(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 December 2012 (13.12.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/168419 A1

(51) International Patent Classification:
F04D 29/66 (2006.01) *F01D 5/02* (2006.01)
F16F 15/36 (2006.01) *F03B 11/00* (2006.01)

(21) International Application Number: PCT/EP2012/060874

(22) International Filing Date: 8 June 2012 (08.06.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11169466.7 10 June 2011 (10.06.2011) EP

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

[Continued on next page]

(54) Title: METHOD, APPARATUS AND SYSTEM FOR REDUCING VIBRATION IN A ROTARY SYSTEM OF A POWER GENERATOR

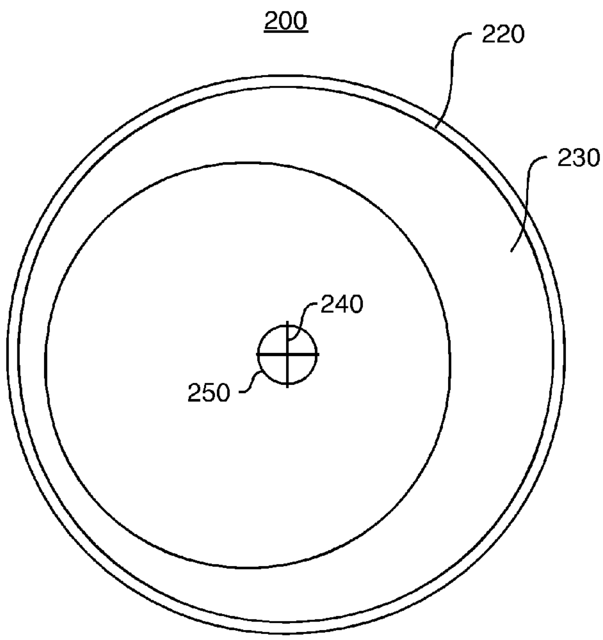


FIG. 3

(57) Abstract: A method of reducing vibration in a rotary system of a power generator, comprising balancing said rotary system, characterized by providing a rotational element (220) comprising a chamber (210) having a fulcrum on a rotational axis (240) of said rotational element (200), comprising a circumferential balancing area (220) and being partially filled with an amount of a thixotropic balancing substance (230). A corresponding apparatus and system.

WO 2012/168419 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Method, Apparatus and System for Reducing Vibration in a Rotary System of a Power Generator

Field of the Invention

Embodiments of the invention described herein relate generally to reducing vibration, and more particularly to a method, an apparatus and a system for reducing vibration in a rotary system of a power generator such as an electrical power generator.

Background of the Invention

A power generator is a machine for generating a form of energy from another form of energy, for example for generating electrical energy, that is electricity, from chemical energy or mechanical energy. Chemical energy may be released be burning fuel, for example gas such as natural gas or bio gas, oil, and coal. Mechanical energy may be available as potential energy, for example in the form of water in a reservoir, or kinetic energy, for example in the form of wind. Thus, the power generator may operate directly or indirectly, for example the fuel is burnt to produce steam and the steam drives the power generator to generate electricity. Power generation, that is energy generation, is power transformation, that is energy transformation.

The power generator may be comprised within a housing, for example a case or building such as a plant. The power generator may be comprised in a system, for example a power storage system for receiving and storing excess power during oversupply, and releasing and transmitting power during peak demand.

The power generator may comprise a rotor. For generating electricity having a frequency of 50 Hz, the rotor may rotate at 50 revolutions per second, that is 3000 revolutions per minute (rpm). For generating electricity having a frequency of 60 Hz, the rotor may rotate at 60 revolutions per second, that is 3600 revolutions per minute (rpm). The power generator may generate electricity in a range from a few watts (W) or kilowatts (KW) to several megawatts (MW) or gigawatts (GW).

