Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3105810 C 2022/08/02

(11)(21) 3 105 810

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(22) Date de dépôt/Filing Date: 2010/01/29

(41) Mise à la disp. pub./Open to Public Insp.: 2010/09/16

(45) Date de délivrance/Issue Date: 2022/08/02

(62) Demande originale/Original Application: 3 007 550

(30) Priorité/Priority: 2009/03/10 (NZ575464)

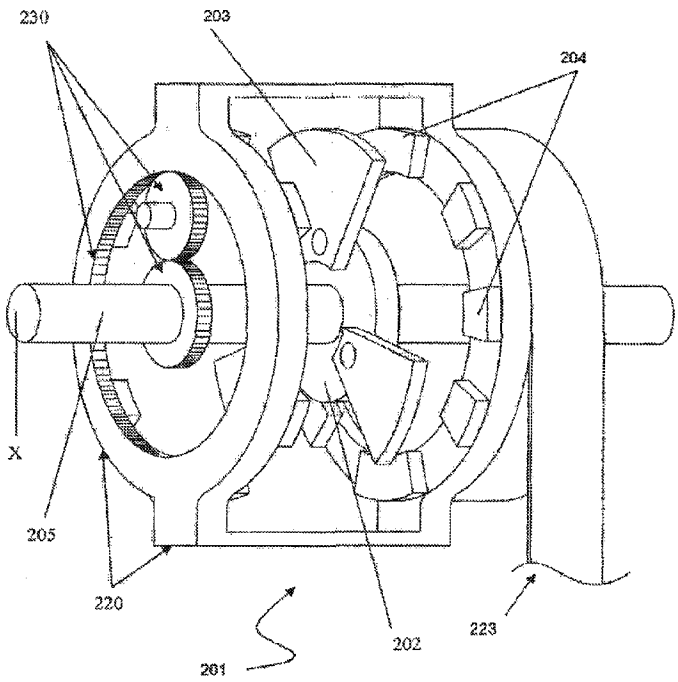
(51) Cl.Int./Int.Cl. *H02K 49/04* (2006.01)

(72) Inventeurs/Inventors:
ALLINGTON, CHRISTOPHER JAMES, NZ;
DIEHL, ANDREW KARL, NZ;
ROBERTSON, BRUCE JOHN, NZ

(73) Propriétaire/Owner:
EDDY CURRENT LIMITED PARTNERSHIP, NZ

(74) Agent: RIDOUT & MAYBEE LLP

(54) Titre : MECANISMES DE FREINAGE
(54) Title: BRAKING MECHANISMS



(57) Abrégé/Abstract:
An eddy-current braking mechanism including a rotor, rotatable about a rotor axis; at least one electrically conductive member coupled to the rotor for rotation therewith; at least one magnet configured to apply a magnetic field extending at least partially orthogonal to the plane of rotation of the conductive member, and characterised in that upon rotation of the rotor, the conductive member is configured to move at least partially radially from the rotor axis into the applied magnetic field.

ABSTRACT

An eddy-current braking mechanism including a rotor, rotatable about a rotor axis; at least one electrically conductive member coupled to the rotor for rotation therewith; at least one magnet configured to apply a magnetic field extending at least partially orthogonal to the plane of rotation of the conductive member, and characterised in that upon rotation of the rotor, the conductive member is configured to move at least partially radially from the rotor axis into the applied magnetic field.

Date Reçue/Date Received 2021-01-12

BRAKING MECHANISMS

TECHNICAL FIELD

The present invention relates to braking mechanisms and more particularly to an improved eddy-current braking mechanism.

BACKGROUND ART

Eddy-current braking systems are used in a range of applications to provide non-contact braking and offer a significant advantage over conventional friction brakes as there is no frictional contact between the braking surfaces.

Eddy-current brakes function on the principle that when a conductor moves through a magnetic field (or vice-versa) the relative motion induces circulating 'eddies' of electric current in the conductor. The current eddies in turn induce magnetic fields that oppose the effect of the applied magnetic field. Eddy-current brakes thus utilise the opposing magnetic fields to act as a brake on movement of the conductor in the magnetic field, or vice versa. The strength of the eddy current magnetic field, and therefore the opposing force is dependant on a number of factors including the:

- strength of the applied magnetic field;
- magnetic flux through the conductor;
- geometrical dimensions of the conductor and magnetic field, e.g. size, physical separation;

Date Reçue/Date Received 2021-01-12

- electrical conductivity of the conductor; and

- relative velocity between the conductor and magnetic field.

A variable braking force is thus achieved by varying any one or more of the above parameters.

To aid clarity and avoid prolixity, reference herein is made with respect to applications requiring a braking/retarding torque for rotating members and more particularly to an auto-belay system for which the present invention has particular application. However, reference herein to an auto-belay system should not be seen to be limiting as it will be appreciated by one skilled in the art that there are innumerable applications for eddy-current braking systems.

The speed of rotation (angular velocity) of the rotor with respect to the magnetic field will herein be referred to as the "rotation speed" or where convenient shortened to "speed".

Rotary plate-type eddy-current braking systems typically use a paramagnetic conductive disc that is configured to rotate in a plane orthogonal to a magnetic field applied by magnets positioned on one or both sides of the disc. The eddy currents, and corresponding magnetic field, are generated when the disc is rotated relative to the magnetic field. A braking torque is thereby applied to the rotating disc. A higher relative velocity between the conductor and magnets will result in a higher braking torque thereby potentially limiting the rotation speed.

The braking torque is linearly proportional to the speed only until a threshold 'characteristic speed' is reached. Above this characteristic speed the braking torque response to speed becomes non-linear and peaks before beginning to

Date Reçue/Date Received 2021-01-12

reduce with further speed increases. This characteristic is illustrated in Figure 1 which shows an approximate plot of braking torque against rotation speed for a typical disc-type eddy-current braking system. The characteristic speed is dependant on the resistivity of the disc which is dependant on the temperature, materials, magnetic permeability, and construction of the disc.

The braking torque of a typical eddy current disc system operating below the characteristic speed is determined approximately by the following relationship:

$$T \propto AdB^2R^2\omega$$

Where the braking torque T is proportional to:

A - the conductor surface area intersecting the magnetic field;

B^2 - applied magnetic field strength - squared;

d - thickness of the disc;

R^2 - the radius (distance) from the axis of rotation to the conductor in the magnetic field - squared;

ω - rotational speed.

A non-linear response of braking torque may thus be achieved by varying the magnetic field strength B and/or the distance to the center of rotation R.

The magnetic field can be supplied by permanent magnets and/or electro-magnets. The strength of the magnetic field is dependant on the magnetic field intensity and the configuration of the magnetic circuit, i.e. the materials used and spatial positions of the components in the system.

Date Reçue/Date Received 2021-01-12

For permanent magnet systems, variation of the magnetic circuit (e.g. variation in *A*, *d* or *R*) is the most effective way to alter the braking torque. Typical eddy-current brake systems thus position the magnets toward the periphery of the disc to maximise *R*.

Common magnetic circuit configurations utilise permanent magnets positioned on one or both sides of the disc with steel backing behind each magnet. The steel plates are provided to enhance the magnetic field strength while providing structural support for the magnets.

An auto-belay device is used in climbing, abseiling and the like to control the descent rate of the climber. The auto-belay also automatically retracts line when the climber is ascending to maintain line tension thus avoiding slack occurring in the line.

Existing auto-belay systems typically use a friction-brake or hydraulic dampening mechanism to control the descent rate. Friction-brakes clearly have disadvantages compared with eddy-current brakes as the frictional contact involves substantial heat generation, wear and corresponding safety problems. Hydraulic dampening mechanisms are expensive and vulnerable to leaks, pressure and calibration problems.

An ideal auto-belay system would provide a constant or controllable descent rate with minimal friction and corresponding wear while also providing sufficient braking force in a small compact device.

The prior art is replete with various eddy-current braking systems. However, none of the prior art systems appear suitable for application in an auto-belay or other

Date Reçue/Date Received 2021-01-12

applications where a constant speed of rotation is required where the torque applied may vary.

Typical prior art plate-type braking systems use various magnetic circuit configurations and have attendant pros and cons. Examples of typical prior art devices are described below.

One prior art plate-type eddy-current braking device is described in US 4,567,963 by *Sugimoto* and comprises a conductive disc coupled to a rotor via an overdrive gear arrangement to rotate the disc at a proportionally greater rotational speed than the rotor. The rotor includes a spool from which a line is dispensed. A series of permanent magnets are attached to an iron plate extending parallel to the disc's plane of rotation and spaced radially with respect to the axis of rotation. These magnets produce eddy-currents in the disc during rotation and, axiomatically, a corresponding magnetic field and braking effect. The *Sugimoto* system also includes radiator fins to assist in dissipation of the heat generated by the eddy-currents in the disc. The rotation of the rotor is retarded with an increasing force as the rotational speed (ω) increases. The overdrive arrangement provides an increased retardant force compared to a disc directly coupled to the rotor and thus, in the *Sugimoto* device, the aforementioned torque relationship would be similar to $T \propto AdB^2R^2k\omega$ where k is the overdrive gear ratio.

While the *Sugimoto* device may be more effective than simple plate-type systems it cannot be adjusted to vary the braking force applied and relies on an overdrive mechanism to improve braking force i.e. by increasing the relative speed between disc and magnetic field. The overdrive mechanism adds to cost, complexity, size, wear, increased heat generation and possibility of failure.

Date Reçue/Date Received 2021-01-12

Furthermore, the speed of rotation of the rotor will still vary with the applied torque.

The *Sugimoto* device has provided a larger braking effect relative to smaller devices by varying the rotational speed. However, the gear mechanism constrains the limits of size and thus the degree of miniaturisation possible. The *Sugimoto* device is thus undesirable for auto-belays which require a compact device with safe, reliable operation during frequent, and/or prolonged use.

A similar device to that of *Sugimoto* is described in US 5,342,000 by *Berges et al. Berges et al.* describe a plate-type eddy-current braking system with a centrifugal clutch that engages the eddy-current braking system when the rotor reaches a sufficient rotational speed.

It should be noted that neither the *Sugimoto* nor *Berges et al* devices can be adjusted to control the braking effect without disassembling and changing the overdrive gear ratios or magnet strength. Thus, these devices prove inconvenient in applications that need to accommodate different applied torques.

Attempts have been made at providing variable braking systems and exemplary devices are described in US 4,612,469 by *Muramatsu*, EP 1,480,320 by *Imanishi et al.*, US 3,721,394 by *Reiser* and US 6,460,828 by *Gersemsky et al.*

The *Muramatsu* device has a rotating disc with a manually adjustable position with respect to a magnet array, thus providing a means in which to vary the area (*A*) of magnetic field intercepted by the disc. The *Muramatsu* device may be adjustable to vary the braking effect and the maximum braking torque achievable but is still constrained by the size of the disc and strength of magnets, thus proving inconvenient where a smaller size is advantageous, e.g. for auto-belay devices. Furthermore, the *Muramatsu* device must be varied manually.

Date Reçue/Date Received 2021-01-12

The device described by *Imanashi et al* works on a similar principle to that described by *Muramatsu*. However, instead of varying the disc area intersected by the magnetic field, the *Imanashi et al* system uses a magnet array attached to a linear drive to move the array axially away or toward the disc to respectively reduce or increase the separation and the magnetic field flux the disc intersects. As with the *Muramatsu* device, the braking effect of the *Imanashi et al.* cannot be automatically adjusted to accommodate different applied torques.

An automatic version of the *Imanashi et al.* device is described in US 3,721,394 by *Reiser* and positions a line spool coupled to a conductive disc above a magnet array with a spring therebetween. As the line is unwound from the spool, the weight on the spring reduces and the spring extends, increasing the spacing between the disc and magnet and thereby decreasing the braking effect as the line is unwound. The spring is calibrated so that the speed of rotation of the spool remains constant as the line is unwound. The *Reiser* system is reliant on a static supporting arrangement and varying weight change in the spool and is thus unsuitable for an auto-belay device. Furthermore, the braking effect of the *Reiser* device varies only with rotation speed and magnetic field strength and not applied torque.

A brake for a hoist is described in US 6,460,828 by *Gersemsky et al.* and uses a magnetic circuit that varies the position of a magnet with respect to a rotating conductive disc. The magnet is attached to a free end of a pivoting arm with a spring attached to the free end and to a static point adjacent the disc. As the disc rotates, the eddy-currents induced provide a braking effect on the disc to inhibit rotation. A reactive force is applied to the magnet by the braking effect to pivot the arm to move the magnet radially outward to increase braking torque. The spring

Date Reçue/Date Received 2021-01-12

will compress and oppose this reactive force thereby providing a braking effect on the disc. Reverse rotation of the disc will result in an opposing reactive force that will force the magnet in an opposite direction, the spring then extending and opposing the reactive force to apply the braking effect. Thus, the *Gersemsky et al.* system provides a sufficient braking effect regardless of the direction of rotation of the disc. The radial movement of the magnet also increases braking effect as a result of increasing relative velocity.

The *Gersemsky et al.* system, while fulfilling its purpose, is limited in adaptability as the braking torque applied is dependant on only the relative velocity (proportional to speed of rotation and radius to axis of rotation) of the magnets. Furthermore, auto-belay devices typically require braking in only one direction and thus universal braking devices such as the *Gersemsky et al.* system may be unsuitable.

It would thus be advantageous to provide an eddy-current braking mechanism that is capable of limiting the speed of rotation of a rotor over a wide range of applied loads or torques.

It is an object of the present invention to address the foregoing problems or at least to provide the public with a useful choice.

All references, including any patents or patent applications cited in this specification may be referred to for understanding . No admission is made that any reference constitutes prior art. The discussion of the references states what their authors assert, and the applicants reserve the right to challenge the accuracy and pertinency of the cited documents. It will be clearly understood that, although a number of prior art publications are referred to herein; this reference does not

Date Reçue/Date Received 2021-01-12

constitute an admission that any of these documents form part of the common general knowledge in the art, in New Zealand or in any other country.

It is acknowledged that the term 'comprise' may, under varying jurisdictions, be attributed with either an exclusive or an inclusive meaning. For the purpose of this specification, and unless otherwise noted, the term 'comprise' shall have an inclusive meaning - i.e. that it will be taken to mean an inclusion of not only the listed components it directly references, but also other non-specified components or elements. This rationale will also be used when the term 'comprised' or 'comprising' is used in relation to one or more steps in a method or process.

Further aspects and advantages of the present invention will become apparent from the ensuing description which is given by way of example only.

DISCLOSURE OF INVENTION

According to a first aspect of the present invention there is provided an eddy-current braking mechanism including;

- a rotor, rotatable about a rotor axis;
- at least one electrically conductive member coupled to the rotor for rotation therewith;
- at least one magnet configured to apply a magnetic field extending at least partially orthogonal to the plane of rotation of the conductive member; and

Date Reçue/Date Received 2021-01-12

characterised in that upon rotation of the rotor, the conductive member is configured to move at least partially radially from the rotor axis into the applied magnetic field.

