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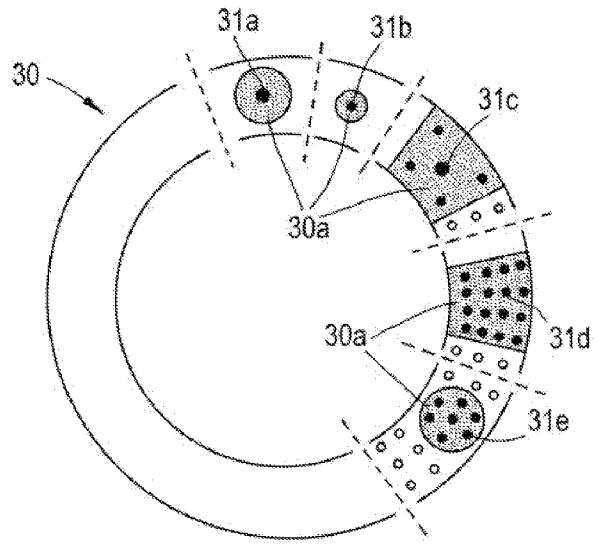
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(54) Title: MAGNETIC GEAR ARRANGEMENT

Fig.5



(57) Abstract: A magnetic gear arrangement comprises: a first gear member for generating a first magnetic field, a second gear member for generating a second magnetic field, and a coupling device which provides arrangements of interpoles between the first gear member and the second gear member. The interpoles couple the first and second magnetic fields such that different arrangements of interpoles produce different gearings between the first and second gear members. The coupling device comprises a superconducting body having a critical temperature and further comprises a plurality of temperature control elements for heating respective regions of the superconducting body. When heated above the critical temperature each region becomes active to at least partly form a respective interpole, and when cooled below the critical temperature each region becomes inactive.

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MAGNETIC GEAR ARRANGEMENT

The present invention relates to magnetic gear arrangements, particularly magnetic gear arrangements having a variable gear ratio.

Gearboxes and gear arrangements are utilised in a wide range of situations in order to couple drive mechanisms. Traditionally, gearboxes have been formed from gear wheels having appropriate teeth numbers and sizes to provide a desired gear ratio. However, such gearboxes have a number of disadvantages. Firstly, they require the use of lubricating oils, which may act as contaminants or fire hazards and may prove ineffective in hot or cold environments, where the oil viscosity varies, or in a low pressure environment, where the oil may evaporate. Furthermore, gearboxes based on gear wheels may be noisy, making them unacceptable for low noise environments such as in hospitals, libraries and residential areas, or for clandestine military activities.

More recently, magnetic gearboxes have been provided which comprise respective gear rotors with interpoles between them. The rotors incorporate permanent magnets, and the interpoles act to modulate the magnetic flux transferred between the gear rotors. Such magnetic gearboxes enable a speed-changing mechanical device to be provided in which there is no mechanical contact between input and output shafts, thus avoiding many of the problems of noise and wear that arise in gearboxes having contacting moving parts.

Figure 1 shows a schematic cross-sectional view of a magnetic gear arrangement of the prior art. The magnetic gear arrangement 200 is an epicyclic gearbox and comprises an inner rotor 202 and an outer rotor 206. Permanent magnets providing respective pole pairs 204, 208 are fixed to the inner and outer rotors 202, 206, the opposing poles of each permanent magnet being respectively indicated by dark and light shading. The permanent magnets 204 affixed to the inner rotor 202 have alternating polarity along the circumference of the rotor. Similarly, the permanent magnets 208 affixed to the outer rotor 206 have alternating polarity along the circumference of that rotor. Typically, one rotor is mechanically coupled to a drive mechanism and the other rotor is mechanically coupled to a driven mechanism.

The inner and outer rotors 202, 206 have different numbers of pole pairs 204, 208. Typically, the number of pole pairs of the outer rotor 206 is greater than the number of pole pairs of the inner rotor 202.

Pole elements 210 are provided between the inner rotor 202 and the outer rotor 206 and form an array to provide a coupling element having a cylindrical shape.

Each pole element 210 forms one interpole for modulating the magnetic fields produced by the inner rotor 202 and the outer rotor 206, so as to couple the two fields and hence the motion of the rotors. The angular position of the interpoles is a factor in determining the gearing of the magnetic gearbox.

The motion of the rotors 202, 206 may be either co-rotational or counter-rotational, depending on the number of magnets affixed to each rotor and the angular position/number of interpoles.

WO 2007/135369 discusses a variety of magnetic gear arrangements.

It is desirable to provide gearboxes in which the number and/or spacing of interpoles, or the torque transmission capability of the coupling element is adjustable.

In general terms, the present invention provides a magnetic gear arrangement in which the number and/or torque carrying capacity of interpoles may be adjusted by varying the temperature of the elements that provide the interpoles.

In particular, a first aspect of the present invention provides a magnetic gear arrangement comprising:

a first gear member for generating a first magnetic field,

a second gear member for generating a second magnetic field, and

a coupling device which provides arrangements of interpoles between the first gear member and the second gear member, the interpoles coupling the first and second magnetic fields such that different arrangements of interpoles produce different gearings between the first and second gear members;

wherein the coupling device comprises a superconducting body having a critical temperature and further comprises a plurality of temperature control elements for heating respective regions of the superconducting body, such that when heated above the critical temperature each region becomes active to at

least partly form a respective interpole, and when cooled below the critical temperature each region becomes inactive. By a “different gearing” is meant a different gearing ratio between the first and second gear member and/or a different direction of relative movement between the first and second gear member. By a “different arrangement of interpoles” is meant a different number and/or distribution of interpoles in the coupling device, including the possibility that when the regions become inactive, no interpoles are provided, such that the first and second gear members are decoupled.