Vibration is a major factor in a power generator. Vibration negatively effects durability that is service interval and life time, safety and comfort. With regard to safety, vibration has a direct influence on stability and may cause material fatigue and damage. With regard to comfort, vibration has a direct influence on noise and may increase a level of noise. Moreover, vibration-induced noise may be amplified by the system comprising the power generator.

A main source of vibration is a rotary system of the power generator, comprising a drive unit and a power generating unit. The rotary system may comprise a shaft, a bearing, a rotor or a combination thereof. Vibrations may comprise rotation-speed-dependent vibrations generally originating from the rotary system. Vibrations may damage rolling-element bearings, for example ball bearings or roller bearings, used, for example, as bearings, or seals.

In order to reduce vibration, the rotary system may initially be balanced during production of the rotary system by selectively removing material from a rotating element of the rotary system such that its centre of gravity (CofG) is moved to its centre of rotation (CofR), that is fulcrum. Removing material may comprise abrading, for example grinding, material from the rotating element, or drilling a hole into the rotating elements, or a combination thereof. However, the removing step is an additional step in production, requiring time and increasing cost, particularly in large-volume production.

Moreover, owing to wear and tear of the rotary system, or collection of particles, for example dirt, on the rotor, vibration in the power generator generally increases over time. In more detail, owing to wear and tear of a rotating element, its CofG moves away from the CofR over time causing an imbalance causing vibration.

In a wind turbine generator (WTG), the rotary system further comprises blades. The blades may comprise, for example, wood or composite materials, such as glass-fibre-reinforced material or carbon-fibre-reinforced material. The blades change over time, and they tend to get heavier in service. There is blade wear or erosion owing to hard particles, such as sand. Furthermore, owing to light-weight construction of the blades, air cells in the blades may fill with water, in particular where a skin of the blades becomes porous. This is known as water-ingress or trapped-water problem. Furthermore, blades may be repaired during their life time. As a result, a blade’s centre of gravity (CofG) moves over time. In general the movement is larger, and therefore more severe, for a span centre of gravity, that in a hub-to-blade-tip direction of the blade, than for a chord centre of gravity, that is in a leading-edge-to-tailing-edge direction of the blade. When the chord CofG is located aft of an ideal CofG, a turning moment is located aft of the ideal CofG. When the chord CofG is located forward of the ideal CofG, the turning moment is located forward of the ideal CofG. As a consequence, vibration in the rotary system increases.

DE 198 57 646 discloses a method of balancing tires by introducing a balancing substance inside the tire comprises placing a substance with definite properties, shape, geometry and weight inside the tire and moving to the point of imbalance by rotating the tire.

WO 2010/003988 discloses a method for reducing vibration in a rotary system of an aircraft, for example an aeroplane or a rotorcraft, such as a helicopter.

WO 2011/061228 discloses a method of reducing vibration in a rotary system of a watercraft, for example a cargo ship.

WO 2011/061227 discloses a method of reducing vibration in a rotary system of a motor vehicle, for example a car.

WO 2009/140022 discloses a machine comprising: a magnetic thrust bearing comprising: a rotor portion; a stator portion; and a housing substantially surrounding said stator portion and said rotor portion; said rotor portion comprising a thrust disk adapted to be circumferentially attached to a rotor and to rotate with the rotor, said thrust disk defining a thrust disk first side and a thrust disk second side, said first side opposing said second side.

WO 2010/006859 discloses a bearing arrangement and a bearing block composed of a magnetic radial bearing for the contact-less support of a rotor shaft of a rotating machine, and composed of a safety bearing for catching the rotor shaft. Accordingly, both bearings are connected to each other permanently and in an axially aligned manner, and are elastically suspended with regard to a bearing shield, a machine housing, or a foundation of the rotating machine.

For these and other reasons, there is a need for the invention as set forth in the following in the embodiments.

Summary of the Invention

The invention aims to provide a method, an apparatus and a system for reducing vibration in a rotary system of a power generator.