In general, movement of the conductive member through the applied magnetic field induces an eddy-current in the conductive member when the conductive member intersects the magnetic field.

To aid clarity and avoid prolixity, reference herein will be made to the conductive member being coupled to the rotor. However, it will be appreciated that a 'reverse' configuration is also possible and within the scope of the present invention. This 'reverse' configuration may have the magnet coupled to the rotor and configured to move toward a conductive member such that the conductive member will intersect the magnetic field.

To aid clarity and to avoid prolixity the present invention will be described herein with respect to a braking mechanism for an auto-belay for which the present invention has particular application. However, it should be appreciated that the present invention may be used in other rotary braking or retarding applications and thus reference herein to an auto-belay is exemplary only and should not be seen to be limiting.

It will also be appreciated that the present invention may also be used in linear braking applications by coupling the rotor to a linear device, e.g. by a cam or chain drive mechanism.

Reference herein to "radial" movement of the conductive member should be understood to include any movement with a component in a direction toward or

Date Reçue/Date Received 2021-01-12

away from the axis of rotation of the rotor and/or conductive member and should be interpreted to include both linear and non-linear radial movement.

Reference herein to "outward" radial movement refers to movement in a direction away from the axis of rotation and similarly "inward" refers to a direction toward the axis of rotation.

Reference herein to the conductive member being "coupled" to the rotor should be understood to mean any direct or indirect connection such that the conductive member rotates with the rotor. It should also be appreciated that connection need not be mechanical.

To aid clarity, the magnetic field applied by the magnet will herein be referred to as the "applied" magnetic field and the magnetic field(s) generated by eddy-currents in the conductive member are referred to as "reactive" magnetic field(s).

In preferred embodiments the eddy-current induced in the conductive member generates a reactive magnetic field opposing the applied magnetic field. The reactive force generated by the opposing 'applied' and 'reactive' magnetic fields is thus transferred to the conductive member to oppose movement thereof. As the conductive members are coupled to the rotor, the rotation of the rotor is also opposed by the reactive force.

As used herein, the terms "brake" or "braking" respectively refer to any apparatus or process for applying a force opposing movement of an object.

As used herein, the term "rotor" refers to any rotatable element and may include a: driveshaft, axle, gear, screw, disc, wheel, cog, combination thereof or any other rotatable member.

Date Reçue/Date Received 2021-01-12

As used herein, the term "conductive member" refers to any electrically conductive, preferably non-ferrous member

As used herein, the term "magnet" refers to any magnet or device capable of generating a magnetic field and may include electromagnets, 'permanent' magnets, 'temporary' magnets, magnetised ferromagnetic materials, or any combination thereof.

Preferably, the conductive member is configured to move at least partially radially from the rotor axis into the magnetic field.

Preferably the conductive member rotates with the rotor about the rotor axis.

It should be appreciated that the conductive member need not be directly connected to the rotor and could instead be connected via intermediate gears or other couplings. In such embodiments the gear or coupling attached to the conductive member can be considered the 'rotor' or part thereof.

It should also be appreciated that in such embodiments where the conductive member is indirectly coupled to the rotor, the conductive member may rotate about another axis parallel or non-parallel to the rotor axis.

In a further embodiment, the rotor may be coupled to an input shaft or the like via an overdrive, or underdrive, gear transmission arrangement, such that the rotor rotates at a different speed to that of the input shaft.

Preferably, the rotor is coupled to a spool of line and configured for rotation therewith. Thus, the rate of line dispensing, or retracting, from the spool can be controlled by controlling the speed of rotation of the rotor with the braking mechanism.

Date Reçue/Date Received 2021-01-12

Preferably, the braking mechanism includes a plurality of electrically conductive members (henceforth referred to simply as conductive members).

The braking effect may be increased by increasing the number of conductive members moving through the applied magnetic field. However, the number and size of the conductive members will be limited by the size and weight constraints of the application. Thus, for example, in auto-belay applications, preferably three said conductive members are provided.

Preferably, the conductive member is pivotally attached to the rotor and configured to pivot about a pivot axis to move at least partially radially into the applied magnetic field upon rotation of the rotor.

Preferably, the conductive member is pivotally attached to the rotor at a point eccentric to the rotor axis.

The conductive member preferably has a center of mass (or mass centroid) eccentric to the pivot and rotor axes. The conductive member will thus pivot as a result of torque applied to the conductive member by the rotor via the pivot connection and by centrifugal effects acting on the conductive member which are centred on the center of mass. The strength of centrifugal effect is dependant on the rotor speed and applied torque, thus the conductive member will move radially at a rate dependant on the rotor speed as well as a result of applied torque.

In another embodiment, the center of mass (or mass centroid) may be located at the pivot axis. For example, the conductive member may be shaped with a counter balance arrangement with an even mass distribution about the pivot axis. Such an embodiment provides a transfer of radial force directly about the pivot axis and as such does not apply a moment to the arm about the pivot axis. Therefore the

Date Reçue/Date Received 2021-01-12

braked response in this embodiment is independent of the radial force acting on the arm mass.

It should be appreciated that the conductive member may be of any shape suitable for the application. The shape of the conductive member determines the area of magnetic field intersected by the conductive member when moving radially into the magnetic field, the eddy-currents and reactive magnetic field generated, and therefore the corresponding braking torque. The shape of the conductive member may be modified to modify the braking torque characteristics required for an application.

Preferably, one end of a biasing device, such as a spring or other biasing member/mechanism, is attached to the conductive member at a point distal to the pivot axis and the other end to the rotor at a position to provide a bias opposing the radial movement of the conductive member resulting from rotor rotation. Calibration of the biasing device thus provides a means for controlling the rate of radial movement of the conductive member and therefore the area of conductive member intersecting the applied magnetic field. The braking force applied to the conductive member during movement through the applied magnetic field may also be applied to the rotor via the biasing device and/or through the attachment of the conductive member to the rotor.

Preferably, the biasing device includes a calibration mechanism capable of selectively increasing and/or decreasing the level of biasing device bias applied. Such a calibration mechanism may, for example, be provided by a tensioning screw that is capable of reversibly contracting/extending a spring to thus adjust the biasing device bias applied. Such a tensioning screw may prove useful in calibrating the braking mechanism quickly and easily without requiring

Date Reçue/Date Received 2021-01-12

disassembling to adjust or replace the biasing device. In auto-belay applications such quick calibration may prove important where it is necessary to change the maximum rotation speed required.

It will be appreciated that the biasing device may be configured to bias the conductive member toward or away from the applied magnetic field depending on the requirements of the respective application. For example, in applications requiring increasing braking torque with increasing applied torque (to prevent acceleration), the biasing device preferably biases the conductive member radially out of the applied magnetic field.

In an alternative embodiment, (for applications requiring a decreasing braking torque with applied torque) the biasing device may be attached to the conductive member and to the rotor to provide a bias to the conductive member to move the conductive member radially into the applied magnetic field. The conductive member may be configured to move radially inward on rotation, e.g. by providing a counterweight or positioning the mass centroid on an opposing side of the pivot axis to the biasing device attachment. Such an embodiment may be achieved for example by providing a conductive member on one end of a lever pivotable about an intermediate point, the other lever end having a counterweight configured to move outwardly under centrifugal effects when the rotor rotates. The conductive member, or alternatively the counterweight, may be attached to the rotor via a biasing device to bias the conductive member towards the applied magnetic field. Therefore, as the rotor rotates, the lever will pivot the conductive member away from the magnetic field against the bias and braking torque applied to the conductive member.

Date Reçue/Date Received 2021-01-12

Preferably, the biasing device is attached to the rotor at a position spaced from the eccentric pivot axis in the direction of rotation to be braked.

In an alternative embodiment, the biasing device may be provided as a torsion spring or similar attached at one end to the rotor and at the other end to the conductive member about the pivot axis, the torsion spring configured to oppose pivoting of the conductive member toward or away (depending on the application) from the magnetic field.

The aforementioned spring configurations constrain the pivoting range of the conductive member between the maximum and minimum spring extension, preferably with, respectively, the maximum and minimum area of conductive member intersecting the applied magnetic field.

The pivoting range is also preferably constrained to one side of the pivot axis to ensure that the braking torque is only applied in one rotation direction and not the opposing direction. Such a 'unidirectional' configuration is useful in auto-belay applications where it is undesirable to have a braking effect on the line when ascending, as this will oppose the line retraction mechanism and potentially create slack in the line.

The rate at which the conductive member moves toward the magnetic field is dependant on the applied torque, 'spring' bias and the reactionary centrifugal force acting on the conductive member, i.e. the conductive member will move toward the magnetic field if the component of applied torque and centrifugal force (dependant on rotation speed and conductive member mass) opposing the spring bias is greater than the spring bias. As the spring extends, the spring 'bias' or restoring force F_S increases approximately according to $F_S = k\,x$, where k is the

Date Reçue/Date Received 2021-01-12

spring constant and x is the extension from equilibrium. Once the conductive member is in the magnetic field, the eddy-current reactive force will be added to the pivoting caused by the applied torque and centrifugal force, the spring bias thus opposes all three forces and the spring will therefore extend until the restoring force equals the torque applied to the conductive member about the pivot axis.

Preferably, the braking mechanism includes a plurality of permanent magnets arranged in a generally circular or arcuate magnet array, concentric with the rotor.

In an alternative embodiment the braking mechanism may include a plurality of permanent magnets arranged in a linear array, for example in a square or triangular array, with the rotor axis generally in the center thereof.

Preferably, two said arrays are provided on opposing sides of the plane of rotation of the conductive member, the magnets of each array having opposite poles substantially opposing each other. A magnetic field is thus created that extends between the opposing poles (North opposing South) of opposing magnets, preferably in a direction substantially perpendicular to the plane of rotation of the conductive member.

In an alternative embodiment, one array may be provided on one side of the rotor and a steel or ferromagnetic plate located on the other side. However, it will be appreciated that such a 'one-sided' magnetic array may provide a weaker magnetic field than a comparative two-sided array.

In a further embodiment, the magnet array provided on one or both sides of the conductive member may be arranged in a Halbach, or similar configuration to focus the magnetic field in the direction of the conductive member.

Date Reçue/Date Received 2021-01-12

Preferably, the magnet array is provided with a steel or other ferromagnetic backing attached to a surface of the magnets on an 'outer', opposing side to the conductive member.

In yet another embodiment the magnet may be provided as a single magnet shaped to encircle the rotor and conductive member such that radial movement of the conductive member will result in the conductive member intersecting the applied magnetic field. .

It will be appreciated that in order for an eddy-current effect to be generated, the conductive member must intersect and move relative to the magnetic field. By way of example, this may be achieved by:

a) fixing the magnet in position and rotating the rotor and conductive member such that the conductive member intersects and moves through the magnetic field and *vice versa*; or

b) rotating both the conductive member and the magnet, but at differing angular velocity, e.g. the rotor and conductive member may be configured to rotate in the same direction as the magnet but at a greater angular velocity, or alternatively, the magnet may be configured to rotate in the opposite direction to that of the conductive member.

Thus, in one preferred embodiment, the magnet is fixed in position such that it does not rotate with the rotor, the rotor and conductive members rotatable relative to the magnet such that the conductive member intersects and moves through the magnetic field. It should be appreciated that the term "fixed" as used in this embodiment refers to a magnet being static relative to the rotor, e.g. similar to a

Date Reçue/Date Received 2021-01-12

motor stator. Thus, the term "fixed" should not be interpreted to mean the magnet is fixed in position relative to any housing, superstructure or other objects.

In a preferred embodiment the magnet is configured to rotate upon rotation of the rotor at a different angular velocity to that of the rotor.

Rotation of the magnet(s) relative to the rotor as the rotor is rotating provides a mechanism for varying the relative angular velocity and hence the strength of the braking torque. The magnet(s) may be rotated in the same direction as the rotor to reduce the braking torque or in the opposite direction to increase it.

In a preferred embodiment the magnet is coupled to the rotor for rotation therewith in a substantially opposing direction to that of the rotor.

In a preferred embodiment the rotor is coupled to the magnet via a coupling transmission.

In this embodiment a coupling transmission may be used to alter the relative angular velocity of the rotor (and conductive member) relative to the magnet, where the applied torque drives a drum connected to the magnets and coupled to the rotor via a coupling transmission. In alternate embodiments the arrangement may be the other way round.

Reference to a coupling transmission throughout this specification should be understood to refer to a mechanism used to transmit power between two articles to which it is coupled. A coupling transmission may be a mechanical or fluid gear transmission, or a chain drive or friction coupling, or by any other such transmission as are well known to those skilled in the art.

Date Reçue/Date Received 2021-01-12

For example, a gear transmission may be configured to rotate the magnet(s) in the opposing direction to that of the rotor, thereby potentially multiplying the relative velocity between the conductive member and magnet.

This braking mechanism may thus achieve an increased braking effect by increasing the relative speed between the conductive member and magnet, without a significant increase in materials or size.

In other embodiments the rotor may be coupled to the magnet by a variety of means, including by a chain drive or a friction coupling.

In a further embodiment, a stop may be provided for limiting the range of radial movement of the conductive member.

Preferably, the stop is positioned to limit the radial movement of the conductive member to a position of maximum magnetic field intercepted.

Such a stop can be utilised to transfer the braking force applied to the conductive member to the rotor by effectively 'fixing' the conductive member with respect to the rotor while the conductive member is in the magnetic field.

Furthermore, provision of such a stop provides a 'safety' feature to ensure that if the biasing device breaks, detaches or otherwise fails, the conductive member will still apply a braking torque (preferably maximum) to the rotor. Without such a stop, the conductive member may move out of the magnetic field and no longer apply a braking torque.

In an alternative embodiment, the stop may be provided as part of a biased ratchet mechanism, the conductive member moving against the bias to progressive radial positions and thus progressive levels of braking torque.

Date Reçue/Date Received 2021-01-12

According to another aspect of the present invention there is provided an eddy-current braking mechanism including;

- a rotor, rotatable about a rotor axis;
- at least one electrically conductive member coupled to the rotor for rotation therewith;
- at least one magnet configured to apply a magnetic field extending at least partially orthogonal to the conductive member; and

characterised in that upon rotation of the rotor, the conductive member is configured to move radially outward from the rotor axis into the applied magnetic field, movement of the conductive member through the applied magnetic field thereby inducing an eddy-current in the conductive member when the conductive member intersects the magnetic field.

Preferably, the magnetic field primarily extends substantially orthogonally to the plane of rotation of the conductive member.

Preferably, a plurality of magnets and conductive members are provided, each conductive member capable of reversible movement into a magnetic field applied by one or more of the magnets.

Preferably, the conductive member is configured to move with respect to the rotor along a radial track from the rotor axis in response to rotation of the rotor.

Preferably, the conductive member is configured to move into the magnetic field as a result of radial acceleration applied by the coupled rotor, the conductive member thus moving radially outward with respect to the rotor.