Above the critical temperature, the regions are permeable to magnetic fields and are thus able to participate in coupling the magnetic flux of the first and second magnetic fields. Below the critical temperature, however, the Meissner effect causes the regions to repel surrounding magnetic fields. Thus simply varying the temperatures of the regions can change the type and/or extent of coupling between the first and second gear members.

Advantageously, the coupling device can avoid using iron-based interpoles, and therefore avoid the consequent problems of magnetic saturation associated with ferromagnetic materials (typically of around 2T). The coupling device may thus be compatible with higher flux density superconducting fields, which can lead to an improved torque carrying capacity in the arrangement.

The magnetic gear arrangement may have any one or, to the extent that they are compatible, any combination of the following optional features.

Typically, the first and the second gear members move relative to each during operation of the gear arrangement, and the coupling device is stationary. However, some arrangements may be configured so that the coupling device moves relative to one of the gear members during operation of the gear arrangement, and the other gear member is stationary. Alternatively both gear members and the coupling device could be free to move

The temperature control elements may be electrical resistance heating elements. However, non electrical heating elements may also be possible. For example, the heating elements may be thermally conductive members extending through the superconducting body, the thermally conductive members extending to a source of heat. Alternatively, the superconducting body could be cooled by coolant passages extending through the body, and the temperature control

elements may be passive elements such as valves which can be controlled to prevent the flow of coolant to selected passages, thereby forming heated regions in the superconducting material surrounding those passages. The coupling device may have thermally insulating elements which reduce the flow of heat from the heated regions to the rest of the superconducting body.

The first gear member may have ferromagnets, superconducting magnets, or coils (superconducting or otherwise) for generating the first magnetic field. Likewise, the second gear member may have ferromagnets, superconducting magnets, or coils (superconducting or otherwise) for generating the second magnetic field. Preferably, however, the first gear member has superconducting magnets or coils for generating the first magnetic field and the second gear member has superconducting magnets or coils for generating the second magnetic field. Superconducting magnets or coils can produce higher flux densities than ferromagnets or non-superconducting coils. In addition, gear members with superconducting magnets may be easier to manufacture than gear members with ferromagnets, since the superconducting magnets can be magnetised in situ, e.g. using flux pumping. However, the magnetic fields of the first and second gear members could be generated by ferromagnets or electrical windings.

Preferably, activating different arrangements of regions provides different arrangements of interpoles. In this way, a different gearing between the first and second gear members can be produced.

Deactivating at least some of the regions, or partially deactivating at least some of the regions, typically reduces the magnetically permeable cross-sectional areas of the respective interpoles to reduce the torque transmission capability of the coupling device. However, when regions are deactivated, the arrangement of interpoles, and thus the gear ratio, can remain unchanged. In this way, different torque limits can be placed on the same interpole arrangement.

For example, a first arrangement of interpoles can be provided by heating a first set of regions above the critical temperature, and hence activating those regions. A second set of regions are not heated and are therefore inactive. Thus only the first set of regions forms interpoles. However, a second

arrangement of interpoles can be provided by also heating the second set of regions above the critical temperature. Both sets of regions are then activated to form the second arrangement. The change from the first to the second interpole arrangement, or vice versa, can be effected simply by heating different regions of the superconducting body. The magnetic gear arrangement can be configured such that a change from a first interpole arrangement to a second interpole arrangement results in a reversal of the direction of rotation of the second gear member relative to the first gear member. However, in other embodiments, both interpole arrangements provide co-rotational gear members, or both interpole arrangements may provide counter-rotational gear members.

When none of the regions are heated, all the regions are in a superconducting state and are therefore inactive. If no active regions are available to provide interpoles for coupling the first and second magnetic fields, the coupling device can no longer transfer power between the first and second gear members.

The magnetic gear arrangement may be configured such that each heated region forms a single interpole. In this case, the number of interpoles will decrease when regions are cooled below the critical temperature. The gear arrangement will typically exhibit counter-rotating motion of the first and second gear members in the second arrangement of interpoles when both sets of regions are heated, and co-rotating motion of the first and second gear members in the first arrangement of interpoles when only one set of regions is heated.

Alternatively, the magnetic gear arrangement may be configured such that at least one interpole in an arrangement of interpoles may be formed by a group of neighbouring active regions. That is, the coupling device may include a plurality of neighbouring regions that are sufficiently close together such that when they are all active, they provide a single interpole for the purposes of determining the gear ratio between the first and second gear members.

Preferably, the interpoles are formed entirely by the regions. In this way, cooling the regions below the critical temperature prevents the coupling device from transmitting torque between the first and the second gear members. That is, the gear arrangement can have a clutch functionality.

The magnetic gear arrangement may further comprise a separator element between the first gear member and the second gear member, the separator element being formed of a superconducting material, wherein the separator element prevents or discourages magnetic flux extending between the first and second gear members but bypassing the coupling device. Preferably, the critical temperature of the separator element is equal to or greater than the critical temperature of the superconducting body, so that when the separator element and the body are cooled to the same temperature below the critical temperature of the body they can both be in a superconducting state.

The magnetic gear arrangement may further comprise a housing for the first and second gear members and the coupling device, the housing being formed of a superconducting material. Preferably, the critical temperature of the housing is equal to or greater than the critical temperature of the superconducting body, so that when the housing and the body are cooled to the same temperature below the critical temperature of the body they can both be in a superconducting state. Such an arrangement may be particularly advantageous if the gear members have superconducting magnets or coils. The housing can then contain the very strong magnetic field which may be produced by the magnets.