An aspect of the invention is a method of reducing vibration in a rotary system 120, 130, 140, 150 of a power generator 100, comprising balancing said rotary system 120, 130, 140, 150, characterized by providing a rotational element 120, 124, 130, 135, 140, 144, 150; 200 comprising a chamber 210 having a fulcrum on a rotational axis 240 of said rotational element 120, 124, 130, 135, 140, 144, 150; 200, comprising a circumferential balancing area 220 and being partially filled with an amount of a thixotropic balancing substance 230.

Another aspect of the invention is a method, further comprising rotating said rotational element 120, 124, 130, 135, 140, 144, 150; 200 about the rotational axis 240, such that said thixotropic balancing substance 230 liquefies and distributes itself along the circumferential balancing area 220, and an imbalance of said rotational element 120, 124, 130, 135, 140, 144, 150; 200 is reduced.

Another aspect of the invention is a method, wherein said rotational axis 240 is oriented horizontally; or said rotational axis 240 is oriented vertically.

Another aspect of the invention is a method, wherein said rotational element 120, 124, 130, 135, 140, 144, 150; 200 is an original element of said rotary system 120, 130, 140, 150, a replacement element of said rotary system 120, 130, 140, 150, or a supplemental element to said rotary system 120, 130, 140, 150; said rotational element 130 is a hollow shaft or tubular shaft; said rotational element 130 is an articulated shaft, for example a cardan shaft; or a combination thereof.

Another aspect of the invention is a method, wherein the supplemental element is disc-shaped; or the supplemental element is ring-shaped.

Another aspect of the invention is a method, wherein said rotational element 120, 124, 130, 135, 140, 144, 150; 200 is a shaft 130; said rotational element 120, 124, 130, 135, 140, 144, 150; 200 is a rotor 144 of said power generator 100; said rotational element 120, 124, 130, 135, 140, 144, 150; 200 is a gear wheel; said rotational element 120, 124, 130, 135, 140, 144, 150; 200 is a bearing 135; or a combination thereof.

Another aspect of the invention is a method, wherein said chamber 210 is annular or ring-shaped, or cylindrical; said chamber 210 has a cross section being rectangular, square, semicircle-shaped, bell-shaped or circular; said chamber 210 has a diameter of between approximately 0.005 m and approximately 2 m, or between approximately 0.01 m and approximately 1 m, or between approximately 0.02 m and approximately 0.5 m, or between approximately 0.05 m and approximately 0.2 m, or approximately 0.1 m; said chamber 210 has a length of between approximately 0.01 m and approximately 1 m, or between approximately 0.02 m and approximately 0.5 m, or between approximately 0.05 m and approximately 0.2 m, or approximately 0.1 m; or a combination thereof.

Another aspect of the invention is a method, wherein said amount of said thixotropic balancing substance 230 is between approximately 0.001 kg and approximately 1000 kg, or between approximately 0.002 kg and approximately 500 kg, or between approximately 0.005 kg and approximately 200 kg, or between approximately 0.01 kg and approximately 100 kg, or between approximately 0.02 kg and approximately 50 kg, or between approximately 0.05 kg and approximately 20 kg, or between approximately 0.1 kg and approximately 10 kg, or between approximately 0.2 kg and approximately 5 kg, or between approximately 0.5 kg and approximately 2 kg, or approximately 1 kg; said chamber 210 is filled with the amount of said thixotropic balancing substance 230 to between approximately 1 % and approximately 90 %, or between approximately 10 % and approximately 80 %, or between approximately 25 % and approximately 75 %, or approximately 50 %; or a combination thereof.

Another aspect of the invention is an apparatus for reducing vibration in a rotary system 120, 130, 140, 150 of a power generator 100, characterized by a rotational element 120, 124, 130, 135, 140, 144, 150; 200 comprising a chamber 210 having a fulcrum on a rotational axis 240 of said rotational element 120, 124, 130, 135, 140, 144, 150; 200, comprising a circumferential balancing area 220 and being partially filled with an amount of a thixotropic balancing substance 230.

