the openings into which the rotor bars 244 are inserted, the relief portions 272 can also facilitate insertion of the rotor bars 244 into the slots 248. In one embodiment, each relief portion 272 has an axial length 276 of about four inches, and a radial thickness or width 280 of about 0.03 inches. In comparison, the entire axial length of the slot 248 (which corresponds to the axial length of the lamination stack 236) can be about thirty-six inches. Plus, the radial thickness or width of each slot 248 can be about equal to or slightly larger than (e.g., about 0.007 inches wider than) the width of the rotor bar 244. In some embodiments, the rotor bar width is about one inch or one one-half inches.

[0038] Accordingly, a relief portion 272 is positioned at each end of the slots 248. In which case, a central or medial portion 284 of each rotor bar 244 is held relatively securely within that portion 288 of the slot 248 that does not include the relief portions 272. Alternatively, other embodiments do not include relief portions and/or include relief portions that extend the entire axial length of the slot.

[0039] Various embodiments of the invention provide rotors that are suited for (but not limited to) operation at cryogenic temperatures. Aspects of the invention also include cryogenic pumping systems, electric machines, electric motors, and electric generators that include such rotors. Further aspects of the invention include methods of making and using the foregoing. For example, other aspects of the invention include using a cryogenic pumping system to pump liquefied natural gas, liquefied nitrogen (LN₂), liquid oxygen (LO₂), among other fluids.

[0040] The teachings of the present invention can be applied in a wide range of electric machines including electric motors and electric generators. Accordingly, the specific references to cryogenic pumping systems and cryogenic fluids herein should not be construed as limiting the scope of the present invention to

any specific form/type of cryogenic application. Further, aspects of the invention should also not be limited to use with only cryogenic applications.

[0041] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A cryogenic pumping system for pumping a cryogenic fluid, the cryogenic pumping system comprising a rotor having a plurality of slots, the rotor including at least one endring defining a plurality of openings, each said opening being aligned with a different one of said slots, and a plurality of rotor bars each positioned within a different one of said slots, each said rotor bar including an end portion received within a different one of said openings and welded to the endring.
2. The cryogenic pumping system of claim 1, wherein each said slot includes a relief portion for allowing the rotor bar within said slot to deflect into said relief portion.
3. The cryogenic pumping system of claim 2, wherein each said relief portion is positioned on an interior side of said slot to allow the rotor bar within said slot to deflect generally radially inward into said relief portion.
4. The cryogenic pumping system of claim 1, wherein the rotor includes a plurality of laminations defining said slots.
5. The cryogenic pumping system of claim 4, wherein each weld between the endring and the end portion of each rotor bar is a spaced distance from the laminations.
6. The cryogenic pumping system of claim 5, wherein each said opening extends through the endring from a first side of the endring to a second side of the endring, and wherein each said weld is on the first side of the endring opposite the laminations.

7. The cryogenic pumping system of claim 4, wherein the endring is not welded to the laminations.

8. The cryogenic pumping system of claim 1, wherein each weld between the endring and the end portion of each rotor bar is formed entirely from an aluminum alloy.

9. The cryogenic pumping system of claim 1, wherein the endring and the rotor bars are formed entirely from an aluminum alloy.

10. A method of using a cryogenic pumping system, the cryogenic pumping system including a rotor having a plurality of slots, the rotor including at least one endring defining a plurality of openings, each said opening being aligned with a different one of said slots, and a plurality of rotor bars each positioned within a different one of said slots, each said rotor bar including an end portion received within a different one of said openings and welded to the endring, the method comprising pumping a cryogenic fluid from a first location to a second location using said cryogenic pumping system.

11. The method of claim 10, wherein each said slot includes a relief portion for allowing the rotor bar within said slot to deflect into said relief portion.

12. The method of claim 11, wherein each said relief portion is positioned on an interior side of said slot to allow the rotor bar within said slot to deflect generally radially inward into said relief portion.

13. The method of claim 10, wherein the rotor includes a plurality of laminations defining said slots, wherein each weld between the endring and the end portion of each rotor bar is a spaced distance from the laminations, and wherein the endring is not welded to the laminations.

14. A rotor having a plurality of slots and comprising at least one endring defining a plurality of openings, each said opening being aligned with a different one of said slots, a plurality of rotor bars each positioned within a different one of said slots, each said rotor bar including an end portion received within a different one of said openings and welded to the endring, each said slot including a relief portion for allowing the rotor bar within said slot to deflect into said relief portion.