Preferably, the magnetic gear arrangement further comprises a temperature controller for controlling the temperature of at least some of the heated regions such that, under the control of the temperature controller, the temperatures of heated regions can cross their respective critical temperatures and thereby change from active to inactive or the reverse.

For example, the temperature controller and coupling device may be configured such that the temperature controller varies the temperatures of all the heated regions of the coupling device, all the heated regions having substantially the same temperature. Alternatively, the temperature controller and coupling device may be configured such that the temperature controller varies the temperatures of only a selected portion of the heated regions.

The action of the temperature controller may itself be determined by the operating condition of the first and/or second gear member. For example, the magnetic gear arrangement may further comprise a sensor for detecting the

operating condition of the first and/or second gear member and communicating the operating condition to the temperature controller. The sensor may detect the speed of the first and/or second gear members, and/or the torque transmitted by them. The data gathered by the sensor can then be used to activate the temperature controller when a predetermined operational condition of the gear arrangement is attained.

The first and second gear members typically have respective mechanical couplings. These couplings typically connect a drive mechanism and a driven mechanism.

Typically, the magnetic gear arrangement further comprises a cooling system for the superconducting body of the coupling device. If the magnets or coils on the gear members are non-superconducting, the cooling system may only need to cool the coupling device itself. However, if the gear members have superconducting magnets or coils, then the cooling system preferably cools the gear members as well. The cooling system may then require seals for mechanical couplings to the gear members to enter the cooled region.

The magnetic gear arrangement may be an inline gear arrangement, an epicyclic gear arrangement, or may have a different configuration. The gear members may be rotors or linear gear members.

A second aspect of the present invention provides a method of operating a magnetic gear arrangement, the method comprising:

providing a magnetic gear arrangement according to the first aspect; and

controlling the temperature of at least some of the heated regions such that the temperatures of heated regions cross their respective critical temperatures, and thereby change from active to inactive or the reverse.

The magnetic gear arrangement of the method may have any one or, to the extent that they are compatible, any combination of the optional features of the magnetic gear arrangement of the first aspect.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a schematic cross-sectional view of a magnetic gear arrangement of the prior art;

Figure 2 shows schematically a magnetic in-line gearbox without its cylindrical coupling device in place in (a) an end-on view of a first rotor of the gearbox, (b) an end-on view of a second rotor of the gearbox, and (c) a side view;

Figure 3 shows schematically the gearbox of Figure 2 with the coupling device in place in (a) an end-on view of the first rotor and the coupling device, (b) an end-on of the second rotor and the coupling device, and (c) a side view;

Figure 4 shows schematically (a) an end view, and (b) a side view of the coupling device of Figure 3;

Figure 5 shows schematically a cross-sectional view through a further cylindrical coupling device;

Figure 6 shows schematically a side view of another in-line gearbox;

Figure 7 shows a schematic cross-sectional view of an epicyclic magnetic gearbox;

Figure 8 shows schematically a linear gear arrangement; and

Figure 9 shows schematically a further linear gear arrangement.

A magnetic gear arrangement takes the form of an in-line gearbox having a first rotor 12 (i.e. a first gear member), a second rotor 16 (i.e. a second gear member), and a cylindrical coupling device 20. Figure 2 shows schematically the gearbox without the coupling device in place in (a) an end-on view of the first rotor, (b) an end-on view of the second rotor, and (c) a side view. Figure 3 shows schematically the gearbox with the coupling device in place in (a) an end-on view of the first rotor and the coupling device, (b) an end-on of the second rotor and the coupling device, and (c) a side view.

Superconducting permanent magnets fixed to the first 12 and second 16 rotors form respective pole pairs 14, 18, the opposing poles of each magnet being respectively indicated by dark and light shading. The pole pairs 14 of the first rotor have alternating polarity along the circumference of the rotor. Similarly, the pole pairs 18 of the second rotor have alternating polarity along the circumference of that rotor. Respective drive shafts 13, 15 extend from the rotors.

The first 12 and second 16 rotors have different numbers of pole pairs 14, 18. In the embodiment of Figures 2 and 3, the first rotor is shown with four pole pairs, and second rotor is shown with 22 pole pairs.

The coupling device 20 is formed from a cylinder of superconducting material. Above its critical temperature, the material preferably provides a high magnetic permeability to encourage magnetic flux to extend through the material in preference to e.g. surrounding air, and also preferably has a high flux density saturation level. Below its critical temperature, the material repels magnetic fields due to the Meissner effect and thus is inactive in coupling the magnetic flux. In the gearbox, the coupling device is cooled, e.g. by a coolant, to a temperature below the critical temperature.

Figure 4 shows schematically (a) an end view, and (b) a side view of the coupling device 20. Electrical conductors 21 extend from end to end of the cylinder, the conductors heating surrounding regions 20a of the cylinder by resistive heating. Thus respective locally heated regions are formed around the conductors. In these regions, the superconducting material is locally above its critical temperature, and thus permeable to the magnetic fields generated by the first 12 and second 16 rotors. The extent of the heated regions depends on factors such as the thermal conductivity of the superconducting material, the heat flow from the conductors, and the effectiveness of the coolant. Thermally insulating elements (not shown) may be included in the coupling device to reduce the flow of heat from the heated regions to the non-heated regions of the device. For example, the superconducting material of the device may have recesses, slots or gaps which receive sheets of thermally insulating material and which define the boundaries of the heated regions.