Yet another aspect of the invention is a rotary system 120, 130, 140, 150 of a power generator 100, for reducing vibration in said rotary system 120, 130, 140, 150, characterized by a rotational element 120, 124, 130, 135, 140, 144, 150; 200 comprising a chamber 210 having a fulcrum on a rotational axis 240 of said rotational element 120, 124, 130, 135, 140, 144, 150; 200, comprising a circumferential balancing area 220 and being partially filled with an amount of a thixotropic balancing substance 230.

Brief Description of the Several Views of the Drawing

While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the invention, a more particular description of the invention will be rendered by reference to specific embodiments thereof, which are depicted in the appended drawing, in order to illustrate the manner in which embodiments of the invention are obtained. Understanding that the drawing depicts only typical embodiments of the invention, that are not necessarily drawn to scale, and, therefore, are not to be considered limiting of its scope, embodiments will be described and explained with additional specificity and detail through use of the accompanying drawing in which:

Fig. 1 shows a schematic view of a power generator, to which the invention may be applied;

Fig. 2 shows, for a preferred embodiment of the invention, a cross-sectional view of the cylindrical chamber at an initial point in time;

Fig. 3 shows, for the preferred embodiment of the invention, a cross-sectional view of the cylindrical chamber at a point in time, when the thixotropic balancing substance is distributed along the circumferential balancing area of the chamber;

Fig. 4 shows a cross-sectional view of a chamber in a rotational element according to yet another embodiment of the invention;

Fig. 5 shows a cross-sectional view of a chamber in a rotational element according to yet another embodiment of the invention;

Fig. 6 shows a cross-sectional view of a chamber in another rotational element according to yet another embodiment of the invention;

Fig. 7 shows a cross-sectional view of another chamber in a rotational element according to yet another embodiment of the invention;

Fig. 8 shows a cross-sectional view of another chamber in a rotational element according to yet another embodiment of the invention;

Fig. 9 shows a cross-sectional view of yet another chamber in a rotational element according to yet another embodiment of the invention; and

Fig. 10 shows a cross-sectional view of another chamber in another rotational element according to yet another embodiment of the invention.

Detailed Description of the Invention

In the detailed description of the embodiments, reference is made to the accompanying drawing which forms a part hereof and shows, by way of illustration, specific embodiments in which the invention may be practiced. In order to show the structures of the embodiments most clearly, the drawing included herein is a diagrammatic representation of inventive articles. Thus, actual appearance of the fabricated structures may appear different while still incorporating essential structures of embodiments. Moreover, the drawing shows only the structures necessary to understand the embodiments. Additional structures known in the art have not been included to maintain clarity of the drawings. It is also to be understood, that features and/or elements depicted herein are illustrated with particular dimensions relative to one another for purposes of simplicity and ease of understanding, and that actual dimensions may differ substantially from that illustrated herein. In the drawing, like numerals describe substantially similar components throughout the several views. The embodiments are intended to describe aspects of the invention in sufficient detail to enable those of skill in the art to practice the invention. Other embodiments may be utilized and structural, logical or electrical changes or combinations thereof may be made without departing from the scope of the invention. Moreover, it is to be understood, that the various embodiments of the invention, although different, are not necessarily mutually exclusive. For example, a particular element, feature, structure, characteristic, integer or step, or group of elements, features, structures, characteristics, integers or steps described in one embodiment may be included within other embodiments. Furthermore, it is to be understood, that embodiments of the invention may be implemented using different technologies. Also, the term "exemplary" is merely meant as an example, rather than the best or optimal. The detailed description is, therefore, not to be taken in a limiting sense.

Throughout this specification the word „comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

In the description and claims, the terms “include”, “have”, “with” or other variants thereof may be used. It is to be understood, that such terms are intended to be inclusive in a manner similar to the term “comprise”.

