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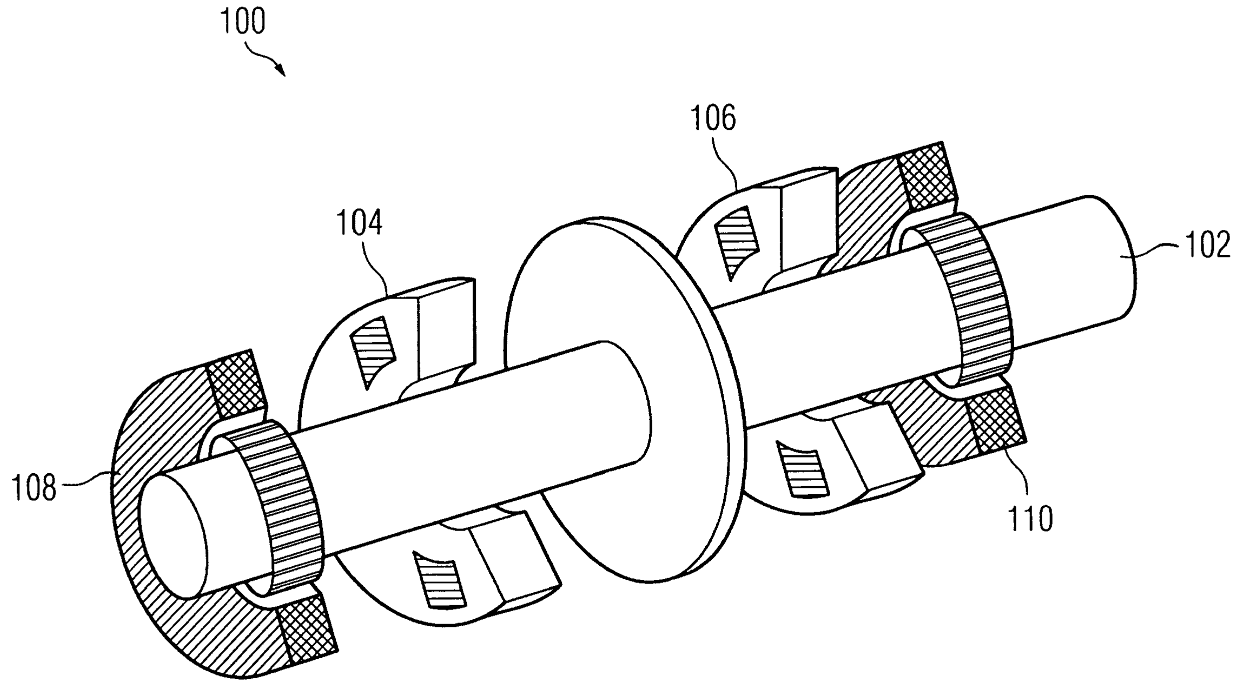
(54) **Additional support for AMB supported rotors by means of permanent magnet bearings**

(57) The present invention provides a robust backup bearing for continuous operation of a rotor. The backup bearing is a magnetic bearing assembly (100) for supporting a rotor (102) adapted to rotate about an axis of rotation. The assembly comprises a plurality of active magnetic bearings (104, 106) positioned axially along the rotor (102) to provide radial support to the rotor (102). The assembly also comprises a plurality of permanent magnetic bearings (108, 110) positioned axially along the rotor (102) as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings (104, 106).

FIG 1



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Description

[0001] The present invention relates to a magnetic bearing assembly, particularly to a magnetic bearing assembly which acts as backup bearings to support a rotor.

[0002] Magnetic bearings are the key components necessary to achieve high rotational speeds without wear while minimizing friction, thus achieving high operational life. A full levitation magnet bearing assembly for a shaft, which is adapted to rotate, could be realized using radial bearings and axial bearings.

[0003] Active magnetic bearings need electric power. An active magnetic bearing (AMB) consists of an electromagnet assembly, a set of power amplifiers which supply current to the electromagnets, a controller, and gap sensors with associated electronics to provide the feedback required to control the position of the rotor within the gap. Active magnetic bearings can be used to support the rotor radially as well as axially. Generally thrust bearings are provided for axial support of a rotor.