The current flowing through the electrical conductors 21 produces a magnetic field which could interact with the fields generated by the first 12 and second 16 rotors to produce an unwanted reaction force in the coupling device. To eliminate or reduce this effect, the conductors can be arranged, e.g. as twisted wire pairs with the current in each wire of the pair flowing in a different direction. With such an arrangement the magnetic field produced by one wire is cancelled out by the magnetic field produced by the other wire of the pair.

The electrical conductors 21 are typically electrically insulated from the surrounding superconducting material, but not thermally insulated.

The cylinder of superconducting material of the coupling device 20 is held at superconducting temperatures (i.e. below the critical temperature) by the coolant. Energising the electrical conductors 21 produces the heated regions 20a around the conductors. The heated regions, thus activated, form interpoles for coupling the first and second magnetic fields. Although formed by heating, these interpoles are analogous to the interpoles formed by the pole elements 210 of the prior art magnetic gear arrangement of Figure 1. The number and distribution of interpoles is a factor in controlling the gearing of the gearbox.

In Figure 4 the electrical conductors 21, and hence the heated regions 20a, extend from end to end of the cylindrical coupling device 20. However, other paths for the electrical conductors are possible. For example, the conductors could turn towards the rotors 12, 16 at the ends of the cylinder to encourage the magnetic fields generated by the rotors to enter the heated regions of the coupling device.

A sheet of further superconducting material may be positioned between the in-line rotors 12, 16 to prevent magnetic flux from travelling directly from one rotor to the other (bypassing the interpoles). The critical temperature of the separator element can be equal to or greater than the critical temperature of the coupling device 20 so that they are both in a superconducting state when they are cooled by the coolant to the same temperature below the critical temperature of the device.

If the cylindrical coupling device 20 is extended beyond the rotors 12, 16, the ends of the cylinder can be closed off around the rotors (with holes in the end walls to accommodate the drive shafts 13, 15) to form an enclosing housing for the gearbox. This can provide shielding (by the Meissner effect) to contain the high magnetic fields which may be formed in the gearbox, limiting the interference they may cause to other systems. This might be beneficial e.g. in submarine applications.

The coupling device 20 can have different numbers and arrangements of electrical conductors 21 in order to produce different shapes, sizes and arrangements of heated regions 20a. In particular, changing the angular

positions of the interpoles formed by the heated regions allows the gearbox gear ratio and/or relative direction of rotation to be changed, depending on the number of pole pairs on each rotor. Further, varying the cross-sectional area of the heated regions allows the amount of torque that can be transmitted by the coupling device to be correspondingly varied, i.e. smaller cross-sections allow less torque to be passed from rotor to rotor. The shape of the heated region can have a filtering effect on the magnetic fields, allowing harmonics to be introduced or removed.

Figure 5 shows schematically a cross-sectional view through a further cylindrical coupling device 30, and illustrates different arrangements of electrical conductors 31a-e and different modes of operation (it is unlikely that all the different conductor arrangements would be used in an one device). The areas shaded grey are heated regions 30a whose temperatures are held above the critical temperature of the superconducting material of the coupling device by heat flowing from the conductors. Electrical conductors shown as black circles are carrying current, and hence heating the surrounding material. Larger black circles indicate higher currents and therefore more heating. Electrical conductors shown as grey circles are not carrying current. Conductor 31a carries a higher current than conductor 31b and thus produces a correspondingly larger heated region, such that the interpole formed by the heated region has an increased torque-carrying capability. Conductors 31c have a central conductor carrying a relatively high current and outer conductors carrying a relatively low current to produce an approximately rectangular cross-sectioned heated region. Conductors 31d all carry the same current and are distributed in order to also produce an approximately rectangular cross-sectioned heated region. Conductors 31e are distributed in a similar way to conductors 31d, but only a central group of the conductors 31e carry current, thereby producing a smaller heated region and reducing the torque-carrying capability of the interpole formed by the heated region.

The electrical conductors 31a-e can be under the control of a temperature controller (not shown) which is able to switch the conductors on and off, and set the level of current to the conductors, in order to achieve different coupling

effects. In general, the higher the conductor density within the coupling device 30, the greater the number of interpole arrangements that can be produced.

The conductors can be energised separately, or connected in series or parallel. They may receive an AC or DC supply. A poly-phase AC supply can be used to produce a rotating pattern of heated regions and hence of interpoles, offering a means for controlling or altering the speed of the rotors as long as the rate at which the heated regions can be activated and deactivated is compatible with the desired speed of rotation of the pattern. The rate of activation and deactivation is likely to be determined to a significant extent by the thermal properties of the superconducting material.

Many different magnetic gear arrangements are possible. Figure 6 shows schematically a side view of an in-line gearbox 40 similar to the gearbox of Figures 2 and 3, but with the magnets on the end faces of the rotors 42, 46 producing respective pole pairs 44, 48, and the coupling device 50 formed as a superconducting cylinder positioned between the rotors.

Figure 7 shows a schematic cross-sectional view of a magnetic gear arrangement according to another embodiment of the present invention. The magnetic gear arrangement is in the form of an epicyclic gearbox 60 and comprises an inner rotor 62 and an outer rotor 66. Superconducting permanent magnets fixed to the inner and outer rotors form respective pole pairs 64, 68. A coupling device 70 between the rotors 62, 66 has a cylindrical superconducting body, with axially extending heated regions 70a forming an arrangement of interpoles for coupling the magnetic fields of the rotors.