In the description and claims, the terms “coupled” and “connected”, along with derivatives such as “communicatively coupled” may be used. It is to be understood, that these terms are not intended as synonyms for each other. Rather, in particular embodiments, “connected” may be used to indicate, that two or more elements are in direct physical or electrical contact with each other. However, “coupled” may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other.

In the description and claims, terms, such as “upper”, “lower”, “first”, “second”, etc., may be only used for descriptive purposes and are not to be construed as limiting. The embodiments of a device or article described herein can be manufactured, used, or shipped in a number of positions and orientations.

Fig. 1 shows a schematic view of a power generator 100, to which the invention may be applied. The power generator 100 may comprise a housing 110. The housing 110 may be a case or building such as a plant. The power generator 100 comprises a drive unit 120 for providing rotary energy at a shaft 130 having a fulcrum on a rotational axis 240. As indicated in Fig. 1, the drive unit 120 may comprise a turbine with one, two, three or more turbine wheels 124 housed in a turbine housing 122, and an exhaust 126 coupled to the turbine housing 122 and extending through the housing 110. The turbine may typically be powered by gas such as natural gas or bio gas, or steam. However, the drive unit 120 may be powered by other sources of power comprising, for example, hydraulic power, pneumatic power or wind energy. The drive unit 120 may comprise an internal combustion engine powered by, for example, gas, such as natural gas or bio gas, oil, gasoline or diesel. The power generator 100 further comprises a power generating unit 140 coupled to the drive unit 120 for receiving the rotary energy, and generating power, such as electrical power. As indicated in Fig. 1, the power generating unit 140 may comprise a rotor 144 housed in a stator 142 and connected to the shaft 130. The power generator 100 may comprise one, two, three or more support elements 180 having bearings 135 and being arranged along the shaft 130 for supporting the shaft 130. Rotating elements of the power generator 100 such as turbine wheels 124, shaft 130, bearing 135 and rotor 144 form a rotary system of the power generator 100. The rotary system of the power generator 100 may optionally comprise a gear box 150 arranged between the drive unit 120 and the power generating unit 140 for coupling the drive unit 120 and the power generating unit 140. The gear box may be an indexing gear box, that is a shift gear box. The gear box 150 may convert a rotational speed of the drive unit 120 to a rotational speed of the power generating unit 140. The gear box 150 may increase or decrease the rotational speed. The gear box 150 may or may not change direction of the rotation. The gear box 150 may redirect the rotary energy into another direction. The gear box 150 may distribute the rotary energy among one, two, three or more drive units 120 and one, two, three or more power generating units 140.

The power generator 100 may be oriented horizontally, vertically, or at any suitable angle.

The power generator 100 may generate electrical power, that is electricity, for example in the form of alternating voltage and alternating current such as alternating voltage and alternating current having a frequency of 50 Hz or 60 Hz. For generating electricity having a frequency of 50 Hz, the shaft 130 and rotor 144 may rotate at 50 revolutions per second, that is 3000 revolutions per minute (rpm). For generating electricity having a frequency of 60 Hz, the shaft 130 and rotor 144 may rotate at 60 revolutions per second, that is 3600 revolutions per minute (rpm). The power generator 100 may generate electricity in the range from a few watts (W) to several gigawatts (GW), for example in the range from a few kilowatts (KW) to several megawatts (MW).

The power generator 100 may transform a primary energy, that is input energy, directly into a secondary energy, that is output energy. Alternatively, the power generator may transform the primary energy indirectly, that is via one, two, three or more intermediate energies, into the secondary energy.

The drive unit 120 may be driven by a chemical energy as a primary energy.