Date Reçue/Date Received 2021-01-12

Preferably, a biasing device, such as a spring or equivalent biasing member/mechanism is attached to the conductive member and to the rotor to provide a bias opposing the outward radial movement of the conductive member. Calibration of the biasing device thus provides a means for controlling the rate of radial movement of the conductive member and therefore the area of conductive member intersecting the magnetic field.

This 'linear' embodiment thus provides a braking mechanism that works independent of the direction of rotation of the rotor.

The configuration of the braking torque applied to both the 'linear' and 'pivoting' (i.e. with pivoting conductive member) embodiments can be modified and calibrated by changing the level of bias thereby providing an effective means of accommodating applications requiring specific braking torque profiles.

An eddy-current braking mechanism according to the present invention may be configured such that the speed of rotation of the rotor is constant over a range of applied torques (the "operating range"), the applied torque being the force applied to the rotor causing it to rotate. This constant speed of rotation may arise due to any increase in the applied torque (in the operating range) being balanced by an equal and opposite increase in the braking torque arising from the induced eddy current as the conductor intersects more of the magnet field.

Thus when the rotor initially begins to rotate an eddy-current braking mechanism according to the present invention behaves like a prior art device in that the speed of rotation increases substantially linearly with the applied torque. This situation continues until the electrical conductor, which is coupled to the rotor to rotate with it, enters the applied magnetic field of the magnet. Movement of the conductor

Date Reçue/Date Received 2021-01-12

through the magnetic field induces eddy currents in the conductor which oppose the motion through the magnetic field, thus providing a braking force on the motion of the conductor. The magnitude of the braking force depends on a number of factors, including the degree to which the conductor intersects the magnetic field and the strength of the field.

In an eddy-current braking mechanism according to the present invention the strength of the magnetic field, configuration of the conductor, and the biasing mechanism, may all be chosen such that an increase in torque applied to the rotor is balanced by an equal and opposite increase in braking torque throughout the required operating range of torque, thus resulting in a constant speed of rotation of the rotor throughout the operating range.

At some applied torque the conductor may intersecting the maximum area of magnetic field available under the particular embodiment of the invention. At this torque the braking force is also at a maximum. Therefore, as the applied torque is increased further the speed of rotation will again become substantially linear with respect to the increase in applied torque

According to another aspect of the present invention there is provided a line dispensing device including:

- a braking mechanism substantially as hereinbefore described, and
- a spool of line coupled to the rotor and/or conductive member for rotation therewith.

Preferably, the line dispensing device is an auto-belay.

Date Reçue/Date Received 2021-01-12

Preferably, the rotor and/or spool includes a biased retracting mechanism for opposing extension of line from the spool, the retracting mechanism configured to retract the line when tension applied to the line falls below a predetermined level.

As used herein, the term "line" refers to any cable, rope, string, chain, wire, strap or any other length of flexible material.

According to another aspect of the present invention there is provided a method of braking rotation of an object, the method including the steps of:

- coupling a conductive member to the object for rotation therewith;
- providing at least one magnet configured to apply a magnetic field extending at least partially into the plane of rotation of the rotatable conductive member;
- configuring the conductive member to move into the magnetic field upon rotation of the object.

According to another aspect of the present invention there is provided a method of braking rotation of an object substantially as hereinbefore described, including the further step of:

- rotating the object to thus move the conductive member into the magnetic field, the magnetic field thereby inducing an eddy-current in the conductive member.

The present invention may thus provide significant advantages over the prior art by providing an eddy-current braking mechanism capable of one or more of:

- limiting the speed to a constant level over a range of applied torques

Date Reçue/Date Received 2021-01-12

- applying sufficient braking torque using a compact apparatus;
- providing an eddy-current brake for use with auto-descenders/auto-belays.

It will be appreciated that the present invention may therefore find particular use for speed control and/or braking in numerous applications, such as, by way of example, speed control of:

- a rotor in wind, hydro, and other rotary turbines;
- exercise equipment, e.g. rowing machines, epi-cyclic trainers;
- roller-coasters and other amusement rides;
- elevator and escalator systems;
- evacuation descenders and fire-escape devices;
- conveyor systems;
- rotary drives in factory production facilities;
- materials handling devices such as conveyor belts or a braking device in a chute for example, or to control the descent rate of an item down a slide;
- dynamic display signage, e.g. in controlling the rotation speed of rotating signs;

Date Reçue/Date Received 2021-01-12

- roadside safety systems, e.g. the brake may be connected in a system to provide crash attenuation through the dissipation of energy in the brake.

Indeed, the present invention may be used in any rotary braking and/or speed limiting system.

BRIEF DESCRIPTION OF DRAWINGS

Further aspects and advantages of the present invention will become apparent from the following description which is given by way of example only and with reference to the accompanying drawings in which:

Figure 1 shows a plot of Torque vs. Speed for an exemplary prior art eddy-current braking mechanism;

Figure 2a shows a schematic plan diagram of an eddy current braking mechanism according to one preferred embodiment of the present invention, the rotor being stationary;

Figure 2b shows a schematic plan diagram of the eddy current braking mechanism of figure 2a with the rotor rotating under an intermediate braking torque;

Figure 2c shows a schematic plan diagram of the eddy current braking mechanism of figures 2a and 2b with the rotor rotating under a maximum braking torque;

Figure 3 shows a schematic side elevation of part of the eddy current braking mechanism of figure 2;

Date Reçue/Date Received 2021-01-12

Figure 4 shows a schematic side elevation of part of an alternative configuration to the eddy-current braking mechanism shown in figures 2 and 3;

Figure 5a shows a force diagram of the eddy-current braking mechanism shown in figures 2 and 3 when a torque is initially applied to the rotor, i.e. at a 'start-up';

Figure 5b shows a force diagram of the eddy-current braking mechanism shown in figures 2 and 3 when the applied torque is increasing;

Figure 5c shows a force diagram of the eddy-current braking mechanism shown in figures 2 and 3 when a constant torque applied is matched by the braking torque, i.e. at 'steady-state';

Figure 5d shows a force diagram of the eddy-current braking mechanism shown in figures 2 and 3 at maximum braking torque;

Figure 5e shows a force diagram of the eddy-current braking mechanism shown in figures 2 and 3 when the applied torque is decreasing;

Figure 6 shows a plot of Torque vs. Speed of the rotor used with the braking mechanism of figures 2-3 and 5;

Figure 7 shows a plot of Speed vs. Torque of the rotor used with the braking mechanism of figures 2-3 and 5;

Figure 8 shows a plot of Speed vs. Torque of an alternative configuration of the braking mechanism of figures 2-3 and 5;

Date Reçue/Date Received 2021-01-12

Figure 9 shows yet another plot of Speed vs. Torque of an alternative configuration of the braking mechanism of figures 2-3 and 5;

Figure 10a shows a schematic plan diagram of an eddy current braking mechanism according to a second preferred embodiment of the present invention;

Figure 10b shows an enlarged view of part of the braking mechanism shown in figure 10a;

Figure 11 shows a schematic illustration of an eddy current braking mechanism according to another embodiment of the present invention; and

Figure 12 shows a schematic illustration of an eddy current braking mechanism according to embodiments described herein.

BEST MODES FOR CARRYING OUT THE INVENTION

Figure 1 shows a plot of Torque vs. Speed for an exemplary prior art eddy-current braking mechanism that utilises a conductive disc configured to rotate in a magnetic field. Eddy-currents are induced in the disc when the disc rotates and a reactive magnetic field is generated opposing the applied magnetic field. The opposing magnetic fields create a reactive force opposing movement of the disc through the magnetic field.

The magnitude of the braking torque applied to the disc is dependant on the magnetic field strength and the speed of rotation, thus as speed increases, the

Date Reçue/Date Received 2021-01-12

braking torque also increases. This system will limit the speed to a certain level depending on the applied torque. However, the braking torque and therefore equilibrium speed are only linearly proportional to the speed within a predetermined operating range (as shown in figure 1), until a threshold 'characteristic speed' (S) is reached where the braking torque becomes non-linear and peaks before beginning to reduce with further speed increases.

The prior art systems are thus only effective at regulating the speed with a linear response to the applied torque until the characteristic speed is reached. Thus, these prior art systems are unsuitable for auto-belay and other applications where it may be desirable to maintain a constant speed over a wider range of applied torques.

Figures 2a-2c, 3 and 5a-5e show an eddy-current braking mechanism according to one preferred embodiment of the present invention as generally indicated by arrow **1**. For clarity, in figures 5a-5e only one conductive member **3** is shown attached to the rotor **2**.

The braking mechanism **1** is coupled to a spool of line (not shown) forming part of an auto-belay device (not shown). The spool of line is connected to a rotor **2** of the braking mechanism **1** and will thus rotate with the rotor 2. A line **23** extends from the spool to a harness of a user. The rotor **2** has a biased retracting mechanism (not shown) for opposing the extension of line **23** from the spool and for automatically retracting the line **23** when the line tension (and applied torque) is reduced, e.g. when a user is ascending while climbing.

The rate of line dispensing from the spool can thus be regulated by controlling the speed of rotation of the rotor **2** with the braking mechanism **1**.

Date Reçue/Date Received 2021-01-12

The braking mechanism **1** includes the rotor **2**, rotatable about a rotor axis **X** and three electrically conductive members provided in the form of pivoting arms **3** coupled to the rotor **2**. The arms **3** are pivotally attached to the rotor **2** at points **8** eccentric to the rotor axis **X.**

A plurality of magnets **4** are provided and fixed in position relative to the rotor axis X. The magnets **4** form two circular arrays **5** (only one shown in figure 2) on opposing sides of the plane of rotation of the arms **3** and rotor **2**.

Figure 3 shows the magnets **4** positioned either side of the plane of rotation of the arms **3**.

Each magnet array **5** is arranged coaxially with the rotor **2** and applies a magnetic field **6** extending orthogonal to the plane of rotation of the arms **3**.

The magnets **4** of the two magnet arrays **5** have opposite poles substantially opposing each other. Thus, a magnetic field **6** is created that extends between the opposing poles (North opposing South) of opposing magnets **4**, in a direction orthogonal to the plane of rotation of the rotor **2** and arms **3**.

Steel or other ferromagnetic backing **7** (shown in figure 3) is attached to the outer surface of each magnet array **5** on an opposing side to the arms **3**. This steel backing **7** helps reinforce the magnetic field **6** as well as potentially protecting the magnets **4** from impact damage.

An alternative configuration is shown in figure 4 where only one magnet array **5** has steel backing **7**.

As shown in the progression from figure 2a to figure 2c, upon a tangential force F_{App} being applied to the rotor **2** (e.g. from a climber descending), the rotor **2** will

Date Reçue/Date Received 2021-01-12

rotate and the arms **3** will pivot about pivot points **8.** As the applied force F_{App} accelerates the rotor **2**, the arms **3** will move into, and intersect the applied magnetic field **6**. Any movement of the arms **3** through the applied magnetic field **6** (e.g. when rotating) induces eddy-currents in the arms **3** which in turn generate reactive magnetic fields opposing the applied magnetic field **6**.

The arms **3** have an arc-shaped outer edge **10** matching the profile of the magnet array **5** so that the maximum area of field **6** is intersected while also minimising size and weight of the arms **3**. The arms **3** are shaped to nest together when the rotor is stationary, i.e. the 'rear' of each conductive member **3** is shaped to abut with the 'front' of the next conductive member **3**. It will be appreciated that reference herein to the rotor being "stationary" refers to the rotor not rotating or moving relative to the magnetic field **6**.

As the arms **3** pivot about the pivot points **8**, a progressively greater part of each arm **3** moves into and intersects the magnetic field **6**. The arms **3** are also shaped so that in the contracted position shown in figure 2a, the arms **3** fit together to occupy the minimal amount of space possible, thereby minimising the size requirements of the braking mechanism **1** while maximising the potential braking torque when in the magnetic field **6** as shown in figures 2b and 2c.

Biasing devices are provided in the form of springs **12** attached to the arms **3** at points **13** distal to the pivot axis **8** and to the rotor **2** at a position **14** spaced from the pivot axis **8** in the direction of rotation ***R*** to be braked, i.e. shown as clockwise in figure 2. The springs **12** thereby provide a bias opposing the pivoting (and thereby radial) movement of the arms **3**. The strength of the springs **12** can be changed to control the movement of the arms **3** toward the magnetic field **6** and therefore the characteristics of the braking mechanism **1**.

Date Reçue/Date Received 2021-01-12

The pivoting range of the arms **3** is constrained by the springs **12** to one sector, thereby ensuring that the arms **3** will only move into the magnetic field **6** when rotating in one direction. Such a 'unidirectional' configuration is useful in auto-belay applications where it is undesirable to have a braking effect on the line **23** when ascending, as this may oppose the line retraction mechanism and potentially create slack in the line **23**.

With reference to Figure 12, safety stops 300 are attached to the rotor 2 and engage with the arms 3 to limit the range of arms 3 pivoting movement. The stops 300 are formed by a sliding engagement between a protrusion (not shown) 310 attached to the arms 3 and a rigid slot (not shown) 320 that is fixed to the rotor 2. The protrusion 310 is free to slide in the slot 320 but is limited by the extent of the slot 320 which limits the range of movement of the arms 3. The stops (not shown) 300 thus provide a 'safety' feature to ensure that if the spring 12 breaks, detaches or otherwise fails, the arms 3 will still apply a braking torque (preferably maximum) to the rotor 2. The stop 300 also assists in transferring braking torque to the rotor 2 when the protrusion 310 reaches the extent of the slot 320.

Safety stops (not shown) are attached to the rotor **2** and engage with the arms **3** to limit the range of arms **3** pivoting movement. The stops are formed by a sliding engagement between a protrusion (not shown) attached to the arms **3** and a rigid slot (not shown) that is fixed to the rotor **2**. The protrusion is free to slide in the slot but is limited by the extent of the slot which limits the range of movement of the arms **3**. The stops (not shown) thus provide a 'safety' feature to ensure that if the spring **12** breaks, detaches or otherwise fails, the arms **3** will still apply a braking torque (preferably maximum) to the rotor **2**. The stop also assists in transferring braking torque to the rotor **2** when the protrusion reaches the extent of the slot

Date Reçue/Date Received 2021-01-12

The arms **3** are mounted eccentrically to the rotor axis **X** such that each arm **3** has a center of mass **9** eccentric to the pivot **8** and rotor axes **X** such that when the rotor **2** rotates, the arms **3** will move radially outward and pivot the arms **3** about the pivot point **8**.

In an auto-belay application, tension is placed on the line **23** wrapped about the rotor **2** or connected spool by a load (e.g. a human) and thereby applies a torque (T_{App} = F_{App} x r) on the rotor **2** to cause rotation.

The applied magnetic field **6** induces eddy-currents in the arm **3** and a reactive magnetic field is generated that opposes the applied magnetic field **6**. The repelling force between the applied and reactive magnetic fields thus provides a reactive force F_{EDDY} opposing the movement of the arms **3** through the magnetic field **6**. Figures 5a to 5e are partial schematic diagrams showing the forces acting on each arm **3**. For clarity, only one arm **3** is shown in figures 5a to 5e.