As well as rotary gear arrangements, the present invention can also be applied to e.g. linear gear arrangements. Figure 8 shows schematically a linear gear arrangement 70 having a low speed member 72 and a high speed member 76. Magnetic poles 74, 78 of alternating polarity are provided by magnets or coils on the members. Between the low and high speed members is a coupling device 80 formed as a linearly extending body. Electrical conductors 81 embedded in the body produce heated regions 80a which form respective interpoles. Figure 9 shows schematically a further linear gear arrangement 90 having a low speed tubular member 92 and a coaxial high speed central shaft member 96. Magnetic poles 94, 98 of alternating polarity are provided by

magnets or coils on the members. Between the low and high speed tubular members is a coupling device 100 formed as a coaxial superconducting tube. Electrical conductors 101 embedded in the tube produce heated regions 100a which form respective interpoles.

Advantageously, the superconducting bodies of the coupling devices described above are compatible with a superconducting magnetic field. For example, the superconducting field could be between 10 and 17T – leading to very dense gearboxes.

While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the spirit and scope of the invention.

CLAIMS

1. A magnetic gear arrangement comprising:

a first gear member for generating a first magnetic field,

a second gear member for generating a second magnetic field, and

a coupling device which provides arrangements of interpoles between the first gear member and the second gear member, the interpoles coupling the first and second magnetic fields such that different arrangements of interpoles produce different gearings between the first and second gear members;

wherein the coupling device comprises a superconducting body having a critical temperature and further comprises a plurality of temperature control elements for heating respective regions of the superconducting body, such that when heated above the critical temperature each region becomes active to at least partly form a respective interpole, and when cooled below the critical temperature each region becomes inactive.

2. A magnetic gear arrangement according to claim 1, wherein the first gear member has superconducting magnets or coils for generating the first magnetic field and the second gear member has superconducting magnets or coils for generating the second magnetic field.

3. A magnetic gear arrangement according to claim 1 or 2, wherein activating different arrangements of regions provides different arrangements of interpoles.

4. A magnetic gear arrangement according to any one of the previous claims, wherein deactivating at least some of the regions, or partially deactivating at least some of the regions, typically reduces magnetically permeable cross-sectional areas of the respective interpoles to reduce the torque transmission capability of the coupling device.

5. A magnetic gear arrangement according to any one of the previous claims, wherein the interpoles are formed entirely by the regions.

6. A magnetic gear arrangement according to any one of the previous claims further comprising a separator element between the first gear member and the second gear member, the separator element being formed of a superconducting material, wherein the separator element prevents or discourages magnetic flux

extending between the first and second gear members but bypassing the coupling device.

7. A magnetic gear arrangement according to any one of the previous claims further comprising a housing for the first and second gear members and the coupling device, the housing being formed of a superconducting material.

8. A magnetic gear arrangement according to any one of the previous claims, further comprising a temperature controller for controlling the temperature of at least some of the heated regions such that, under the control of the temperature controller, the temperatures of heated regions can cross their respective critical temperatures and thereby change from active to inactive or the reverse.

9. A magnetic gear arrangement according to claim 8, wherein the action of the temperature controller is itself determined by the operating condition of the first and/or second gear member.

10. A magnetic gear arrangement according to claim 19, further comprising a sensor for detecting the operating condition of the first and/or second gear member and communicating the operating condition to the temperature controller.

11. A method of operating a magnetic gear arrangement, the method comprising:

providing a magnetic gear arrangement according to any one of the previous claims; and

controlling the temperature of at least some of the heated regions such that the temperatures of heated regions cross their respective critical temperatures, and thereby change from active to inactive or the reverse.

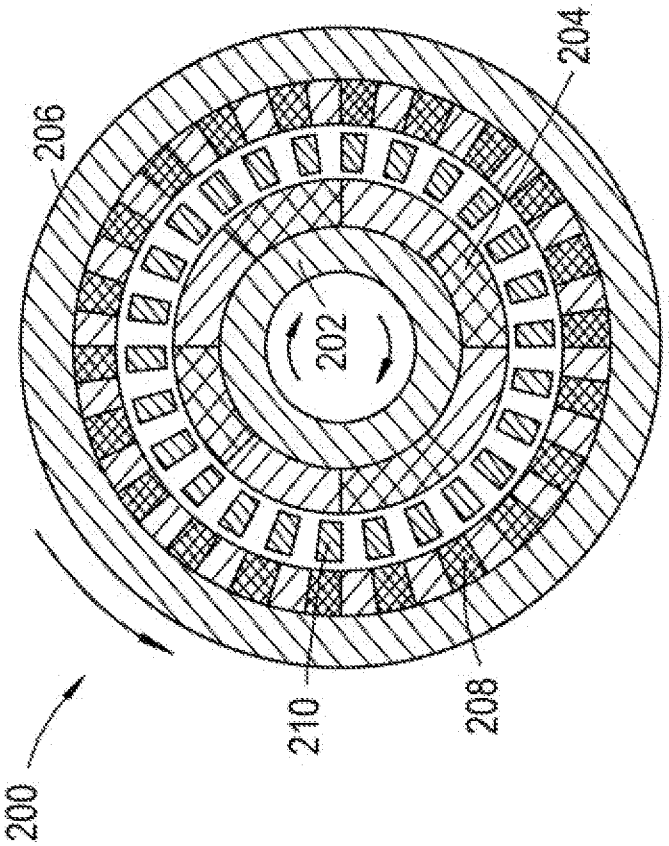


Fig.1

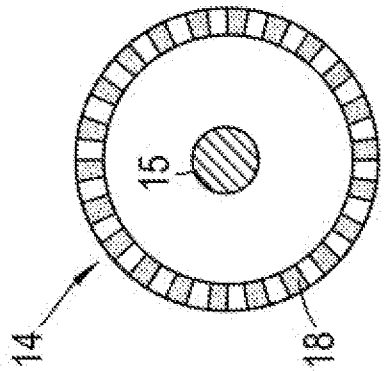


Fig.2(b)