The turbine 122, 124 is driven by a fluid, that is a liquid or gas such as air or steam i.e. a combination of a gas and water vapour, acting as an intermediate energy carrier. The turbine 122, 124 may be driven by steam produced by boiling water by burning fuel comprising gaseous, liquid and solid fuels, for example fossil fuel comprising hydrocarbons such as gas, oil comprising oil shale waste and bituminous rocks or coal, and biogas and biomass such as crops, wood comprising wood pellets and waste comprising sewage, or nuclear fuel by nuclear fission or nuclear fusion, by employing steam emerging under pressure from the ground in geothermal power conversion, by concentrating sunlight using a solar parabolic trough or solar power tower to heat a heat transfer fluid such as molten salt, or using a small difference between cooler deep and warmer surface ocean waters in ocean thermal energy conversion (OTEC). The turbine 122, 124, 126 may be a hot-gas turbine driven directly by a gas produced by combustion of gas such as natural gas or bio gas, or oil. The power generator 100 may be a combined-cycle power generator, wherein the gas turbine 122, 124, 126 is driven by the gas, and a steam turbine (not shown) is driven by residual heat from the burnt gas for generating additional electricity.

The drive unit 120 may be driven by a physical energy a as a primary energy. The drive unit 120 may, for example, be driven by rotational energy of a rotating mass, pressure energy of a compressed gas such as air, or electrical energy.

The turbine 122, 124 may be driven by renewable source. In a hydroelectric power generator 100, the turbine may be driven by flowing water, for example of a river or waste water system, tidal water of an ocean, or falling water, for example of a reservoir comprising a dam, cave and cavern.

In a WTG, the turbine may be driven by naturally occurring wind. In a solar updraft tower, the turbine may be driven by wind artificially produced inside a chimney heated with sunlight.

The power generator 100 may generate the secondary energy instantly from the primary energy, that is when the primary energy is available and the secondary energy is to be consumed. For example, the drive unit 120 of the power generator 100 may generate an amount of compressed air driving the turbine 122, 124 and the power generating unit 140 to produce electrical energy.

The power generator 100 may generate the secondary energy deferred from the primary energy, that is after the primary energy has been available and when the secondary energy is to be consumed. For example, the drive unit 120 of the power generator 100 may generate and store an amount of compressed air in a storage unit (not shown) using primary energy, when the primary energy is available or less expensive, and the amount of compressed air may drive the turbine 122, 124 and the power generating unit 140 to produce electrical energy, when the electrical energy is to be consumed.

The power generator 100 may receive and store secondary energy, when there is a surplus or excess of secondary power or secondary power is less expensive, and generate and transmit secondary energy, when the secondary energy is to be consumed or more expensive. For example, the drive unit 120 of the power generator 100 may generate and store an amount of compressed air in a storage unit (not shown) using electrical energy, when the electrical energy is available or less expensive, and the amount of compressed air may drive the turbine 122, 124 and the power generating unit 140 to produce electrical energy, when the electrical energy is to be consumed or more expensive; or the drive unit 120 may pump an amount of water from a underground storage unit (not shown) into a storage unit (not shown) on or above ground level using electrical energy, when the electrical energy is available or less expensive, and the amount of water may fall back into the underground storage unit (not shown) thereby driving the turbine 122, 124 and the power generating unit 140 to produce electrical energy, when the electrical energy is to be consumed or more expensive. Thus, the power generator 100 may form part of an energy storage system. The energy storage system receives and transmits the same type of energy, such as electrical energy, and may generate power during peak demand.

The power generator 100 may be stationary.

The power generator 100 may be a power plant and may be coupled to a supply grid such as a national supply grid. The power generator 100 may form part of a combined heat and power unit (CHP), that is total energy unit.

Further, the power generator 100 may be portable.

Thus, it may be employed at home, in an office, a business, a shop or a workshop.

Furthermore, the power generator 100 may be employed mobile.

The power generator 100 may be employed in a vehicle, for example a land vehicle such as a wheeled vehicle, in particular a bicycle, car, lorry, truck or motorcycle, a tracked vehicle, or a railed vehicle, in particular a train; an aircraft such as an airplane; a spacecraft; or a watercraft, such as a ship. The power generator 100 may be an electric generator for charging a battery, for example a rechargeable battery or automotive battery, of a vehicle such as a car, or a dynamo of a bicycle. The power generator 100 may form part of a breaking system for recuperating, that is regenerating braking energy by transforming kinetic energy into electrical energy. The power generator may generate power in the range from approximately 1 W to approximately 100 KW, for example in the range from approximately 10 W to approximately 10K W, such as in the range from approximately 100 W to approximately 1 KW.