[0004] For rotating equipments supported on active magnetic bearings especially which provides radial support, it is important to have a backup support if the active magnetic bearing fails. The rotating equipment for example, can be a rotor of a motor, parts of a generator, parts of a compressor or parts of a turbine. Currently backup bearings which act as auxiliary bearings are used to support the rotor, when the AMB is not able to support the rotor. The commonly used backup bearings are sleeve bearings and ball bearings. These types of bearings have limited capacity and durability to support the rotors, since they are purely mechanical bearings which need to be in continuous contact with the rotor to provide the required support. These types of bearings further need lubrication and regular maintenance to keep it operational. These types of mechanical bearings need to be replaced regularly because of the wear and tear associated with the operation. Hence the replacements will increase the down time of the equipments employing these bearings.

[0005] It is an object of the present invention to provide a robust bearing to support the continuous operation of a rotor.

[0006] The said object is achieved by a magnetic bearing assembly for supporting a rotor adapted to rotate about an axis of rotation. The assembly comprises a plurality of active magnetic bearings positioned axially along the rotor to provide radial support to the rotor. The assembly also comprises a plurality of permanent magnetic bearings (PMB) positioned axially along the rotor as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings.

[0007] The said object is further achieved by a compressor unit, comprising an electric motor having a stator and a motor rotor and a compressor module having a compressor rotor and a plurality of compressor stages. The said compressor unit includes a magnetic bearing assembly as explained above, coupled to the motor rotor and the compressor rotor.

[0008] The said object is further achieved by a method of operating a compressor unit having an electric motor and a compressor module coupled together using a common rotor. The method comprises providing a plurality of active magnetic bearings positioned axially along the common rotor to provide radial support to the common rotor. The method further comprises providing a plurality of permanent magnetic bearings axially positioned along the common rotor as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings.

[0009] The underlying idea is to providing a plurality of permanent magnetic bearings axially positioned along the rotor as backup bearing to provide radial support in case one or more of the active magnetic bearings, which are axially positioned along the rotor fails to support the rotor. The use of magnetic bearing as a backup bearing helps to avoid the wear and tear, which is generally associated with the mechanical bearing, finally resulting in a robust and durable bearing. This will also increase the availability of the equipment. This permanent magnetic bearing further do not need any lubrication and repeated maintenance, making them a preferred choice in many applications, for example in subsea.

[0010] In a preferred embodiment, a permanent magnetic bearing which is the backup bearing for an active magnetic bearing is axially positioned along the rotor at a distance from the active magnetic bearing, where said distance is at most twice the length of a diameter of the rotor at that axial position. The axially positioned permanent magnetic bearings are placed in close proximity to the active magnetic bearings. They are placed so close that the distance between the active magnetic bearing and the corresponding permanent magnetic bearing which is designed to provide backup is generally not more than twice the length of a diameter of the rotor at that axial position, where the bearings are positioned. The positioning of the permanent magnetic bearing in this way provides magnetic levitation almost at a location very much closer to the location of active magnetic bearing, effectively making the absence of active magnetic bearing very negligible in case of any failure. This also avoids elaborate design changes which otherwise would have been required if an alternate new location was chosen for the permanent magnetic bearing.

[0011] In a further preferred embodiment, the plurality of active magnetic bearings comprises 2 to 5 active magnetic bearings and the plurality of permanent magnetic bearings comprises 2 to 5 permanent magnetic bearings. Based on the complexity of the rotor design the number of active and permanent magnetic bearings used can be changed. Another factor which influences the number of active or permanent magnetic bearings is rotor dynamics. The maximum speed, diameter, weight etc of the rotor are some parameters that directly affect the rotor dynamics. Radial stiffness and load capacity are few of the key features considered for designing the magnetic bearings. The permanent magnetic bearings are chosen and positioned axially along the rotor considering these parameters and features for providing a smooth transition to permanent magnetic bearing operation from active magnetic bearing operation, if the active magnetic bearing fails.

[0012] In an alternative embodiment, the permanent magnetic bearing is adapted to radially support the rotor while the radial support is provided by the active magnetic bearing to the rotor. The permanent magnetic bearing in parallel with the active magnetic bearing can provide radial support to the rotor even when active magnetic bearing is in operation, thereby sharing the load of the active magnetic bearing. For example, in situations demanding high rotor movements the loading on active magnetic bearing can be reduced by this parallel operation of the active magnetic bearing and the permanent magnetic bearing.