15. The rotor of claim 14, wherein each said relief portion is positioned on an interior side of said slot to allow the rotor bar within said slot to deflect generally radially inward into said relief portion.

16. The rotor of claim 14, wherein the rotor includes a plurality of laminations defining said slots.

17. The rotor of claim 16, wherein each weld between the endring and the end portion of each rotor bar is a spaced distance from the laminations.

18. The rotor of claim 17, wherein each said opening extends through the endring from a first side of the endring to a second side of the endring, and wherein each said weld is on the first side of the endring opposite the laminations.

19. The rotor of claim 16, wherein the endring is not welded to the laminations.

20. The rotor of claim 14, wherein each weld between the endring and the end portion of each rotor bar is formed entirely from an aluminum alloy.

21. The rotor of claim 14, wherein the endring and the rotor bars are formed entirely from an aluminum alloy.

22. An electric machine comprising the rotor of claim 14.

23. A cryogenic pumping system comprising the electric machine of claim
22.

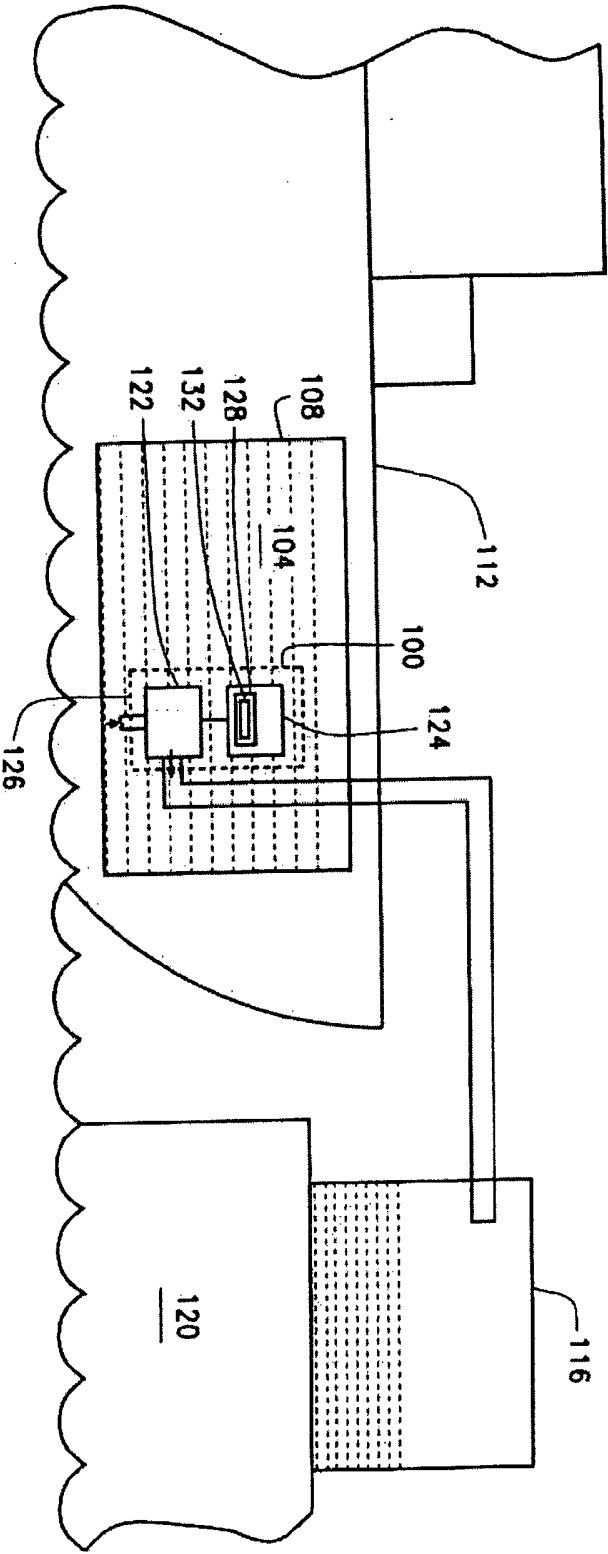


FIG. 1

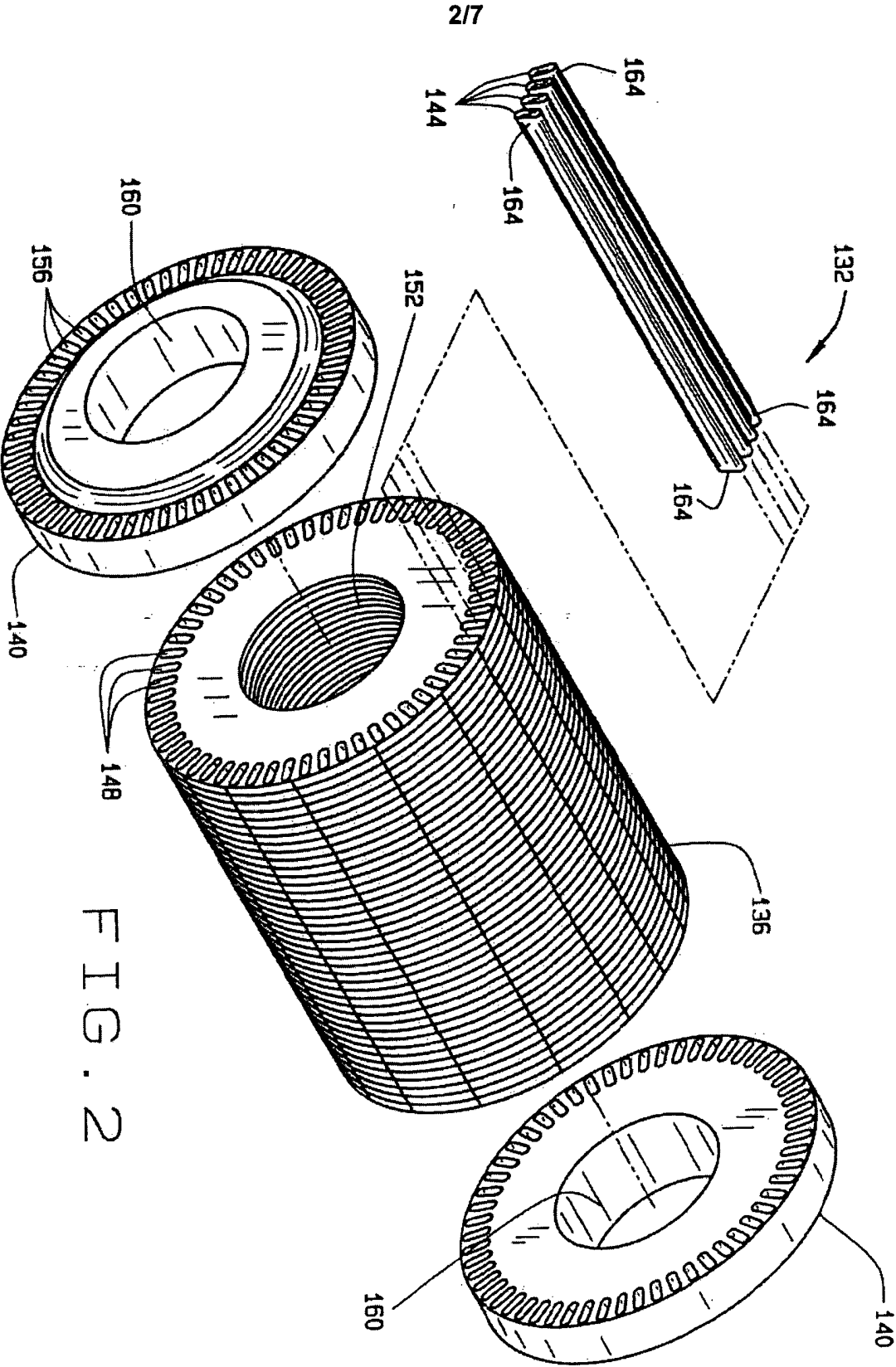
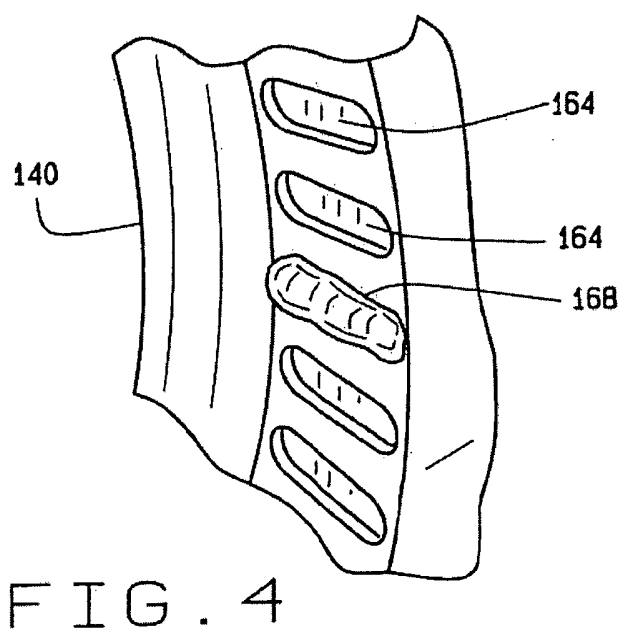
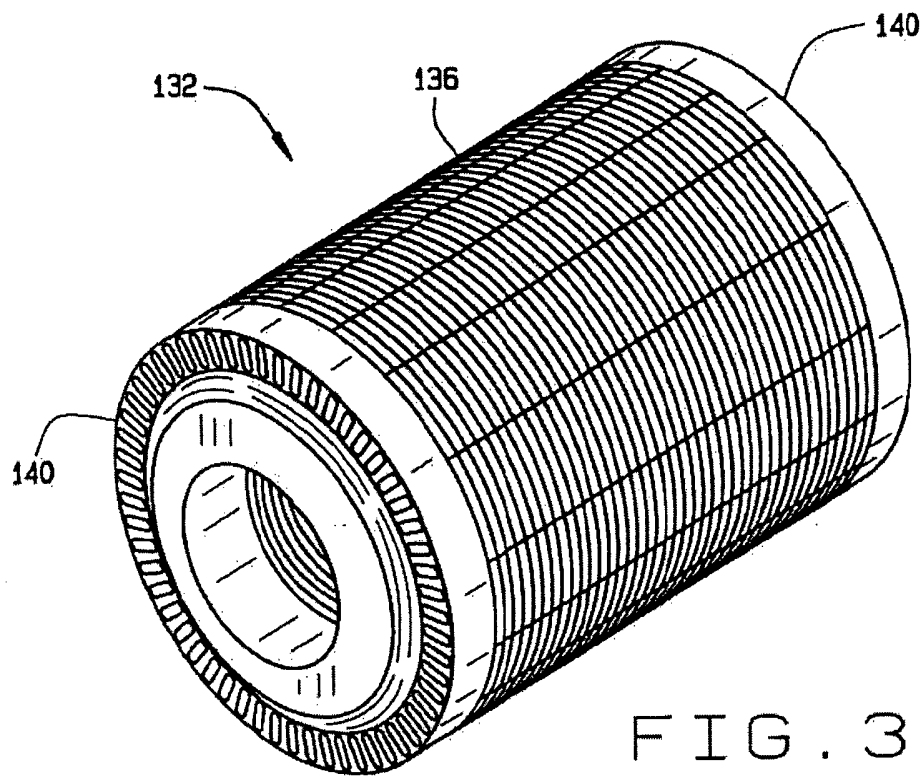