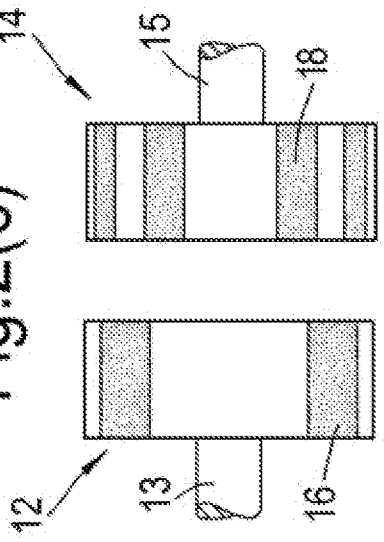


Fig.2(c)

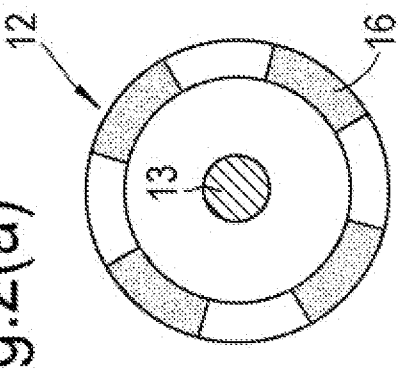


Fig.2(a)

Fig.3(a)

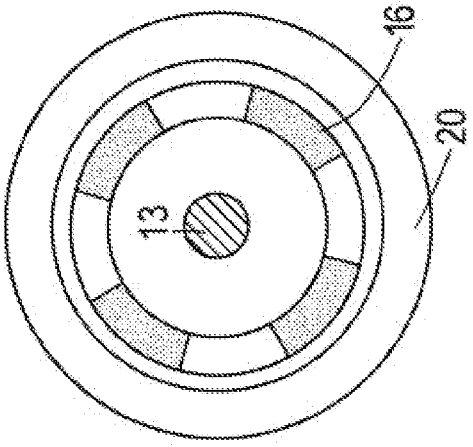


Fig.3(c)

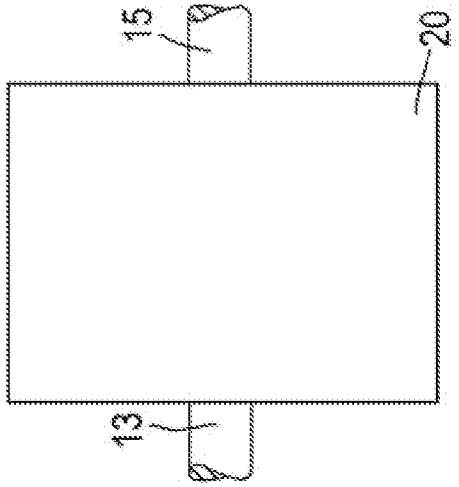


Fig.3(b)

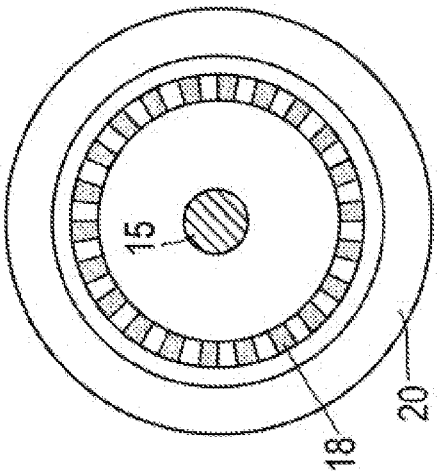


Fig.4(a)

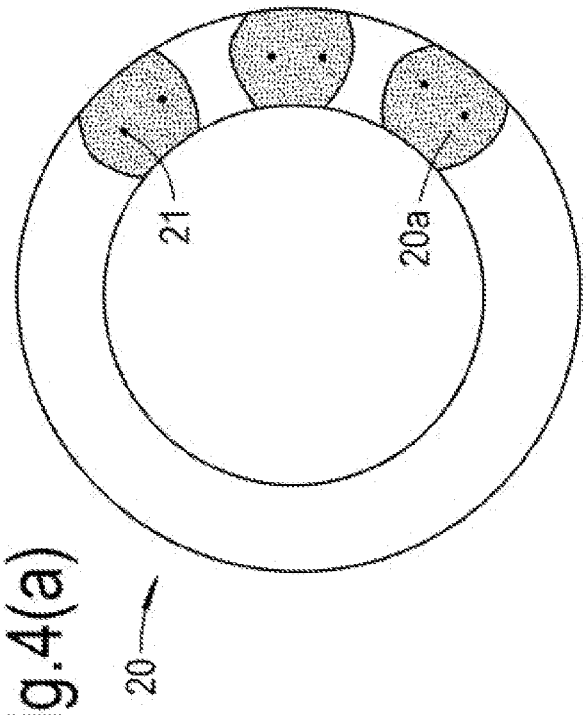


Fig.4(b)