[0013] In an alternative embodiment, the magnetic bearing assembly can be used in a compressor unit. The compressor unit comprises an electric motor having a stator and a motor rotor and a compressor module having a compressor rotor and a plurality of compressor stages. The magnetic bearing assembly as explained above is coupled to the motor rotor and the compressor rotor to provide magnetic levitation. Hence the magnetic bearing assembly could be used as backup bearings as an alternative for mechanical bearings.

[0014] In an alternative embodiment, motor rotor and the compressor rotor is vertically or horizontally mounted. The horizontal and vertical mounting is with respect to a ground or base where the compressor is installed. These orientations of the rotors enable the use of magnetic bearing assembly in compressor units mounted in different ways.

[0015] In an alternative embodiment, the motor rotor and the compressor rotor are coupled to form a common rotor. The common rotor design helps the use of the magnetic bearing assembly to be used in compressors having a single rotor.

[0016] The present invention is further described hereinafter with reference to illustrated embodiments shown in the accompanying drawings, in which:

FIG 1 illustrates a perspective view of the magnetic bearing assembly according to an embodiment of the invention,

FIG 2 illustrates a cross section view of a compressor unit according to an embodiment of the invention, and

FIG 3 illustrates a flow chart representing the operation of a compressor unit.

[0017] FIG 1 illustrates a perspective view of the magnetic bearing assembly 100 according to an embodiment of the invention. The magnetic bearing assembly 100, supports a rotor 102 adapted to rotate about an axis of rotation. Active magnetic bearings 104 and 106 are positioned axially along the rotor 102 to provide radial support to the rotor. These bearings are radial bearings which operate electromagnetically and are constructed in each case in an encapsulated manner. Since the bearings are electro magnetic, there exist a gap between the rotor 102 and each of the electro magnetic bearing, which is maintained for providing the required levitation. These active magnetic bearings make use of position sensors to determine the status of a gap thereby controlling the magnetic levitation required to suspend the rotor in the gap.

[0018] Controlling units are generally employed to regulate the supply of electric current to these active magnetic bearing for controlling the strength of the magnetic field produced by the active magnetic bearing for levitation. The controlling unit and associated electronics are omitted for simplicity of illustration of the invention.

[0019] The magnetic bearing assembly 100 also comprises permanent magnetic bearings 108 and 110 positioned axially along the rotor. These permanent magnetic bearings 110 and 112 acts as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings. These bearings are represented simply for clarity of illustration; in practice, they would typically be formed of multiple concentric magnetic rings on the stator and matching multiple concentric annular poles on the rotor.

[0020] The failure of the active magnetic bearing could be a complete failure or a partial failure. A complete failure for example, could be the non-working of the active magnetic bearing because of any mechanical damage or even non working of any controlling unit associated with the active magnetic bearing. In a partial failure, for example the active magnetic bearing is still operational, but cannot support the full load associated with the rotor.

[0021] The axially positioned permanent magnetic bearings are placed in close proximity to the active magnetic bearings. In one embodiment, a permanent magnetic bearing which is the backup bearing for an active magnetic bearing is axially positioned along the rotor at a distance from the active magnetic bearing, where said distance is at most twice the length of a diameter of the rotor at that axial position. In another embodiment, a permanent magnetic bearing is placed closer to each of the active magnetic bearing, to support said active magnetic bearing in case of a failure. In yet another embodiment one permanent magnetic bearing or multiple permanent magnetic bearings are strategically located axially along the rotor based on the rotor dynamics. The speed, diameter, weight, etc of rotor along with radial stiffness, load capacity are some parameters that directly affect the rotor dynamics. A high rotor speed demands high radial stiffness which needs a permanent magnetic bearing designed to provide high levitation.

[0022] The number of active magnetic bearings and permanent magnetic bearings used in the magnetic bearing assembly can vary, but preferably at least two from each bearing is required to radially support a rotor. Based on the rotor design and rotor dynamics the numbers of active as well as permanent magnetic bearings that can be used vary between 2 to 5. The said range should not be taken as a strict limitation but as a preferred range. For example, based on the complexity of the rotor design and rotor dynamics the number of permanent magnetic bearings provided for the radial support of the rotor can equal or outnumber the number of active magnetic bearings. Based on the complexity the number of active and permanent magnetic bearings can even exceed the above specified preferred range.