FIG. 2

3/7



4/7

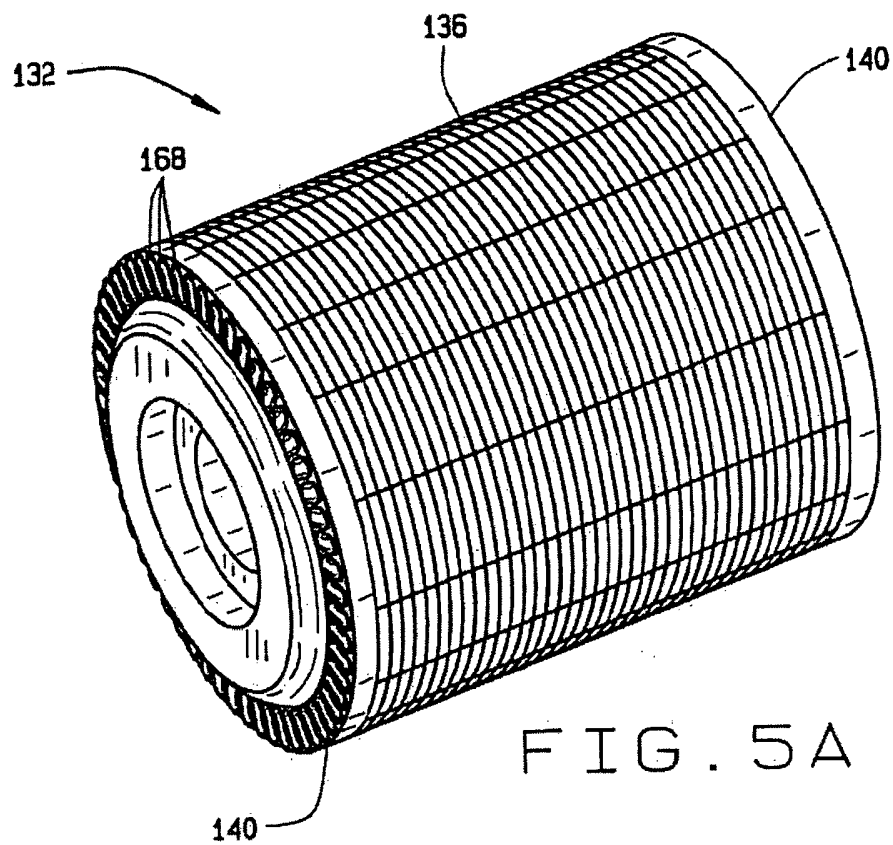


FIG. 5A

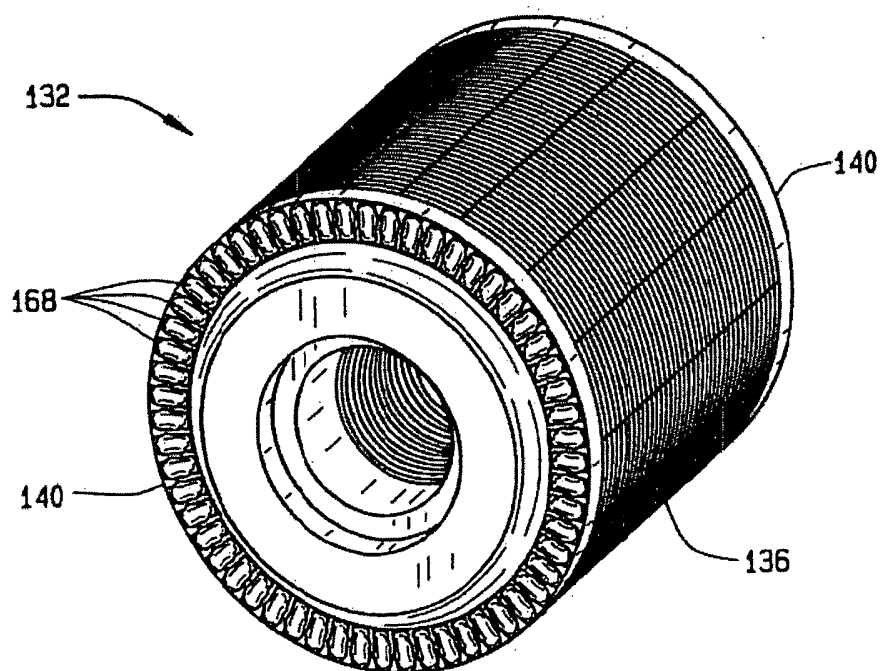


FIG. 5B

5/7

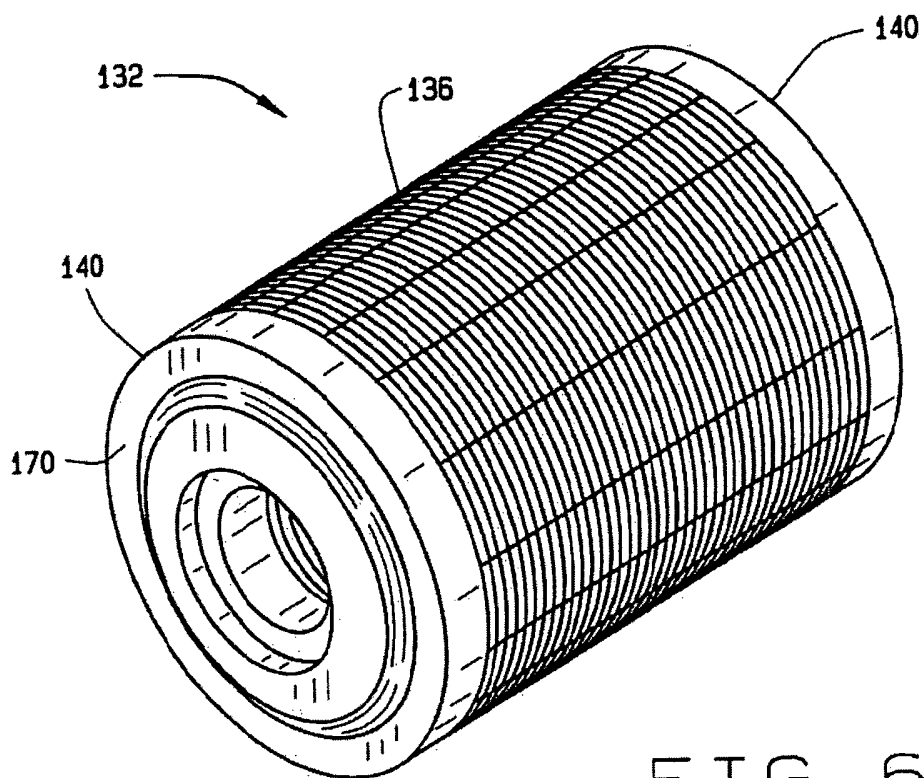


FIG. 6

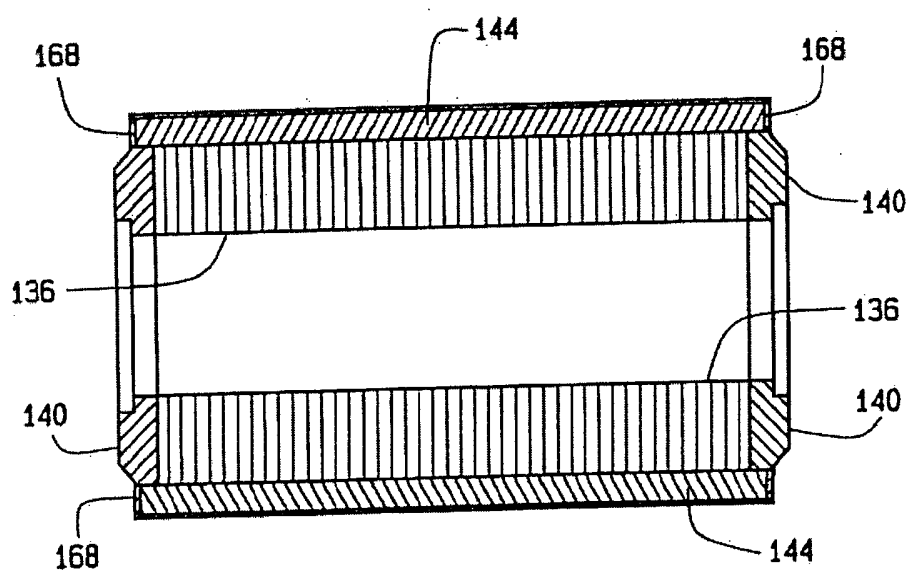


FIG. 7

6/7

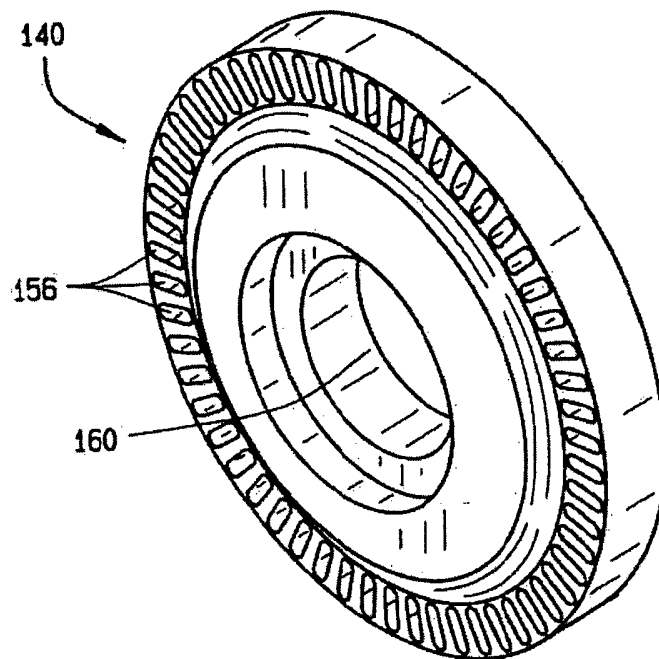


FIG. 8

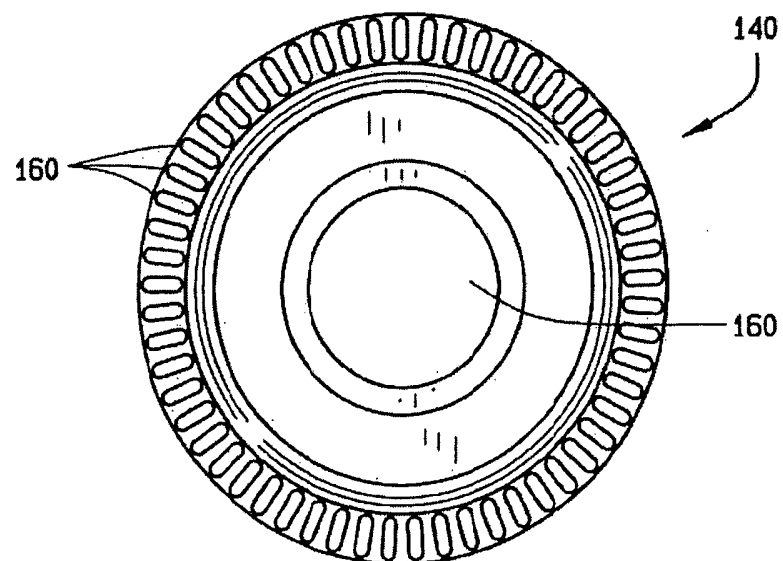


FIG. 9

7/7

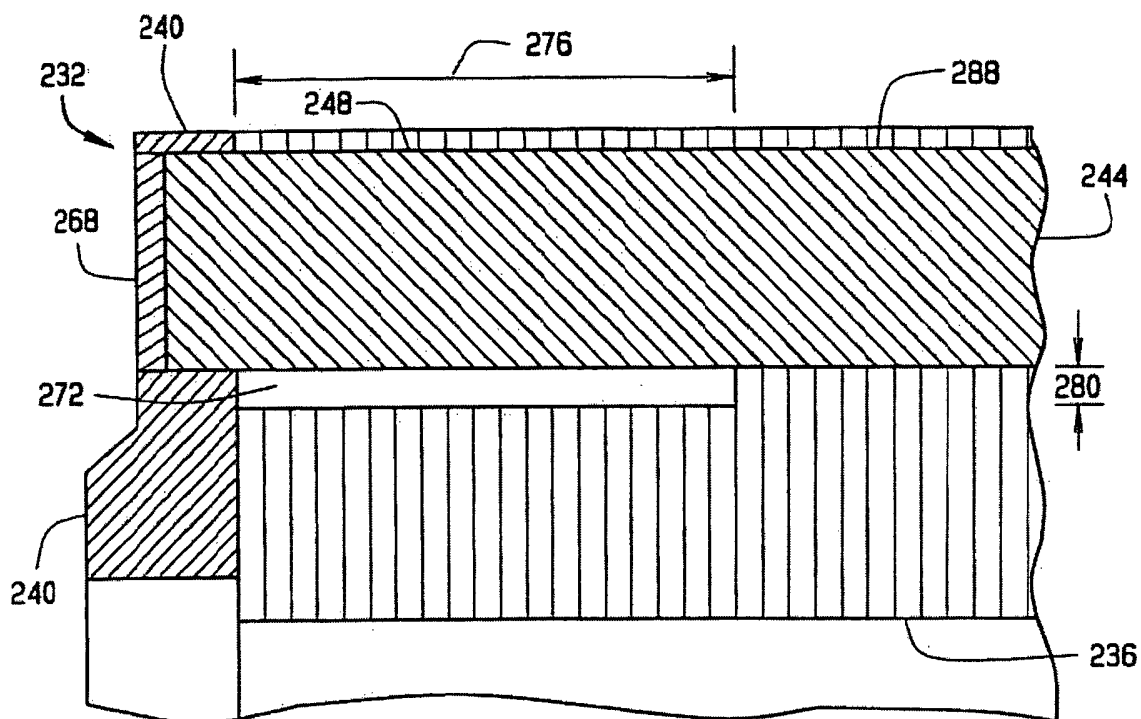


FIG. 10

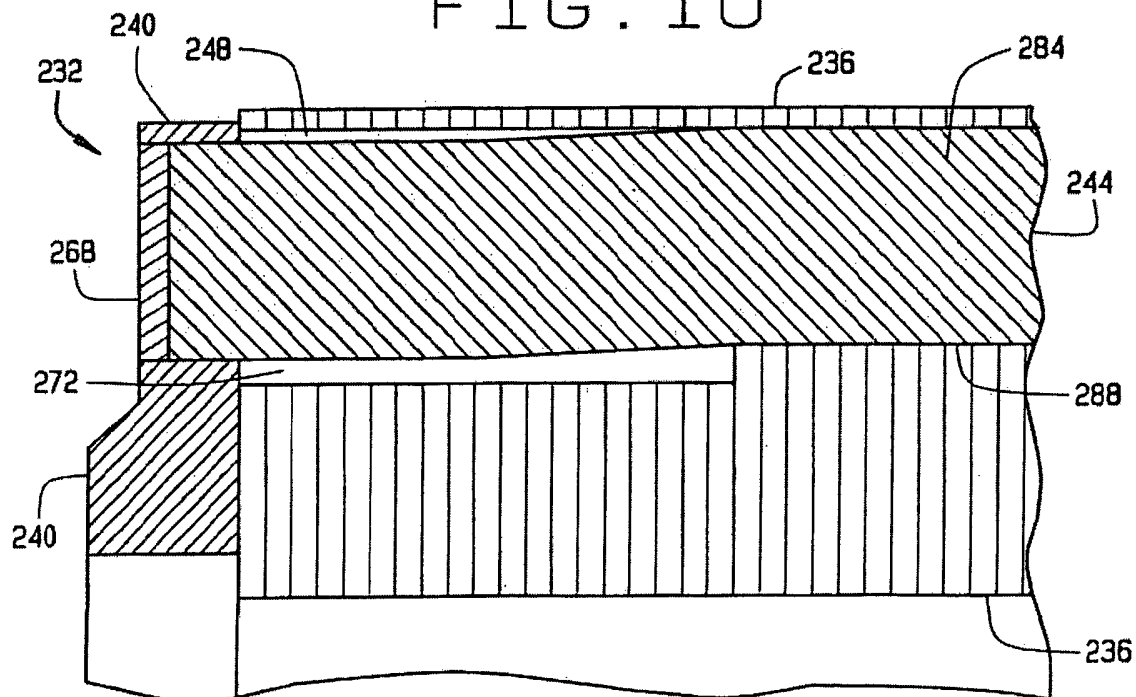


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No

US2005/043729

A. CLASSIFICATION OF SUBJECT MATTER

INV. H02K17/16 F04B37/08 F17C7/02