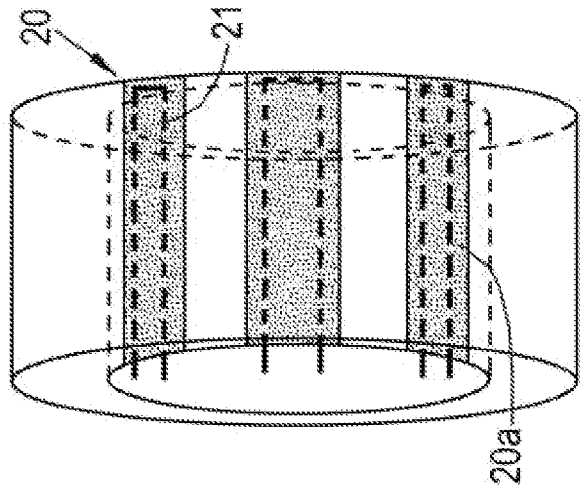


Fig.5

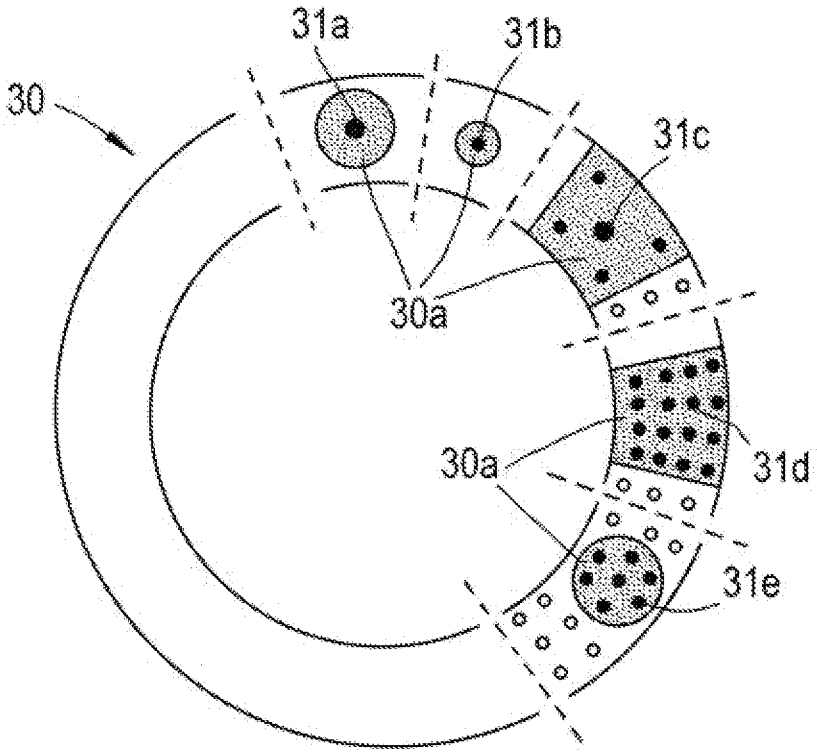


Fig.6

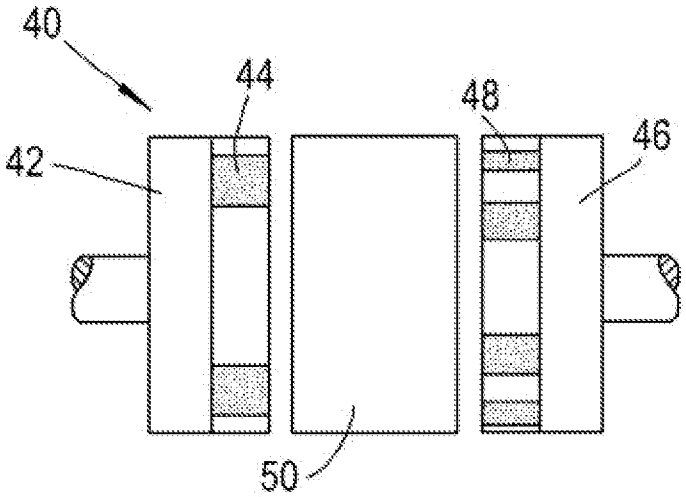


Fig.7

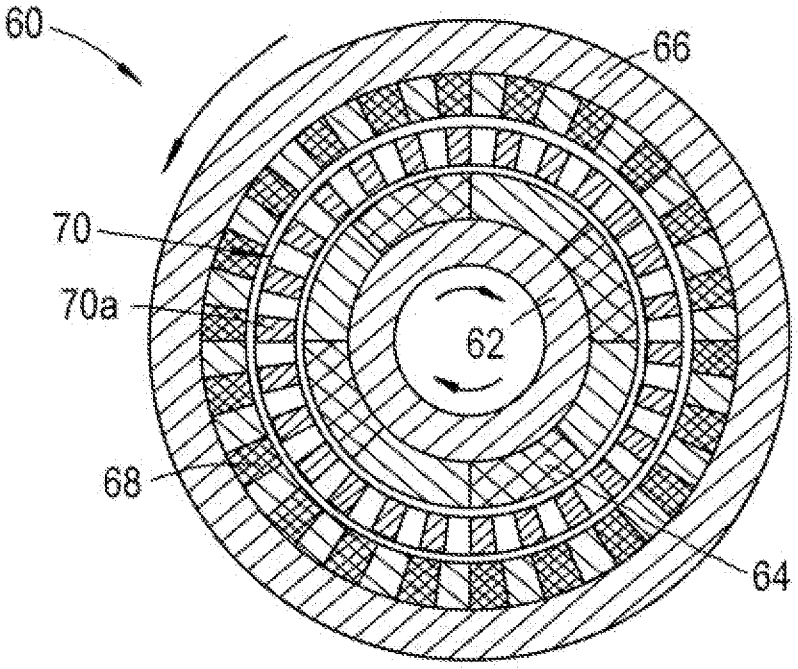


Fig.8

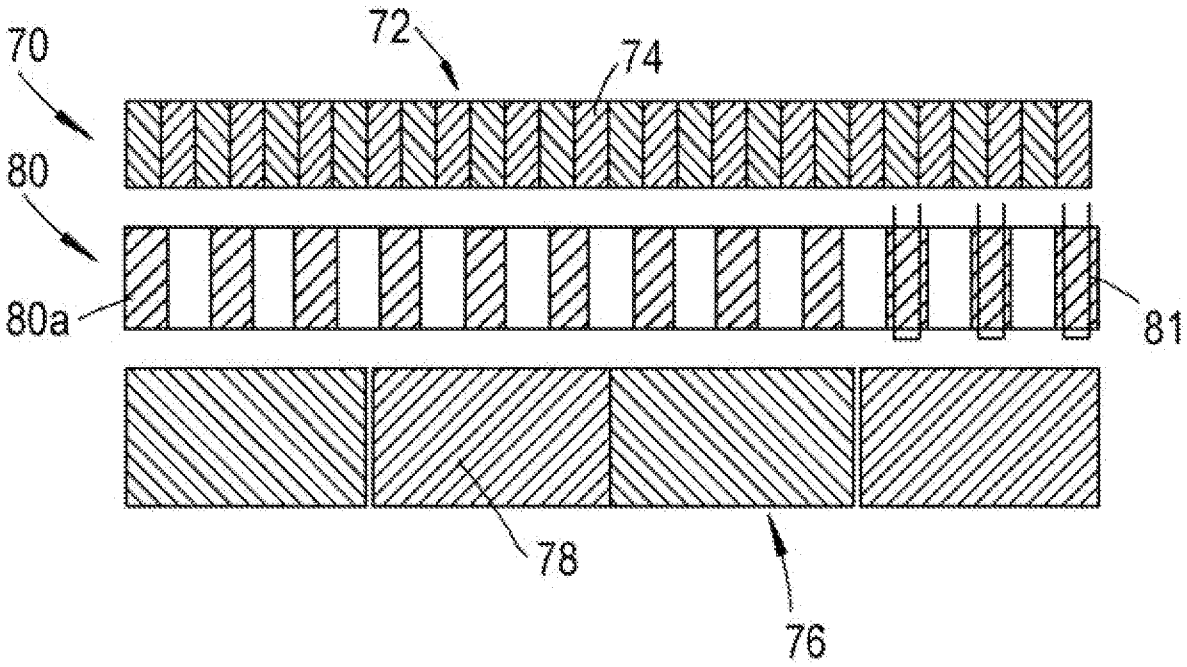
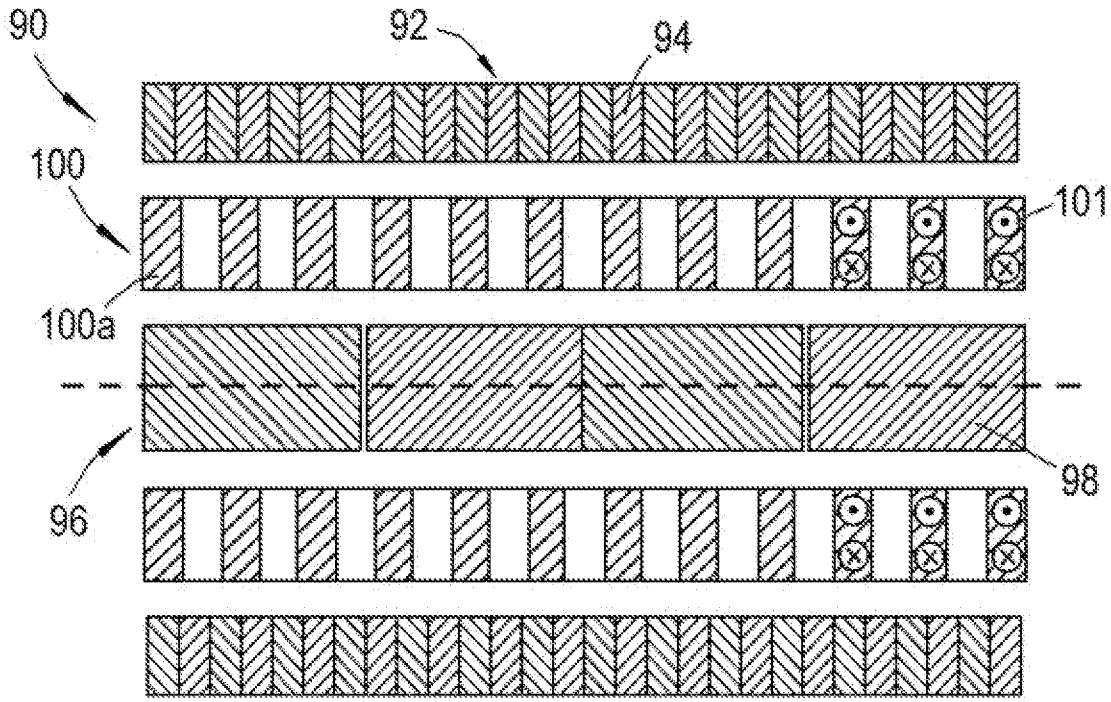


Fig.9



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/070376

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02K49/10 F16H49/00
ADD.

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 F16H

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2007/107691 A1 (ROLLS ROYCE PLC [GB]; BRIGHT CHRISTOPHER GRAHAM [GB]) 27 September 2007 (2007-09-27) page 3, line 14 - page 5, line 2; figure 1	1-11
A	JP 1 138962 A (MATSUSHITA ELECTRIC IND CO LTD) 31 May 1989 (1989-05-31) abstract; figures 1-4	1-11
A	JP 1 026361 A (HITACHI LTD) 27 January 1989 (1989-01-27) abstract; figures 1,2	2

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 May 2011	24/05/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sedlmeyer, Rafael

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2010/070376

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2007107691 A1	27-09-2007	GB 2447592 A	17-09-2008
		US 2010090552 A1	15-04-2010
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