[0023] A permanent magnetic bearing can also be designed to provide radial support to the rotor in parallel with the active magnetic bearing. For example, at higher rotor speeds, the load on the active magnetic bearing can be reduced by this parallel operation of the active magnetic bearing and permanent magnetic bearing. Based on the levitation provided by the permanent magnetic bearing, the levitation provided by the active magnetic bearing is controlled. The radial bearings in this case extend in the circumferential direction around the rotor and are formed in a 360 degree encompassing manner and in one piece.

[0024] FIG 2 illustrates a cross section view of a compressor unit 200 according to an embodiment of the invention. Gas compression systems are used in a wide variety of applications, including air compression for powering tools, gas compression for storage and transport of gas, etc. In each system, motors or gas turbines are provided for driving the compression mechanism to compress the gas. Gas compressors, like centrifugal gas compressors are usually driven by electric motors that are normally a standalone machine in a casing or within a casing that encases the motor and compressor.

[0025] The compressor unit 200 for compressing gas or a fluid generally has a compressor module 202 having a compressor rotor 204 with one or more compressor stages 206, and an electric motor 208 having a stator 210 and a motor rotor 212 for driving the compressor rotor 204 of the compressor unit 200. The compressor module 202 and the electric motor 208 are accommodated in a common gas-tight casing 214, which is provided with a gas inlet 216 and a gas outlet 218. The compressor rotor 204 and the motor rotor 212 are coupled to form a common rotor 220.

[0026] The motor rotor 212 is supported in two radial active magnetic bearings, these being a first radial active magnetic bearing 222 at the upper end of the motor rotor 212 and a second radial active magnetic bearing 224 at the lower end. The compressor rotor 204 is also supported at the two ends by two radial active magnetic bearings, these being a third radial active magnetic bearing 226 in the upper position and a fourth radial active magnetic bearing 228 in the lower position. A thrust bearing 230 is provided at the upper end of the common rotor 220 basically to provide axial support to said common rotor 220.

[0027] A first permanent magnetic bearing 232 is placed closer to the first radial active magnetic bearing 222 and a second permanent magnetic bearing 234 is placed closer to the fourth radial active bearing 228. The first permanent magnetic bearing 222 and the second permanent magnetic bearing 234 provides radial support to the common rotor 220, even if the corresponding first radial active magnetic bearing 222 or fourth radial active magnetic bearing 228 fails. A third permanent magnetic bearing 236 is positioned between the second radial active magnetic bearing 224 and the third radial active magnetic bearing 226; said positioning is done based on the rotor dynamics. In another embodiment, the backup can be realized by providing separate permanent magnetic bearings for the second radial active magnetic bearing and the third radial active magnetic bearing. The permanent magnetic bearings which is the backup bearing for the active magnetic bearings is axially positioned along the common rotor at a distance from the active magnetic bearings, where °said distance is not more than twice the length of a diameter of the common rotor at that axial position.

[0028] In industrial applications, the compressor unit can be manufactured to enable it to be mounted vertically or horizontally with reference to a base. In a compressor unit, which is vertically mounted the motor rotor and the compressor rotor is vertically placed, as shown in FIG 2. In a compressor unit, which is horizontally mounted the motor rotor and the compressor rotor is horizontally placed, i.e. parallel to the base.

[0029] One application of this type of compressor unit is in subsea. For subsea environment applications, the equipment design shall target the highest level of reliability since maintenance costs are extremely high, especially for heavy equipment at deeper water where heavy duty intervention vessels are very limitedly available. Hence durability of the bearing is very important.

[0030] FIG 3 illustrates a flow chart representing the operation of a compressor unit. The compressor unit is similar to the one which is discussed in FIG 2, having an electric motor 208 and a compressor module 202 coupled together using a common rotor 220. At step 310, pluralities of active magnetic bearings are provided in the compressor unit, which are positioned axially along the common rotor to provide radial support to the common rotor. At step 320, a plurality of permanent magnetic bearings are provided, which are axially positioned along the common rotor as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings.