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)

H02K F04B F17C

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 3 134 040 A (BARTH EUGENE W) 19 May 1964 (1964-05-19) abstract; figures 1-3 column 1, lines 15-22 column 3, lines 8-19 column 3, line 63 - column 4, line 18 -----	1-7, 10-23 20,21
X Y	US 3 662 195 A (WARREN PIERCE WIELT) 9 May 1972 (1972-05-09) abstract; figures column 2, lines 53-58 column 3, lines 46-49 -----	1,4,5, 7-10 20,21
X Y	US 5 990 595 A (CROWELL ET AL) 23 November 1999 (1999-11-23) abstract; figures 1,2 column 1, line 67 - column 2, line 19 column 5, lines 7-22 ----- -/--	1,4,5, 7-10 20,21



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

G document member of the same patent family

Date of the actual completion of the international search

13 April 2006

Date of mailing of the international search report

26/04/2006

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Richmond, R

INTERNATIONAL SEARCH REPORT

International application No

No. US2005/043729

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/218400 A1 (RIMMEL DENNIS L) 27 November 2003 (2003-11-27) abstract; figure 7 paragraphs [0001], [0004] sentences 19-22, paragraph 24 paragraphs [0034], [0035] -----	1, 4-7, 10
A	US 4 593 835 A (KIKKAWA ET AL) 10 June 1986 (1986-06-10) abstract; figure 1 -----	1, 10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
US2005/043729

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 3134040	A	19-05-1964	NONE	
US 3662195	A	09-05-1972	NONE	
US 5990595	A	23-11-1999	CA 2215765 A1	04-04-1998
US 2003218400	A1	27-11-2003	AU 2003243306 A1 WO 03100955 A2	12-12-2003 04-12-2003
US 4593835	A	10-06-1986	DE 3465367 D1 EP 0127752 A1 JP 1506585 C JP 59200091 A JP 63056435 B	17-09-1987 12-12-1984 13-07-1989 13-11-1984 08-11-1988