It will be appreciated that the force diagrams of figures 5a – 5e do not show an accurate detailed analysis of the many and varied dynamic forces acting on the arm **3** and thus the forces shown are simplistic and indicative only. The force diagrams 5a-5e, are provided to show a simplified example of the primary forces acting on the arm. Each diagram 5a-5e includes a box with the main forces added to show the approximate net force at the center of mass **9**. It should be appreciated that these forces are indicative only and the force lines may not be of accurate length or direction.

Figure 5a shows a force diagram of the eddy-current braking mechanism **1** in an initial 'start-up' stage where there is only a tangentially applied force F_{App} and the spring **12** is not extended. As this force F_{App} is applied tangentially to the rotor, a

Date Reçue/Date Received 2021-01-12

torque T_{App} is applied to the rotor and it will accelerate from rest. Components ($F_{App}(8)$ and $F_{App}(13)$) of this force F_{App} are respectively applied to the arm **3** via the pivot point **8** and spring connection **13**.

It should be appreciated that in another configuration, an arm(s) may be shaped and positioned such that in the start-up phase at least a portion of the arm intersects the magnetic field. An eddy-current braking effect will thus be applied as soon as the rotor starts to rotate.

Also, as the arm **3** is connected to the rotor **2**, when rotating it will accelerate toward the rotor axis X under centripetal acceleration. The centripetal force is applied to the body via the connections **8**, **13**. F_{cp} is the force exerted by the mass centroid **9** on the arm **3** resisting the centripetal acceleration of the arm 3.

The arm 3 also has an inertia resisting changes in movement. For the purposes of this analysis this inertia will relate to the arm mass and moment of inertia acting about the mass centroid **9**.

The forces shown in figures 5a - 5e are detailed in the following table with approximate formulae. It will be appreciated that these formulae and forces are approximate and indicative only.

Force	**Symbol**	**Indicative relationship formula**
Applied Force	F_{App}	Force applied by tension on line **23**.
Applied Force through pivot point **8**	$F_{App}(8)$	Component of F_{App} acting through pivot

Date Reçue/Date Received 2021-01-12

		point **8**. Approx equal to $\frac{T_{App} - F_{App(13)} \cdot R_2}{R_1}$ where R_1 is the distance of the pivot point **8** from the rotor axis **X**, and R_2 is the perpendicular distance of the spring **12** from the rotor axis **X**.
Applied Force through connection **13**	$F_{App}(13)$	Component of F_{App} acting through connection **13**. Approx equal to F_s.
Applied Torque	T_{App}	Approx equal to F_{App} x r where r is the radius of the rotor **2** to the line **23**.
Applied Force through pivot **8**	$F_R(8)$	A resultant force from the combination of $F_{App}(8)$, $F_{App}(13)$, F_{cp}, and F_{EDDY} acting on the rotor via pivot **8**
Resultant Force	F_R	A resultant of the force vectors $F_{App}(13)$, $F_{App}(8)$, F_{cp} and F_{EDDY} acting at the arm **3** mass centroid **9**.
Resultant Moment	M_R	A resultant moment acting about the arm **3** mass centroid **9** due to the of the force vectors $F_{App}(13)$, $F_{App}(8)$, F_{cp} and F_{EDDY} and their respective lever arms.
Braking force caused by eddy-current braking	F_{EDDY}	Braking force caused by eddy-current reactive magnetic field interacting with

Date Reçue/Date Received 2021-01-12

effect		applied magnetic field **6**. Approx proportional to area of magnetic field **6** intersected by the arms **3**; strength of the magnetic field 6 intersecting the arms **3**; resistivity of the arms **3**; and relative velocity of the arms **3** with respect to the magnetic field **6**.
Braking torque caused by eddy-current braking effect	T_{EDDY}	Torque applied to the conductive arm **3** by the braking force F_{EDDY} . Approx equal to the F_{EDDY} x l where l is the perpendicular distance from the line of action of the force F_{EDDY} to the pivot point **8**, i.e. R_3 in the drawings.
Spring Bias force	F_S	Approx equal to $kx+c$ where k is the spring constant, x is the extension from equilibrium and c is the spring pre-tension.
Braking torque on rotor	T_B	Proportional to the components of the braking force F_{EDDY} acting through the pivot point 8 and connection **14**.
Centrifugal force acting on the arm **3** mass centroid **9**	F_{cp}	Approx equal to the mass of the arm **3** at the mass centroid **9** multiplied by v^2/R_1 where v is the tangential velocity of the rotor at the pivot point **X.**

Date Reçue/Date Received 2021-01-12

In the start-up state shown in figure 5a, the combined force F_R of the forces $F_{App}(8)$ and $F_{App}(13)$ act approximately on the mass centroid **9** of the arm **3**. The offset of the forces $F_{App}(8)$ and $F_{App}(13)$ from the mass centroid **9**, $R_{FApp(8)}$ and $R_{FApp(13)}$ respectively, provide a moment M_R about the mass centroid **9** of the arm **3**. The force F_R therefore acts to accelerate the arm radially outwards and the moment M_R acts to rotationally accelerate the arm in the same rotational direction as the rotor **2**.

The arm **3** is constrained at the pivot point **8** but is not rigidly fixed at connection **13**.

As the arm **3** is accelerated outward by the resultant force F_R, the arm rotates about pivot point **8** in an anticlockwise direction with respect to the rotor **2** and the spring **12** is extended thus increasing the spring bias F_S and the applied force $F_{App}(13)$. With an increase in F_S a larger proportion of T_{App} is transferred to the arm **3** via the spring **12** and the force $F_{App}(8)$ applied through the pivot **8** is reduced. The resultant force F_R acting on the mass centroid **9** changes the direction in a clockwise motion.

As the applied direction of F_R moves forward of a radial line from the axis **X** to the mass centroid **9**, the force accelerates the arm **3** in a clockwise direction.

Figure 5b shows the applied force F_{App} accelerating the rotor **2** and attached arm **3**. The arm **3** is pivoted at a greater angular displacement than that shown in figure 5a and now intersects the magnetic field **6**. The rotor **2** and arm **3** have gained angular velocity about the rotor axis **X** and the arm **3** is accelerated towards the rotor axis **X** under centripetal acceleration. The mass centroid **9** applies a centrifugal force F_{cp} to the arm **3**.

Date Reçue/Date Received 2021-01-12

In addition to the rotary forces, the eddy-current braking force F_{EDDY} is also applied as the arm **3** is moving through the magnetic field.

The resultant force F_R of the forces $F_{App}(8)$, $F_{App}(13)$, F_{cp}, and F_{EDDY} act on the mass centroid **8** to accelerate the arm **3** further outward from the rotor axis **X**. The resulting anticlockwise rotation of the arm **3** about the pivot **8** increases the distance between connection **13** and connection **14** thereby extending the spring **12**. The extension of the spring **12** increases the spring bias F_S and correspondently increases $F_{App}(13)$ applied to connection **13**.

The rotor **2** will continue to accelerate and the arm **3** will continue to pivot anticlockwise until the force $F_{App}(13)$ applied by the spring **12** on the arm **3** is sufficiently large to balance the forces acting on the arm such that F_R and M_R reduce to zero. At this point, the braking torque T_B applied to the rotor through the transfer of F_{EDDY} via pivot **8** and connection **14** equals the applied torque T_{App}, the angular acceleration is thus equal to zero and the rotor **2** will rotate at a constant speed. A steady-state equilibrium position is then reached as shown in figure 5c.

The variables that contribute to the braking torque T_B applied to the rotor **2** can all be controlled by appropriate calibration of the springs **12** and mass centroid **9**, and thus the braking mechanism **1** can provide substantial control over the braking torque T_B response to suit the particular application.

Any changes in the applied torque T_{App} will result in a commensurate increase in the radial displacement of the arm **3** and the braking torque T_{EDDY} applied by the magnetic field **6** and the reactionary force F_R. However, it will be appreciated that the maximum braking torque T_B achievable is constrained by the physical parameters of the mechanism **1**.

Date Reçue/Date Received 2021-01-12

Figure 5d shows the arm **3** at a point of maximum radial displacement where the maximum magnetic field is intersected by the arm **3**. The braking torque T_B is equal to the applied torque T_{App}. However, any further increases in applied torque T_{App} will not result in the arm **3** moving radially outward as the spring is extended to its maximum extent and the arm **3** is in contact with the safety stop (not shown). The braking torque T_B can therefore not increase any further. Any further increases in applied torque T_{App} will therefore accelerate the rotor 2.

Figure 5e shows a decreasing applied torque T_{App} on the braking mechanism **1**.

As the applied torque T_{App} is reduced, a commensurate decrease in $F_{App}(8)$ occurs to balance the applied torque T_{App} while the spring bias force F_S remains temporarily unchanged. The resultant force F_R from the forces $F_{App}(8)$, $F_{App}(13)$, F_{cp}, and F_{EDDY} act on the mass centroid **9** such that it accelerates the arm **3** inward towards the rotor axis **X**. The resulting clockwise rotation of the arm **3** about the pivot **8** decreases the distance between connection **13** and connection **14**. The resulting reduction in extension of the spring **12** results in a reduction in spring bias F_S and $F_{App}(13)$. At the same time there is a reduction in the area of the arm **3** intersected by the magnetic field **6** with a corresponding reduction in the eddy-current braking force F_{EDDY}.

The arm **3** continues to rotate clockwise about pivot **8** until the forces acting on the arm **3** balance such that the magnitude of F_R is zero with a corresponding reduction in the acceleration of the mass centroid **9** to zero and thus the system in in a state of equilibrium. At this point the braking torque T_B generated by the transfer of the eddy-current braking force F_{EDDY} through the pivot **8** and connection **14** balances the applied torque T_{App} and the acceleration of the rotor **2** is thus zero.

Date Reçue/Date Received 2021-01-12

The speed of rotation can therefore be limited by adjusting the spring bias F_S to ensure that the braking torque T_B increases proportionally to the applied torque T_A and both forces are kept equal throughout an 'operating range' of applied torques.

As aforementioned, the magnitude of the reactive force F_{EDDY} is dependant on the:

- area of magnetic field **6** intersected by the arms **3**;
- strength of the magnetic field **6** intersecting the arms **3**;
- resistivity of the arms **3**; and
- relative velocity of the arms **3** with respect to the magnetic field **6**.

The braking mechanism 1 shown in figures 2-5 provides automatic variation in both the area *A* of the applied magnetic field **6** intersected and the distance *R* between the arms **3** and rotor axis **X** by variation in the radial movement of the arms **3** into the applied magnetic field **6**. Thus, in the operating range, changes in the applied torque $T_{A\,pp}$ will result in a commensurate change in the braking torque T_B applied to the rotor **2**.

It will be appreciated that the maximum braking torque achievable will depend on the physical constraints of the mechanism, e.g. size and strength of magnets, size, thickness and conductivity of the arm **3**. Furthermore, the rotor **2** must experience a minimum applied torque, and therefore minimum rotational acceleration and speed, before the arm **3** applies a sufficient braking torque to limit the rotation speed.

Date Reçue/Date Received 2021-01-12

As alluded to previously, a "reverse" configuration to what has been previously described is also within the scope of the present invention. In this "reverse" configuration, the magnets may be coupled to the rotor and configured to move toward a conductive member such that the conductive member will intersect the magnetic field. With reference to Figures 2a-2c, 3 and 5a-5e, in the "reverse" configuration, braking mechanism 1 includes the rotor 2, rotatable about a rotor axis X, and three pivoting magnets 3 coupled to the rotor 2. The magnets 3 are pivotally coupled with the rotor 2 at points 8 eccentric to the rotor axis X. A plurality of conductive members 4 are provided and fixed in position relative to the rotor axis X. The conductive members 4 form two circular arrays 5 (only one shown in FIG. 2) on opposing sides of the plane of rotation of the magnets 3 and rotor 2.

The braking mechanism **1** limits the speed in an operating range between these maximum and minimum applied torques. Speed profiles of the braking mechanism **1** showing the operating range are shown in figures 6 and 7.

As can be seen from figures 6 and 7, the speed initially increases with applied torque T_{App} until the resultant force F_R acting on the mass centroid **9** accelerates the arms **3** outward into the magnetic field **6** and the reactive braking force F_{EDDY} is applied. The resultant braking torque T_B will increase and then equal the applied torque T_{App}. The speed of rotation is thereby limited to a constant value as no acceleration can occur due to the applied torque T_{App} being continually matched by the braking torque T_B. Increases in applied torque T_{App} are matched by increases in braking torque T_B until an upper limit is reached where the maximum area of magnetic field **6** is intersected and thus the magnetic field reactive force F_B generated is proportional to speed only. After the upper limit, the

Date Reçue/Date Received 2021-01-12

speed profile is similar to prior art devices which vary the braking torque T_B with speed only.

Different speed responses to applied torques can be achieved by varying the spring bias. Examples of alternative speed profiles are shown in figures 8 and 9.

The profile shown in figure 8 is achievable by providing a relatively 'weak' spring (i.e. small restoring bias and spring constant) compared with the embodiment shown in figures 6 and 7 such that the braking torque applied upon magnetic field intersection is greater than the applied torque T_A throughout the operating range. Thus, the speed of rotation is reduced with increasing applied torque T_{App} until the applied torque T_{App} exceeds the braking torque T_B.

Alternatively, as shown in figure 9, a relatively 'strong' spring (i.e. large restoring bias and spring constant) may be used such that the applied torque T_A exceeds the braking torque T_B over the operating range. Thus, the speed of rotation increases linearly with increasing applied torque T_{App} until the braking torque T_B exceeds the applied torque T_{App}.

It will thus be appreciated that the present invention may be modified to accommodate any speed response required for the application simply by adjusting or changing the spring **12**.

Figure 10 shows a braking mechanism **100** according to another embodiment of the present invention with the arms provided in the form of plates **103**. The plates **103** are capable of radial movement along tracks **101** provided in the rotor **102**. The plates **103** are coupled via the tracks **101** to the rotor **102** so that the plates rotate with the rotor **102** and tracks **101**. Springs **112** are attached to the rotor **102**

Date Reçue/Date Received 2021-01-12

and to the plates **103**. The springs **112** when extended apply a biasing force F_S to bias the plates **103** toward the rotor axis **X**.

The torque T_{App} applies a tangential force F_{App} on the plates **103** and the spring applies a centripetal force F_{cp}. The centripetal acceleration of the springs **112** toward the rotor axis **X** results in the plates **103** moving radially outwards into the magnetic field **106** while extending the springs **112**. Thus, the braking force F_B applied will vary proportional to the tangential velocity of the plates **103** and the spring bias F_S.

In contrast to the braking mechanism 1 of figures 2-5, it will be appreciated that this braking mechanism **100** does not provide a set limit to the speed as the movement of the plates **103** is proportional to the rotor speed, rather than also to the applied torque as in the braking mechanism **1**.