[0031] In subsea applications, the compressor units are manufactured to have the common rotor vertically or horizontally mounted with respect to the sea bed. AS discussed in FIG 1, the permanent magnetic bearings are axially positioned and placed at close proximity to the active magnetic bearings or positioned axially along the common rotor based on the common rotor dynamics. During the operation of the compressor unit, the conditions of the bearings are monitored. At step 322, a check is made to assess any partial failure of any active magnetic bearings. If partial failure of any active magnetic bearing is detected, the permanent magnetic bearing can provide a minimum common rotor levitation to maintain operation of the rotor to avoid any damages otherwise would have been caused by an abrupt change in the supply of levitation by the active magnetic bearing. At step 324, the permanent magnetic bearing acts as a backup bearing and work along side with the active magnetic bearing once the partial failure of the active magnetic bearing is detected. At step 326, as there are no problems detected with the active magnetic bearing, the rotor can continue its operation. Still the permanent magnetic bearing can additionally support the active magnetic bearing by providing levitation. At step 328, if the active magnetic bearing is found to have completely failed, then according to step 330 the permanent magnetic bearing acts as a complete backup bearing. In another embodiment the backup support for the failure of an active magnetic bearing can be realized using the permanent magnetic bearings along with the auxiliary mechanical bearings.

[0032] Although the invention has been described with reference to specific embodiments, this description is not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternate embodiments of the invention, will become apparent to persons skilled in the art upon reference to the description of the invention. It is therefore contemplated that such modifications can be made without departing from the scope of the present invention as defined.

Claims

1. A magnetic bearing assembly (100) for supporting a rotor (102) adapted to rotate about an axis of rotation, comprising:

- a plurality of active magnetic bearings (104, 106) positioned axially along the rotor (102) to provide radial support to the rotor (102), and
- a plurality of permanent magnetic bearings (108, 110) positioned axially along the rotor (102) as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings (104, 106).

2. The magnetic bearing assembly (100) according to claim 1, wherein a permanent magnetic bearing (108, 110), which is the backup bearing for an active magnetic bearing is axially positioned along the rotor at a distance from the active magnetic bearing (104, 106), where said distance is at most twice the length of a diameter of the rotor at that axial position.

3. The magnetic bearing assembly (100) according to claim 1 or 2, wherein the plurality of active magnetic bearings (104, 106) comprises 2 to 5 active magnetic bearings (104, 106).

4. The magnetic bearing assembly (100) according to claim 1 to 3, wherein the plurality of permanent magnetic bearings (108, 110) comprises 2 to 5 permanent magnetic bearings (108, 110).

5. The magnetic bearing assembly (100) according to any of the claims 1 to 4, wherein the permanent magnetic bearing (108, 100) is adapted to radially support the rotor (102) while the radial support is provided by the active magnetic bearing (104, 106) to the rotor (102).

6. A compressor unit (200), comprising

- an electric motor (208) having a stator (210) and a motor rotor (212) ;
- a compressor module (202) having a compressor rotor (204) and a plurality of compressor stages (206); and
- a magnetic bearing assembly (100) as claimed according to claim 1 to 5, coupled to the motor rotor (212) and the compressor rotor (204).

7. The compressor unit (200) according to claim 6, wherein the motor rotor (212) and the compressor rotor (204) are vertically mounted.

8. The compressor unit (200) according to claim 6 or 7, wherein the motor rotor (212) and the compressor rotor (204) are horizontally mounted.

9. The compressor unit (200) according to any of the claims 6 to 8, wherein the motor rotor (212) and the compressor rotor (204) are coupled to form a common rotor (220).

10. A method of operating a compressor unit (200) having an electric motor (208) and a compressor module (202) coupled together using a common rotor (220), the method comprising:

- providing a plurality of active magnetic bearings (222, 224, 226, 228) positioned axially along the common rotor (220) to provide radial support to the common rotor (220), and
- providing a plurality of permanent magnetic bearings (232, 234, 236) axially positioned along the common rotor (220) as backup bearing to provide radial support in case of a failure of one or more of the active magnetic bearings (222, 224, 226, 228).

11. The method according to claim 10, wherein the compressor unit (200) is used in subsea applications.

12. The method according to claim 10 or 11, wherein the common rotor (220) is vertically mounted.

13. The method according to any of the claims 10 to 12, wherein the common rotor (220) is horizontally mounted.

14. The method according to any of the claims 10 to 13, wherein the permanent magnetic bearing (232, 234, 236) which is the backup bearing for the active magnetic bearing (222, 224, 226) is axially positioned along the rotor at a distance from the active magnetic bearing (222, 224, 226, 228), where said distance is at most twice the diameter of the rotor at that axial position.