Thus, the power generator 100 may, among other things, be employed in generating and storing energy, such as electrical energy, that is electricity.

According to embodiments of the invention, one, two, three or more rotational elements 120, 124, 130, 135, 140, 144, 150 of the power generator 100 comprise one, two, three or more chambers 210 having a fulcrum on a rotational axis 240, comprising a circumferential balancing area 220 and being partially filled with an amount of a thixotropic balancing substance 230. The one, two, three or more rotational elements 120, 124, 130, 135, 140, 144, 150 comprising one, two, three or more chambers 210 may comprise metal, for example steel, titanium, copper or aluminium, or composite material, for example glass-fibre-reinforced material or carbon-fibre-reinforced material, or synthetic material, for example plastics or plexiglas. The one, two, three or more rotational elements 120, 124, 130, 135, 140, 144, 150 comprising one, two, three or more chambers 210 may replace original rotational elements 120, 124, 130, 135, 140, 144, 150 of the rotational system. The one, two, three or more rotational elements 120, 124, 130, 135, 140, 144, 150 comprising one, two, three or more chambers 210 may be supplemental elements to the rotational system.

The chamber 210 may be caved into the rotational element such as rotor 144 or gear wheel. The chamber 210 may be situated in a shaft 130, such as a hollow shaft or tubular shaft, and extend partially or fully, such as substantially fully, along the hollow shaft or tubular shaft.

The circumferential balancing area 220 may comprise a nanostructure for improving movability and flow of the thixotropic balancing substance 230, said nanostructure being, for example, formed by a material, such as a varnish, comprising nanoparticles, or imprinted on said circumferential balancing area 220.

The thixotropic balancing substance 230 operates in the chamber 210. Owing to vibration, the thixotropic balancing substance 230 distributes itself along the circumferential balancing area 220, such that a CofG 250 moves towards the rotational axis 240, that is CofR, of the rotational element 120, 124, 130, 135, 140, 144, 150; 200, such as the shaft 130, and the vibration is reduced or minimized or eliminated.

Fig. 2 shows, for a preferred embodiment of the invention, a cross-sectional view of the cylindrical chamber 210 at an initial point in time, when the thixotropic balancing substance 230 partially fills the chamber 210. The thixotropic balancing substance 230 may be evenly distributed along the circumferential balancing area 220 as shown in Fig. 2. For a vertical rotational axis 240, the thixotropic balancing substance 230 may partially fill the chamber 210 to an even level perpendicular to the rotational axis 240. For a horizontal rotational axis 240, the thixotropic balancing substance 230 may partially fill the chamber 210 to an even level along the rotational axis 240. However, the thixotropic balancing substance 230 may partially fill the chamber 210 in any other manner. Owing to an imbalance of the rotational element 200 or the rotary system, a CofG 250 is offset from the rotational axis 240, that is CofR.

Fig. 3 shows, for the preferred embodiment of the invention, a cross-sectional view of the cylindrical chamber 210 at a point in time, when the thixotropic balancing substance 230 is distributed along the circumferential balancing area 220 of the chamber 210, such that the vibration is reduced. As the rotational element 200 rotates about the rotational axis 240, the thixotropic balancing substance 230 liquefies owing to vibration in the rotary system and distributes itself along the circumferential balancing area 220 of the chamber 210, such that an imbalance of the rotational element 200 is reduced, and, thus, the vibration is reduced. The CofG 250 moves towards the rotational axis 240, that is CofR. When the vibration is reduced, the thixotropic balancing substance 230 may solidify and maintain its position and distribution on the circumferential balancing area 220. Thus, during operation of the rotary system, its balance is constantly adjusted.