The magnet array (not shown) of this 'linear' embodiment is provided in the same configuration as that shown in the first preferred 'pivoting' embodiment shown in figures 2 and 3.

As the plates **103** move radially outward under any rotor rotation (i.e. primarily under centrifugal effects), this 'linear' embodiment provides a braking mechanism **100** that works independent of the direction of rotation of the rotor **102**.

Although the braking mechanism **100** provides a braking effect independent of the rotation direction, the braking torque varies only with the speed of rotation (and therefore centripetal acceleration) and not the torque applied. The speed will only be limited when the braking torque equals the applied torque and thus a greater applied torque (e.g. a heavier person) will result in the speed being limited at a higher equilibrium speed than a correspondingly 'lighter' person. Thus, this braking

Date Reçue/Date Received 2021-01-12

mechanism **100** does not provide the level of control of the braking mechanism **1** shown in figures 2-5.

Another embodiment of a braking mechanism is generally indicated by arrow **201** in figure 11. In this embodiment an array of magnets (**204**) is mounted on a cradle (**220**). A rotor (**202**), having pivotally mounted conductors (**203**), is mounted on an axle (**205**) for rotation about the rotor axis (**X**).

The cradle (**220**) is configured to rotate about the rotor axis (**X**) and is connected to it by a gear transmission (**230**). In the arrangement shown in figure 11 the gear transmission (**230**) is configured such that the cradle (**220**) (including the magnetic array (**204**)) rotates in an opposite direction to the rotor (**202**) (and conductors (**203**)) thus increasing the relative angular velocity of the rotor (**202**) and conductor members (**203**) relative to the magnetic array (**204**). Such an arrangement for the braking mechanism may achieve an increased braking effect.

Aspects of the present invention have been described by way of example only and it should be appreciated that modifications and additions may be made thereto without departing from the scope of the appended claims.

Date Reçue/Date Received 2021-01-12

CLAIMS:

1. An eddy-current braking mechanism comprising:

a rotor, rotatable about a rotor axis;

at least one magnet coupled with the rotor;

an array of electrically conductive members aligned coaxially with the rotor; and

a biasing device attached to the at least one magnet and the rotor, the biasing device being configured to provide a bias opposing the outward or inward radial movement of the at least one magnet;

wherein the at least one magnet coupled with the rotor moves relative to the rotor axis in a radial direction when the rotor rotates around the rotor axis; and

wherein the eddy current braking mechanism is configured such that an increasing portion of the at least one magnet overlaps with the array of electrically conductive members in an axial direction as the rotor goes from stationary to rotating.

2. The eddy-current braking mechanism of claim 1, wherein the biasing device constrains the pivoting range of the at least one magnet between a maximum area of magnet overlap with the electrically conductive members and a minimum area of magnet overlap with the electrically conductive members.

3. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet is coupled directly to the rotor.

4. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet is pivotally coupled to the rotor and pivots about a pivot axis.

5. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet has a center of mass on or eccentric to the pivot and rotor axes.

6. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet is pivotally attached to the rotor at a point eccentric to the rotor axis.

Date Reçue/Date Received 2021-01-12

7. The eddy-current braking mechanism as claimed in claim 1, wherein the biasing device is attached to the rotor at a point eccentric to the pivot axis.

8. The eddy-current braking mechanism as claimed in claim 1, wherein a stop is provided for limiting the range of movement of the at least one magnet.

9. The eddy-current braking mechanism as claimed in claim 8, wherein the stop is positioned at a point of maximum overlap between the at least one magnet and the at least one electrically conductive member.

10. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one electrically conductive member is arranged in two generally circular shapes or arrays, one on each opposing side of the plane of rotation of the at least one magnet.

11. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one electrically conductive member shape or array is provided on one side of the rotor.

12. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet does not overlap the at least one electrically conductive member in a rotor axis direction when the rotor is stationary.

13. The eddy-current braking mechanism as claimed in claim 1, wherein the biasing device is attached to the at least one magnet at a point distal to the rotor axis and to the rotor at a position to provide a bias opposing the at least one magnet movement resulting from rotor rotation.

14. The eddy-current braking mechanism as claimed in claim 1, wherein the mechanism comprises at least two magnets and the magnets move independently.

15. The eddy-current braking mechanism as claimed in claim 1, wherein the mechanism includes at least two magnets and wherein the at least two magnets nest together when the rotor is stationary.

Date Reçue/Date Received 2021-01-12

16. The eddy-current braking mechanism as claimed in claim 1, wherein the mechanism includes at least two magnets and wherein the rear of each magnet abuts with the front of the next magnet when the rotor is stationary.

17. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet is T-shaped.

18. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet has or have an at least partially arc shaped cross-section shape.

19. The eddy-current braking mechanism as claimed in claim 1, wherein the at least one magnet has or have a unidirectional configuration with braking torque only applied in one rotation direction and not the opposing direction.

20. The eddy-current braking mechanism as claimed in claim 1 wherein the rotor is a wheel.

21. An eddy-current braking mechanism comprising:

a rotor, rotatable about a rotor axis;

at least one magnet coupled with the rotor;

an array of electrically conductive members aligned coaxially with the rotor; and

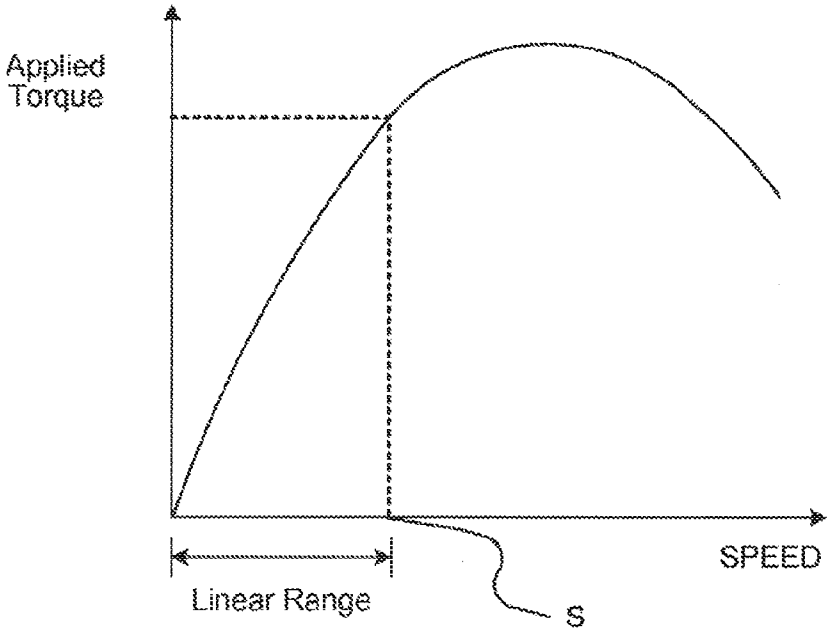
a biasing device attached to the at least one magnet and the rotor, the biasing device being configured to provide a bias opposing the outward or inward radial movement of the at least one magnet;

wherein the at least one magnet coupled with the rotor moves relative to the rotor axis in a radial direction when the rotor rotates around the rotor axis to thereby adjust the amount of overlap between the at least one magnet and the array of electrically conductive members in an axial direction; and

wherein the biasing device constrains the pivoting range of the at least one magnet between a maximum area of magnet overlap with the electrically conductive members and a minimum area of magnet overlap with the electrically conductive members.