15. The method according to any of the claims 10 to 14, wherein the permanent magnetic bearing (232, 234, 236) is adapted to radially support the common rotor (220) while the radial support is provided by the active magnetic bearing (222, 224, 226, 228) to the common rotor (220).

FIG 1

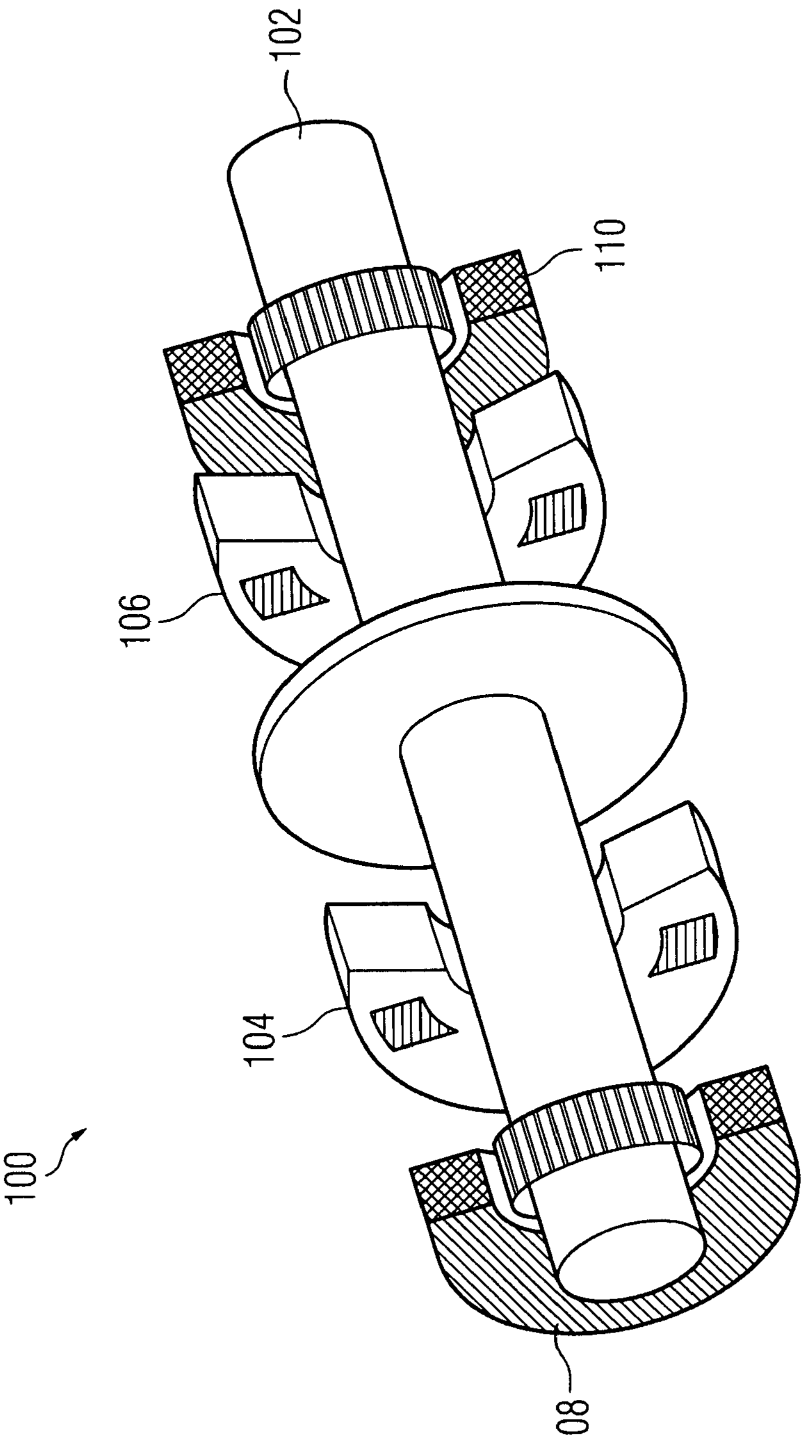

FIG 2

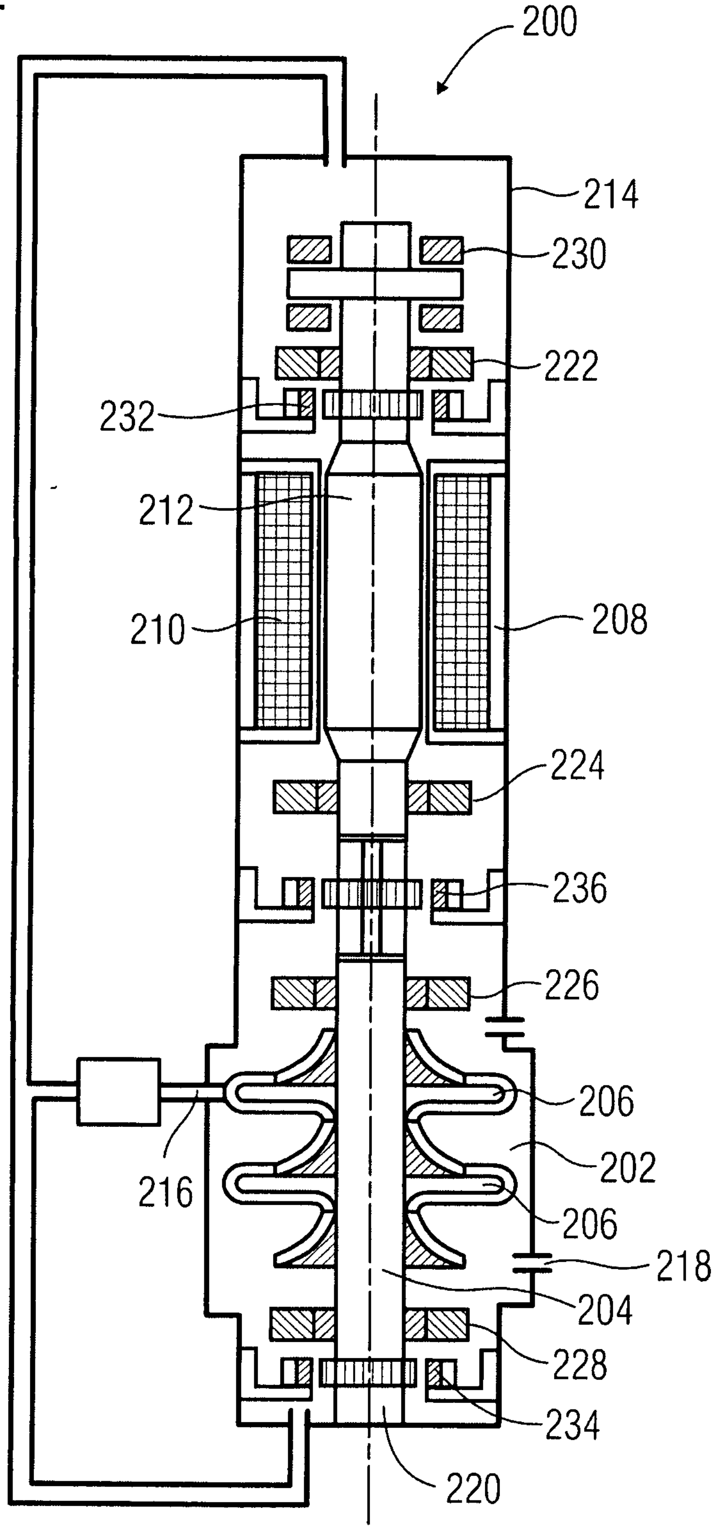
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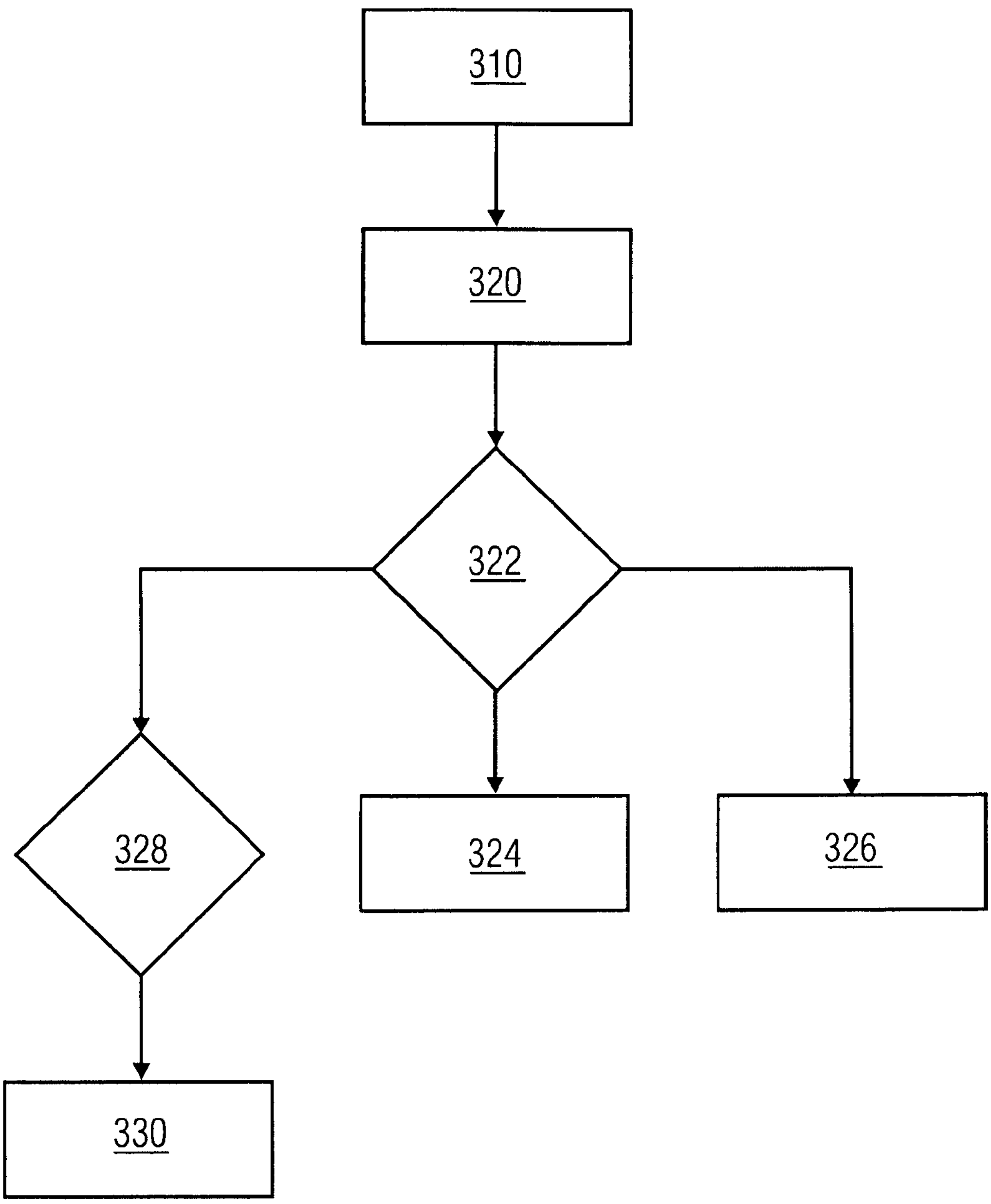
FIG 3



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EUROPEAN SEARCH REPORT

Application Number
EP 10 00 5424

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 5 547 350 A (RAWAL DHARAMENDRA N [US] ET AL) 20 August 1996 (1996-08-20) * the whole document * * figure 5 * * column 5, lines 32-49 *	1-15	INV. F04D29/058 F04D29/048
X	WO 2009/137316 A1 (FMC TECHNOLOGIES [US]; CUNNINGHAM CHRISTOPHER E [US]; FANTOFT RUNE [NO]) 12 November 2009 (2009-11-12) * the whole document * * page 11, line 28 - page 12, line 5 * * figure 3 *	1-15	
X	US 4 379 598 A (GOLDOWSKY MICHAEL P) 12 April 1983 (1983-04-12) * figure 12 *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)
F04D
F16C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	26 October 2010	Ingelbrecht, Peter

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 10 00 5424

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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26-10-2010

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82