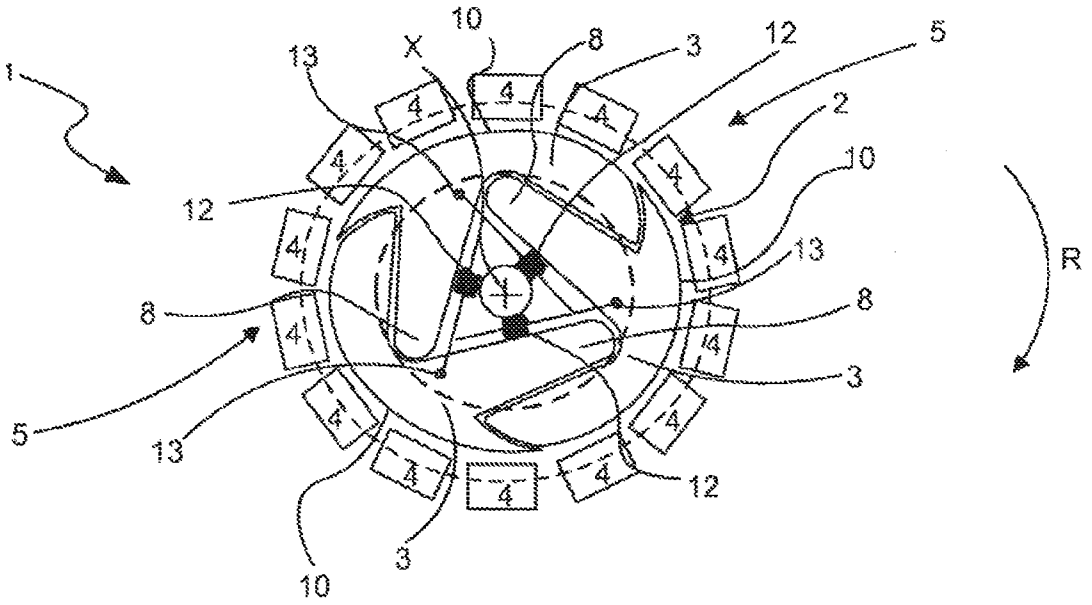
Date Reçue/Date Received 2021-01-12

Figure 1 - Prior Art



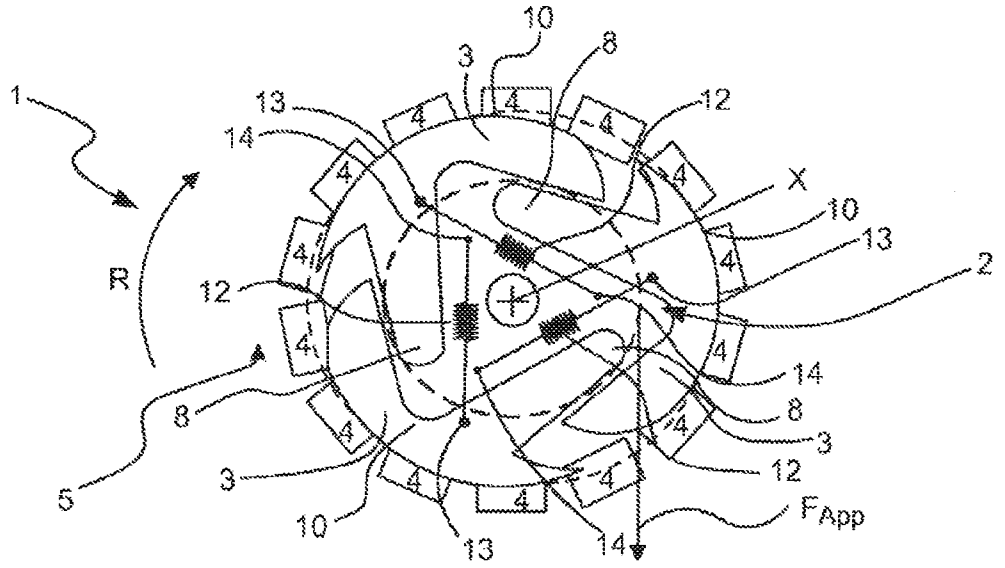
Date Reçue/Date Received 2021-01-12

Figure 2a



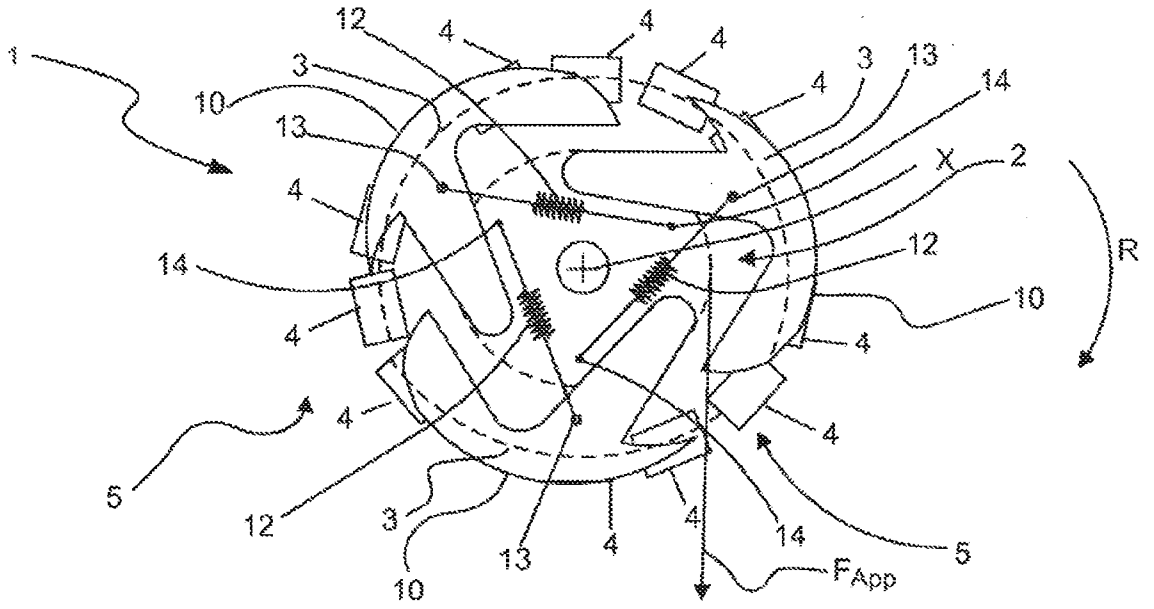
Date Reçue/Date Received 2021-01-12

Figure 2b



Date Reçue/Date Received 2021-01-12

Figure 2c



Date Reçue/Date Received 2021-01-12

Figure 3

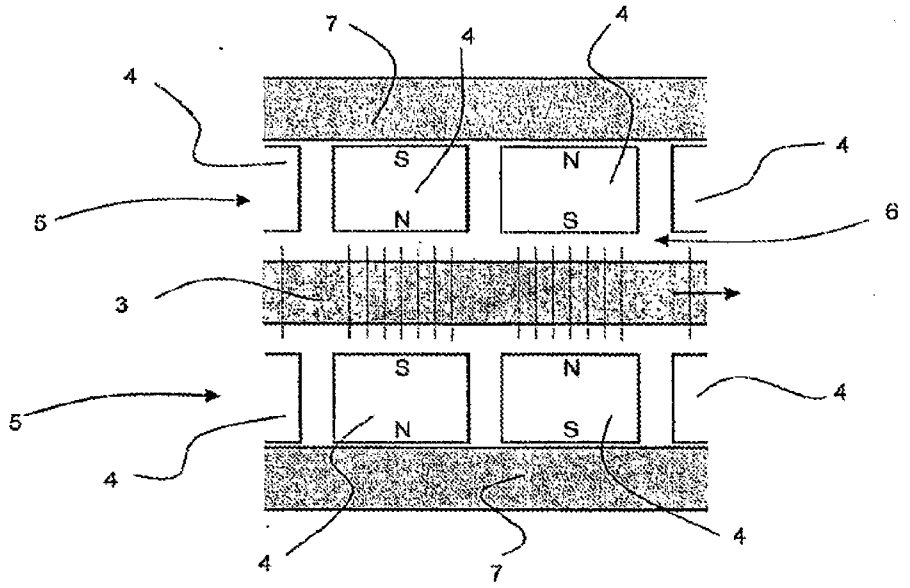
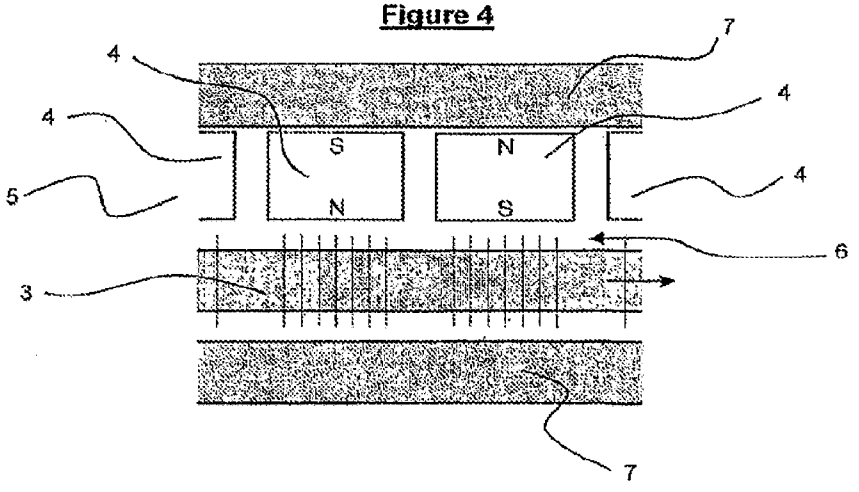
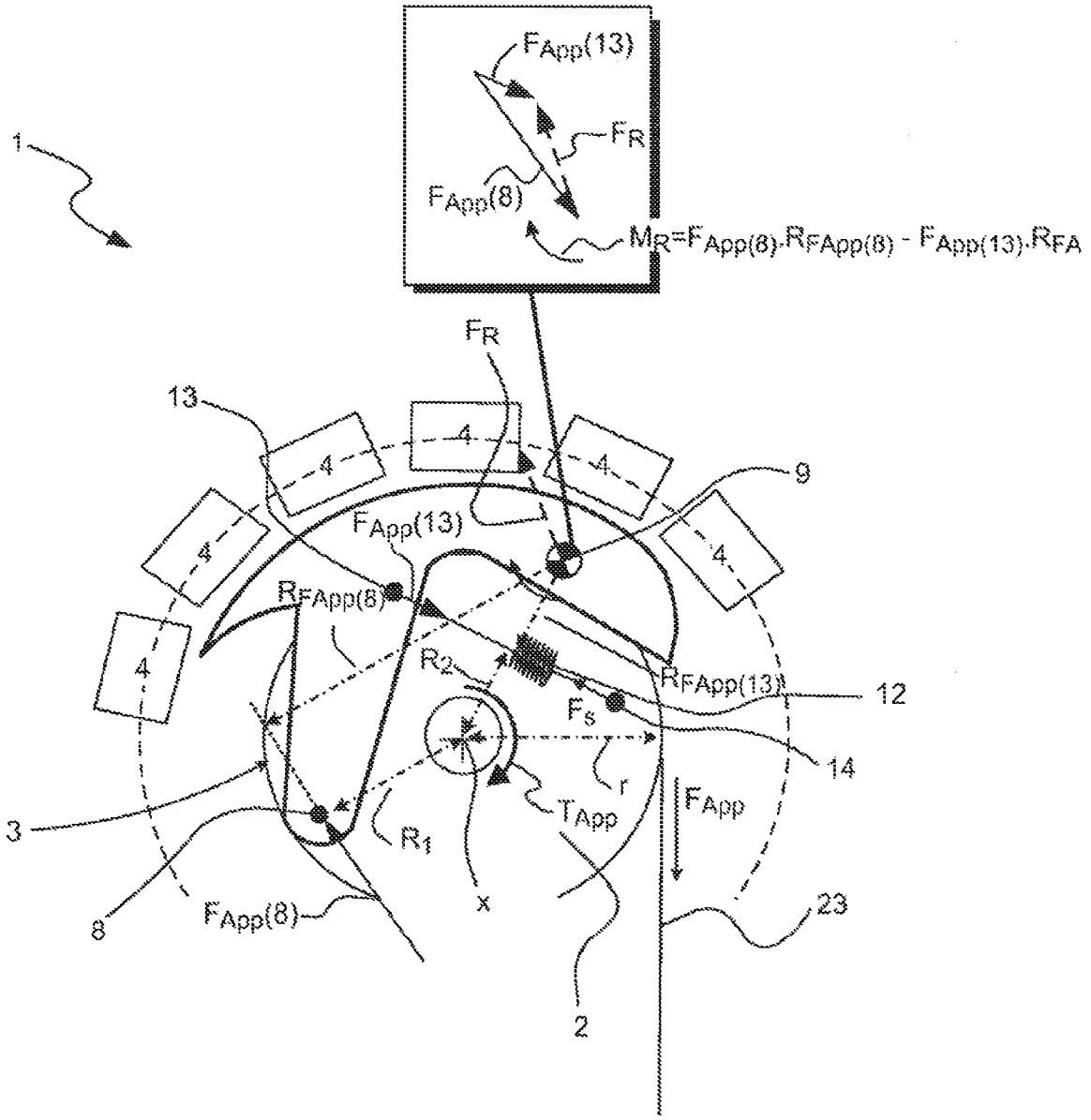


Figure 4



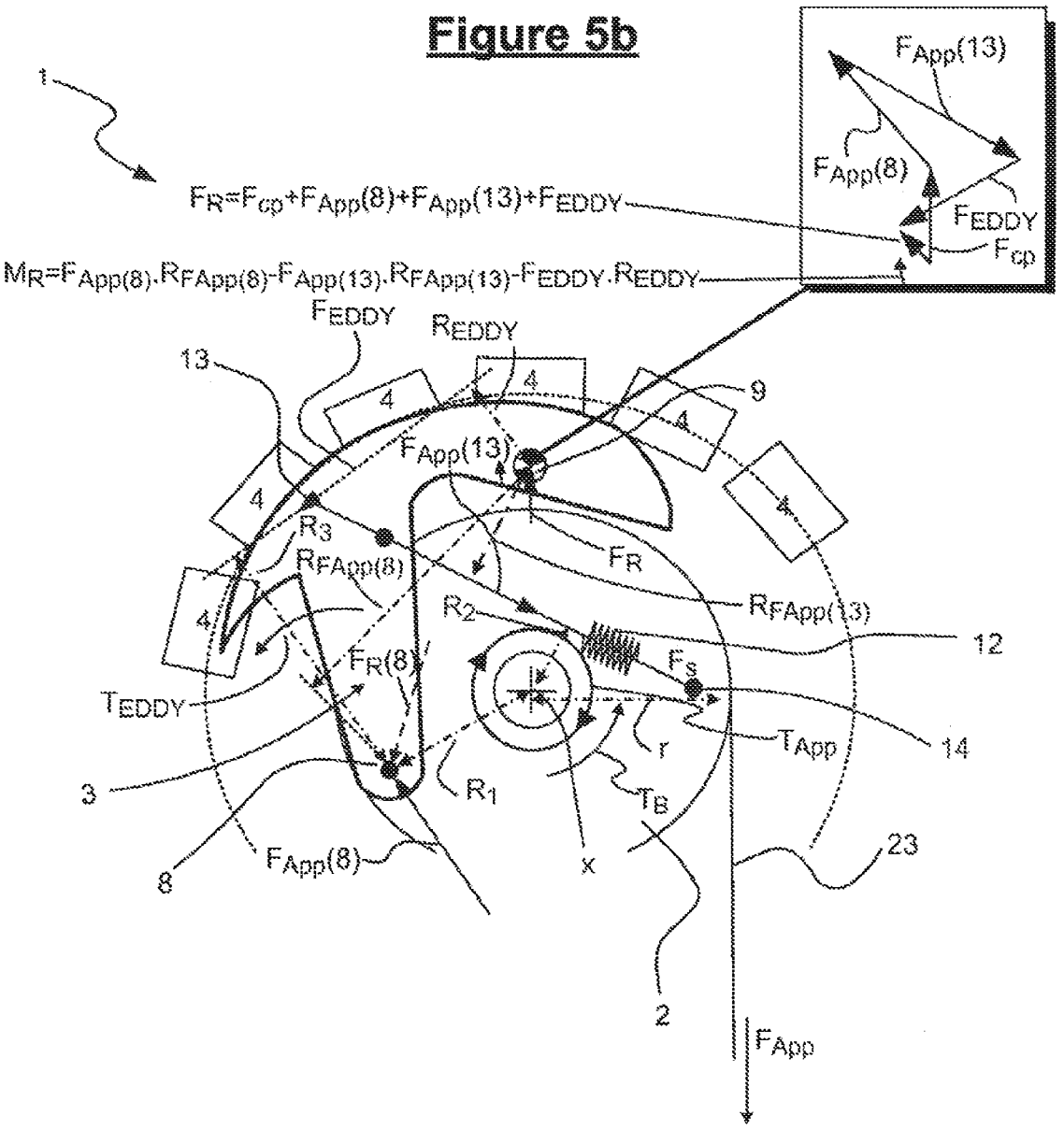
Date Reçue/Date Received 2021-01-12

Figure 5a



Date Reçue/Date Received 2021-01-12

Figure 5b



Date Reçue/Date Received 2021-01-12

Figure 5c

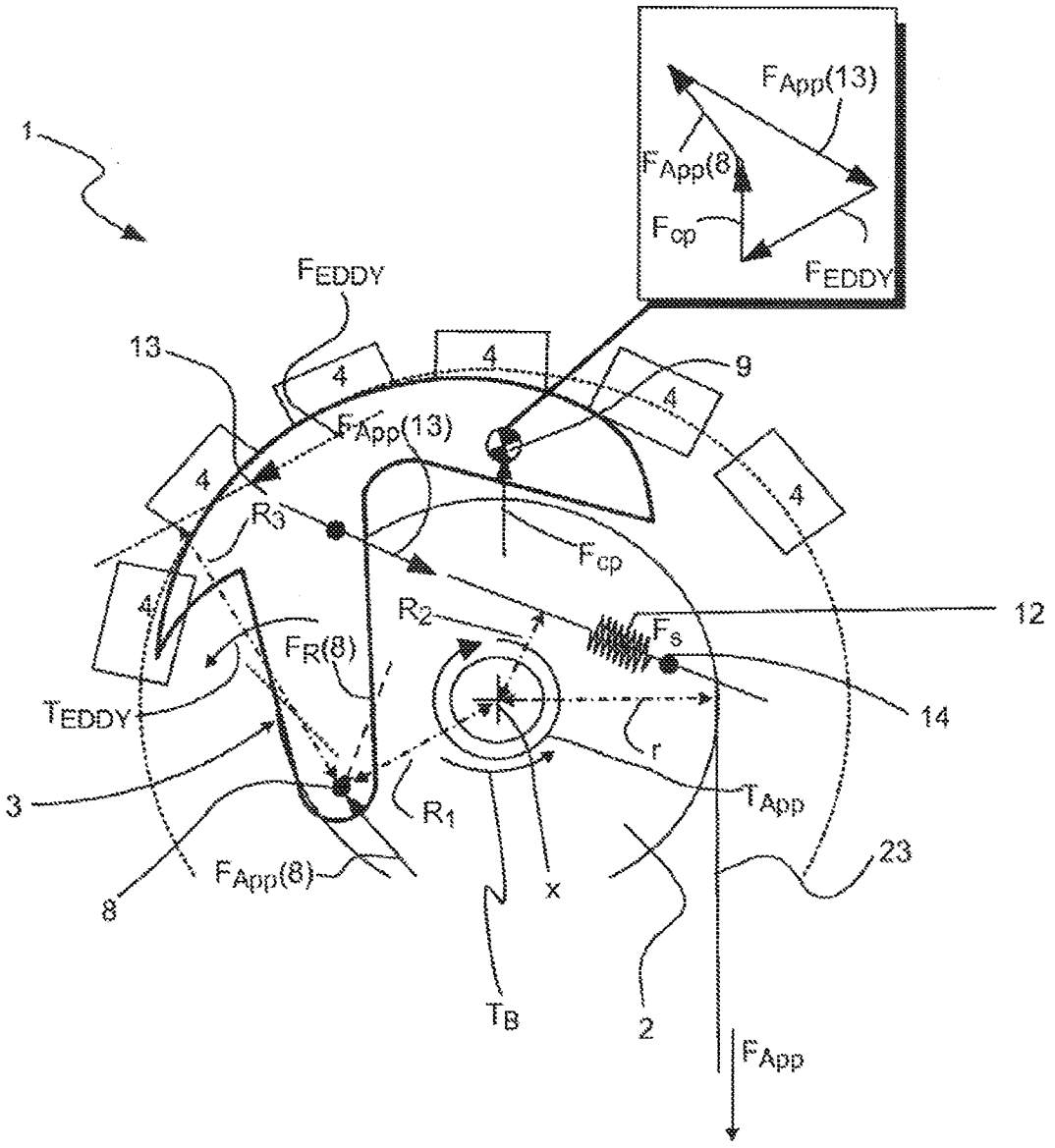

1
FEDDY
13
4
4
9
4
FApp(13)
4
4
R3
Fcp
4
R2
12
Fs
FR(8)
TEDDY
14
r
3
TApp
R1
23
FApp(8)
8
x
TB
2
FApp
FApp(13)
FApp(8)
Fcp
FEDDY

Figure 5d

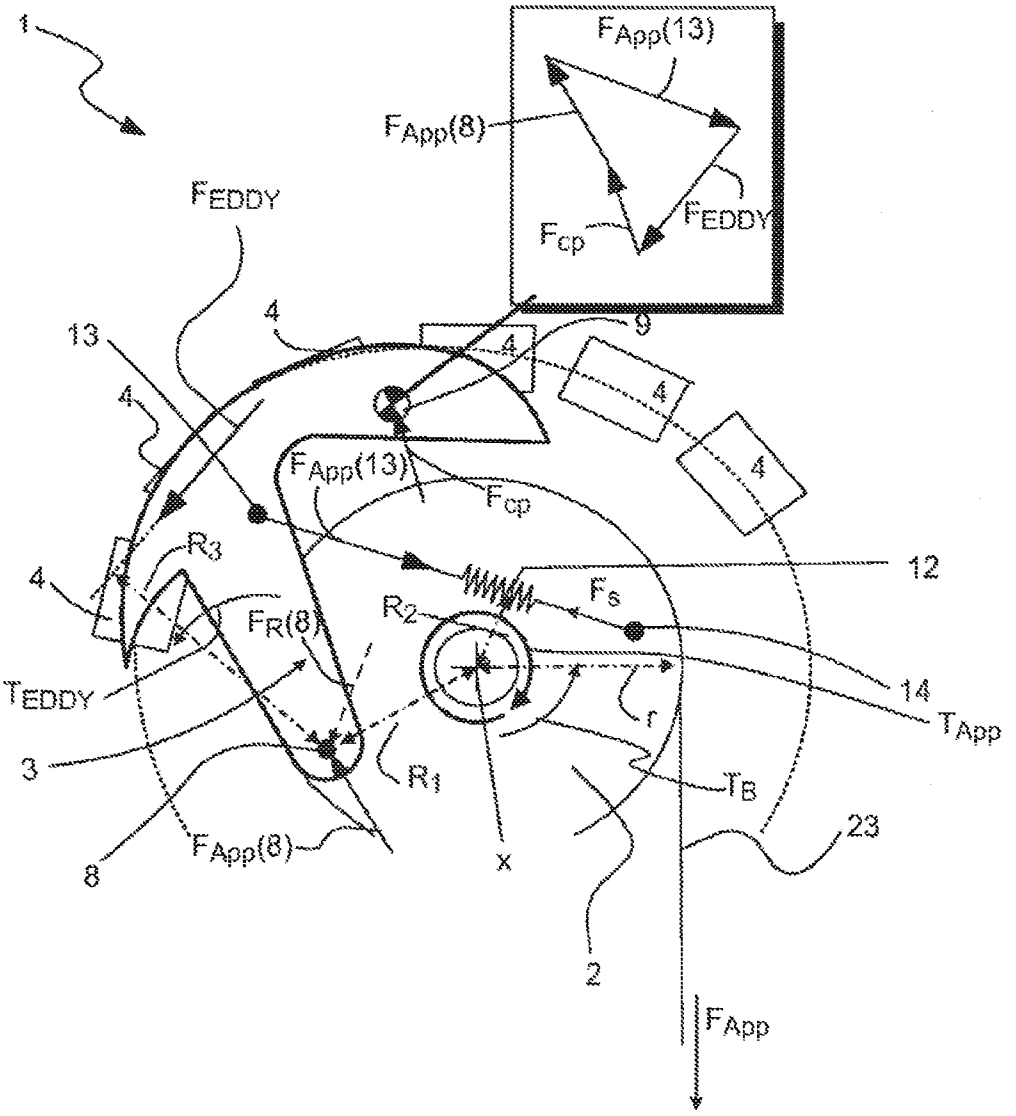
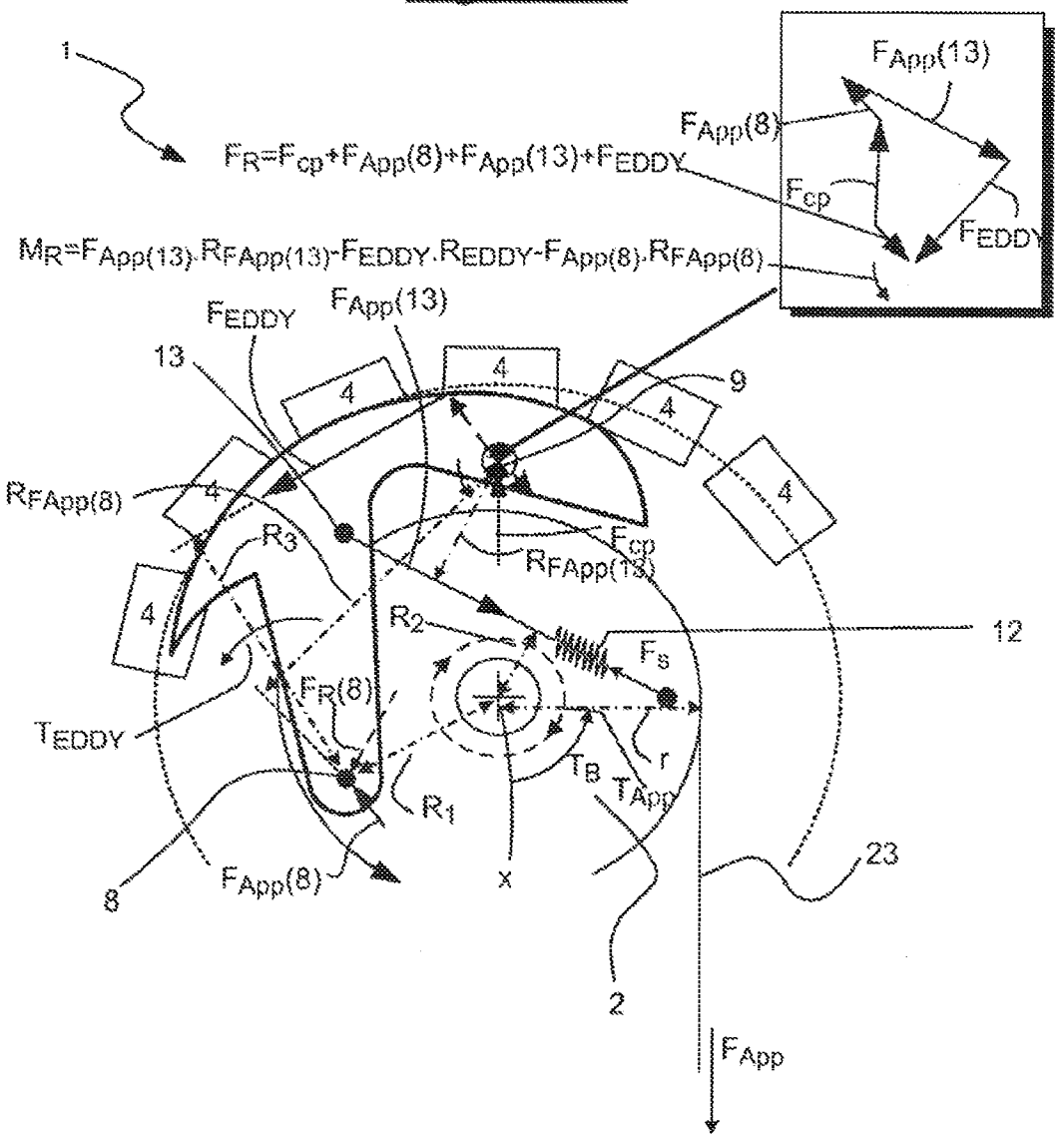
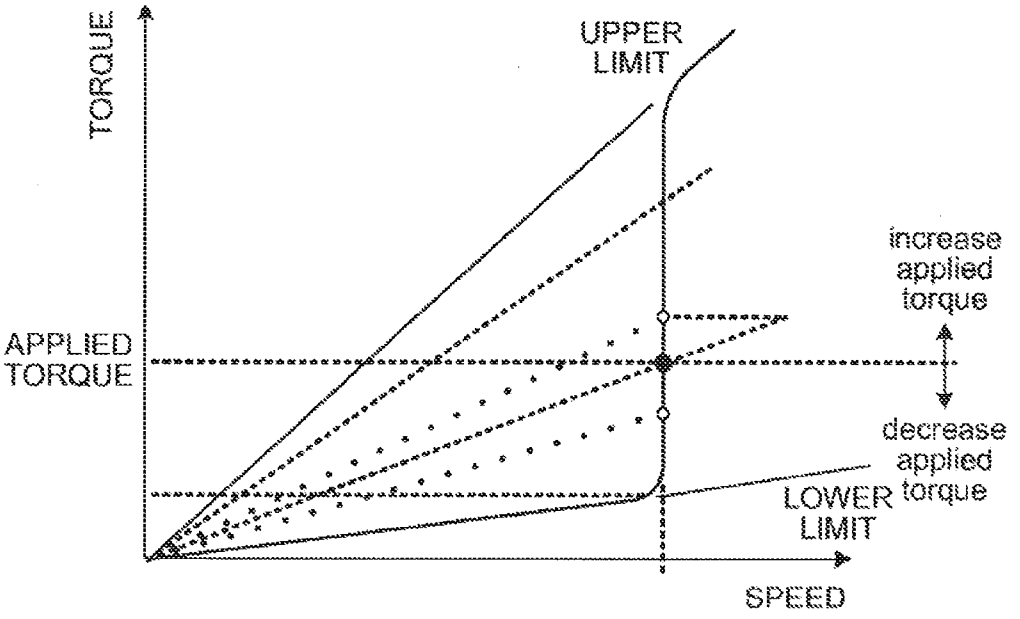

1
FApp(13)
FApp(8)
FEDDY
Fcp
FEDDY
13
4
9
4
4
4
4
FApp(13)
Fcp
12
R3
4
Fs
R2
FR(8)
14
TEDDY
TApp
r
3
R1
TB
23
FApp(8)
8
x
2
FApp

Figure 5e



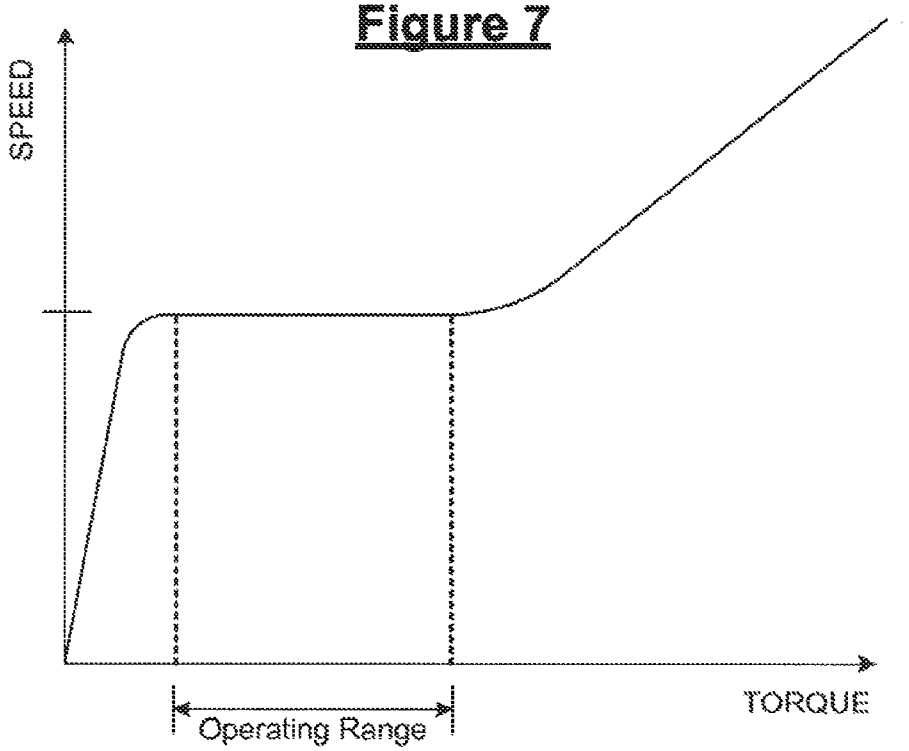
Date Reçue/Date Received 2021-01-12

Figure 6



Date Reçue/Date Received 2021-01-12

Figure 7



Date Reçue/Date Received 2021-01-12

Figure 8

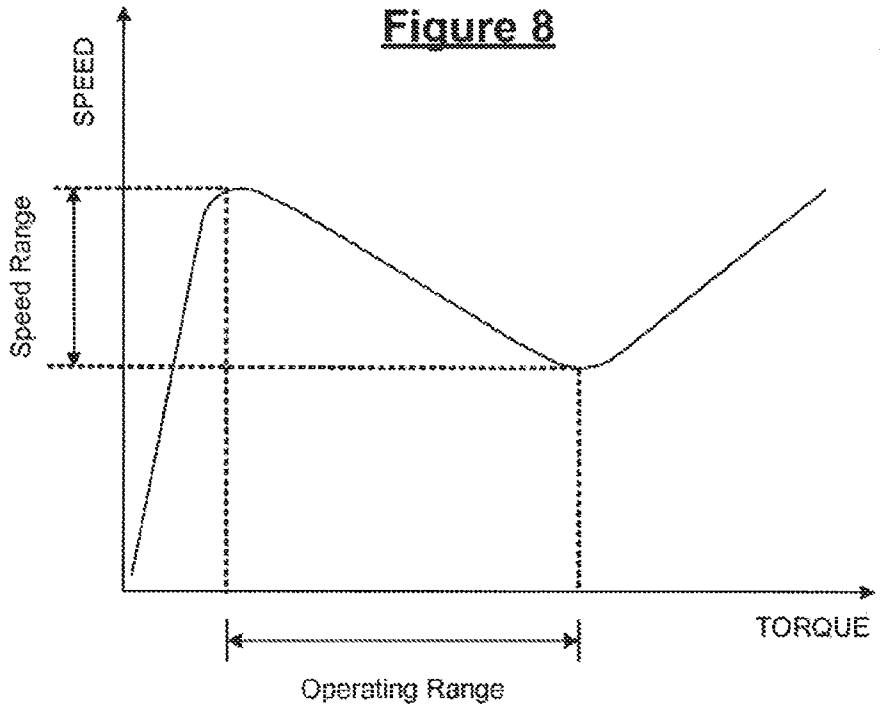
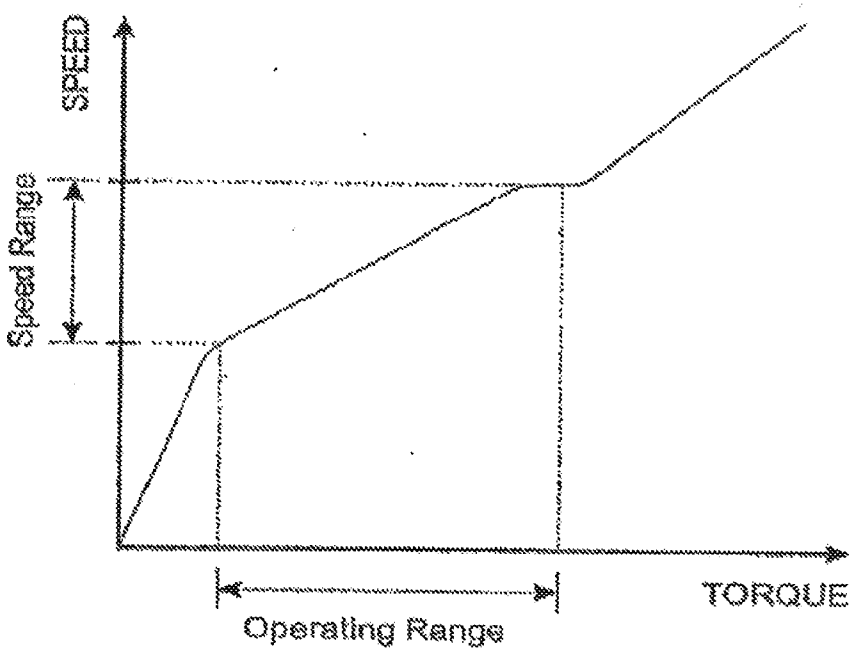


Figure 9



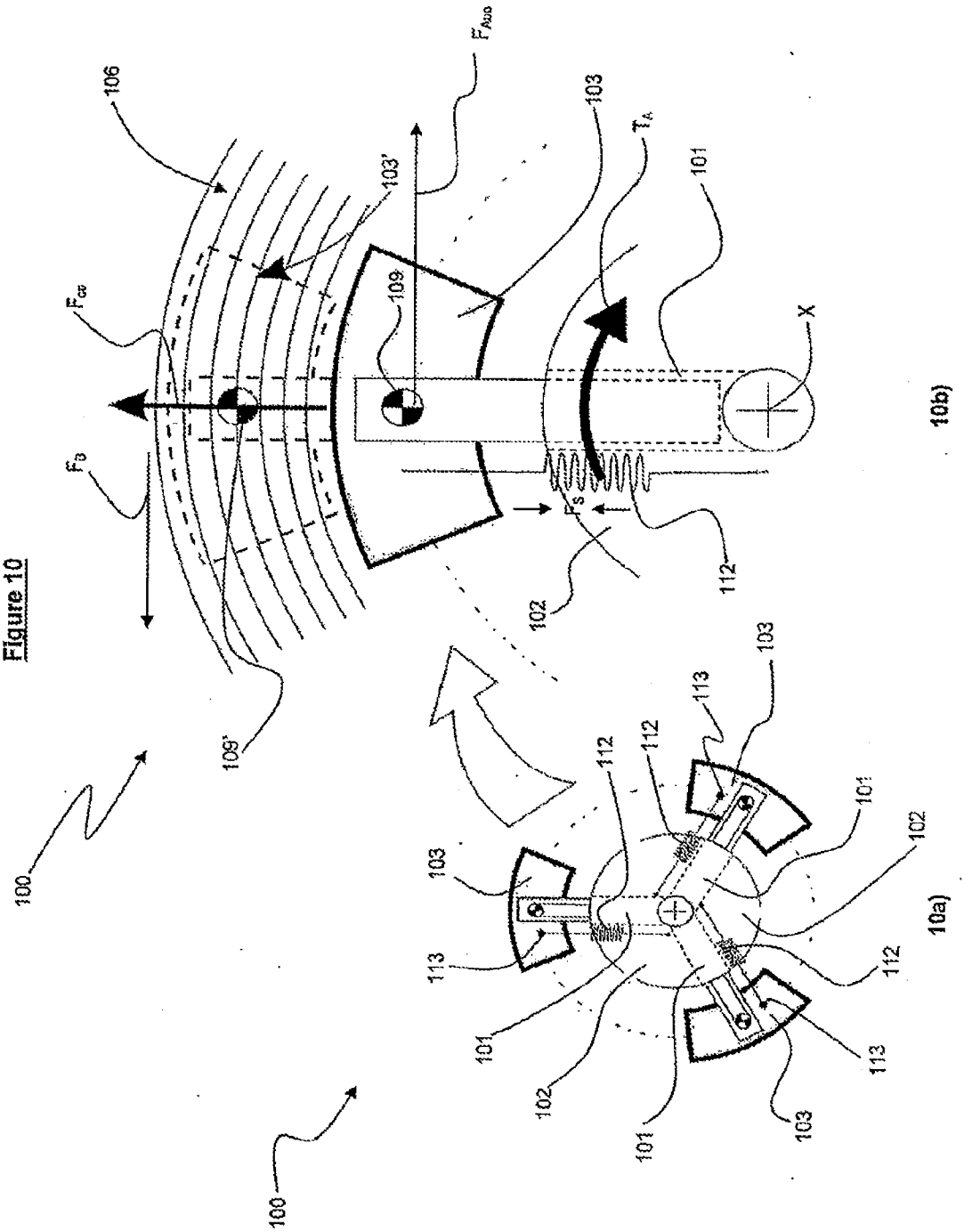
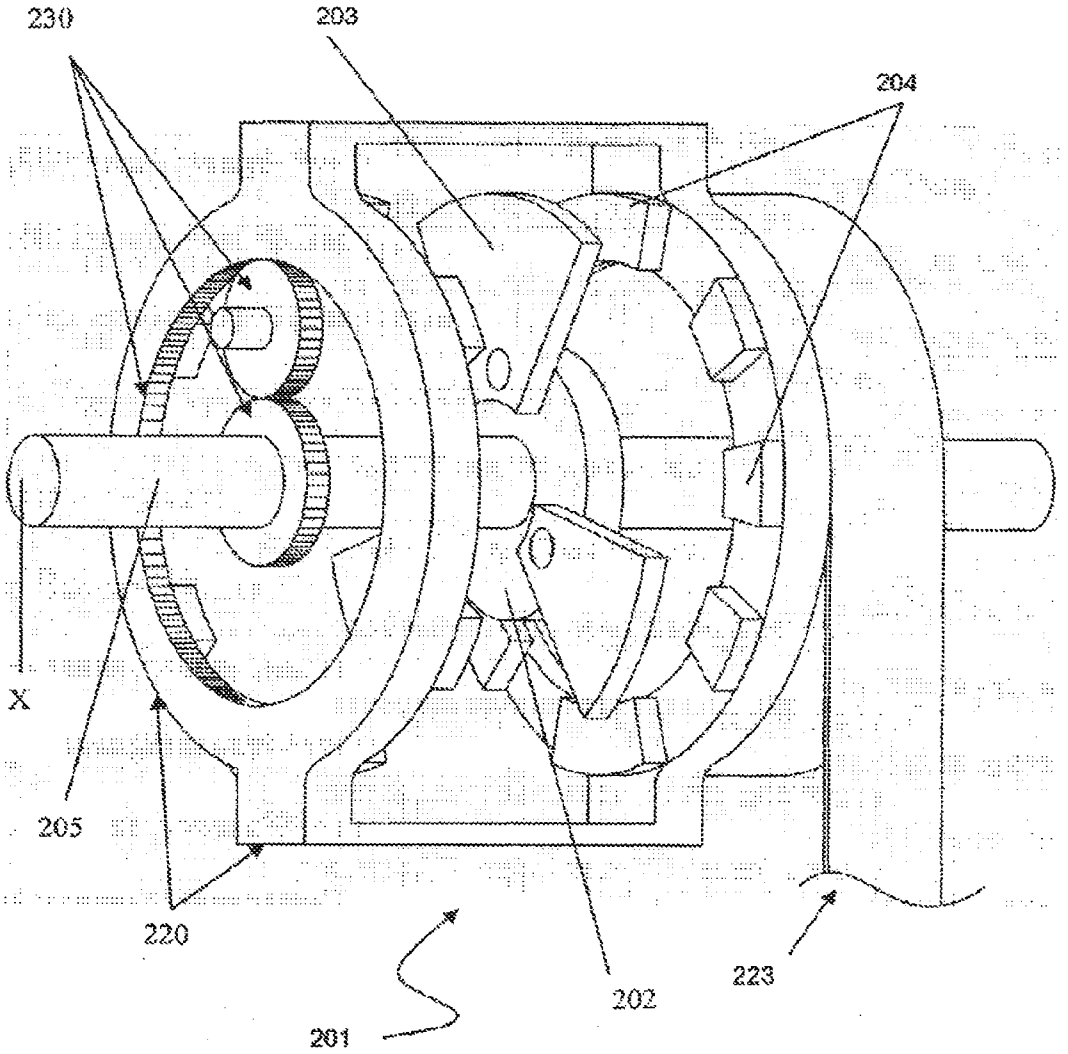

100
106
109'
103'
109
F_{cp}
F_b
F_{Abb}
103
T_A
101
X
F_s
102
112
10b)
100
103
113
112
101
102
10a)

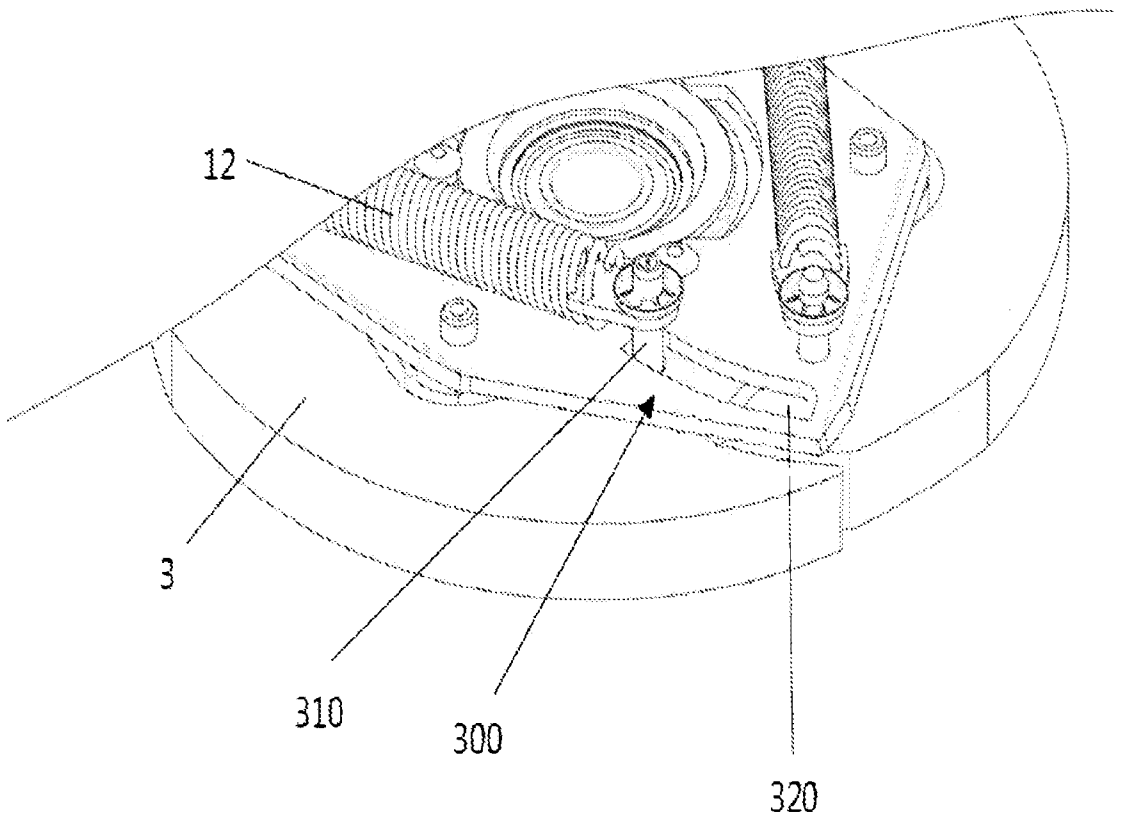
Figure 10

Figure 11

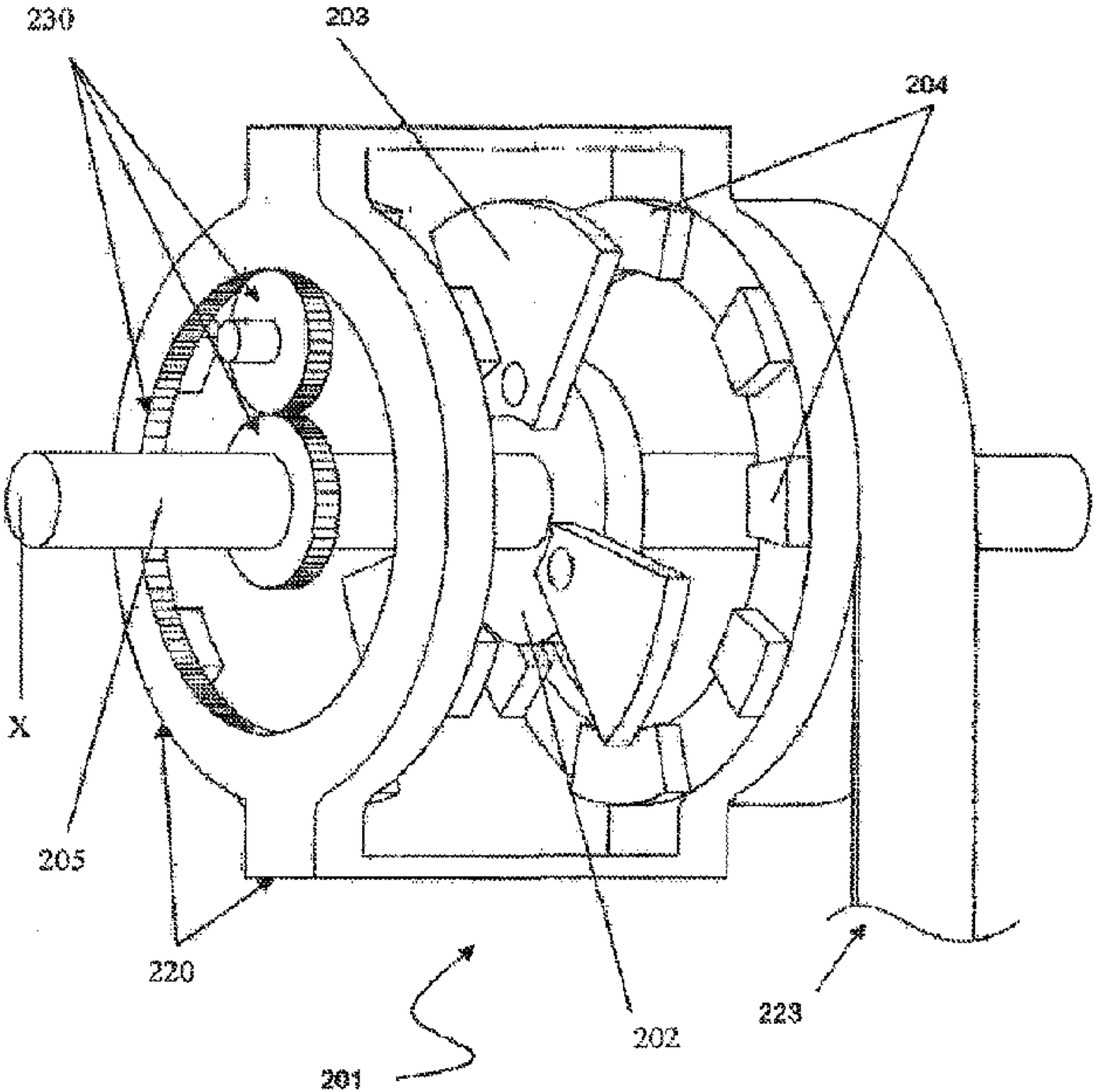


Date Reçue/Date Received 2021-01-12

Figure 12



Date Reçue/Date Received 2021-01-12


230
203
204
X
205
220
201
202
223