The amount of the thixotropic balancing substance 230 may be between approximately 0.001 kg and approximately 1000 kg, or between approximately 0.002 kg and approximately 500 kg, or between approximately 0.005 kg and approximately 200 kg, or between approximately 0.01 kg and approximately 100 kg, or between approximately 0.02 kg and approximately 50 kg, or between approximately 0.05 kg and approximately 20 kg, or between approximately 0.1 kg and approximately 10 kg, or between approximately 0.2 kg and approximately 5 kg, or between approximately 0.5 kg and approximately 2 kg, or approximately 1 kg. The chamber 210 may be filled with the amount of said thixotropic balancing substance 230 to between approximately 1 % and approximately 90 %, or between approximately 10 % and approximately 80 %, or between approximately 25 % and approximately 75 %, or approximately 50 %.

Fig. 4 shows a cross-sectional view of a chamber 210 in a rotational element 200, 204 according to yet another embodiment of the invention. The chamber 210 is caved into the rotational element 200, 204, such as a flywheel, a gear wheel or an additional element, for example a container or vessel. The chamber 210 is annular or ring-shaped. The chamber 210 may have a cross section being rectangular, square (not shown), semicircle-shaped (not shown), bell-shaped (not shown), circular (not shown) or the like.

Fig. 5 shows a cross-sectional view of a chamber 210 in a rotational element 200, 204 according to yet another embodiment of the invention. With reference to Fig. 4, the rotational element 200, 204 comprises a centre hole 260. The centre hole 260 may be circular, square (not shown), hexagonal (not shown) or the like. The centre hole 260 of the rotational element 200, 204 may receive a shaft for coupling the rotational element 200, 204 to the rotational system.

The rotational element 200, 204 may comprise a rotor of a power generator (not shown), and the centre hole 260 houses a shaft (not shown). In a preferred embodiment, the rotational element 200, 204 may be injection-moulded in one, two, three or more parts, and the chamber 210 may be sealed by a sealing element. The sealing element may be a snap-in or snap-on sealing element. In another preferred embodiment, the rotational element 200, 204 may be part of a rotating element of the power generator 100, such as the turbine wheels 124, the shaft 130 or the rotor 144, and the chamber 210 may be sealed by a sealing element. The sealing element may be welded to the rotational element, for example using friction-welding, laser-welding or ultrasonic-welding.

Fig. 6 shows a cross-sectional view of a chamber 210 in another rotational element 200, 206 according to yet another embodiment of the invention. The chamber 210 is caved into the other rotational element 200, 206, such as a flywheel, a gear wheel or an additional element, for example a container or vessel. The chamber 210 is cylindrical. The chamber 210 may have a cross section being rectangular, square (not shown), semicircle-shaped (not shown), bell-shaped (not shown), circular (not shown) or the like.

Fig. 7 shows a cross-sectional view of another chamber 210 in a rotational element 200, 204 according to yet another embodiment of the invention. With reference to Fig. 4, the rotational element 200, 204 comprises an opening 270 providing access to the chamber 210. The opening 270 may be circumferential. The opening is situated, such that the balancing substance 230 is and remains contained in the chamber 210.

Fig. 8 shows a cross-sectional view of another chamber 210 in a rotational element 200, 204 according to yet another embodiment of the invention. With reference to Fig. 5, the rotational element 200, 204 comprises an opening 270 providing access to the chamber 210 as discussed with reference to Fig. 7.

The rotational element 200, 204 may comprise a rotational element of the power generator 100 as described with reference to Fig. 5.

Fig. 9 shows a cross-sectional view of yet another chamber 210 in a rotational element 200, 204 according to yet another embodiment of the invention. With reference to Fig. 5, the rotational element 200, 204 comprises an opening 270 providing access to the chamber 210 as discussed with reference to Figs 7 and 8.

The rotational element 200, 204 may comprise a rotational element of the power generator 100 as described with reference to Fig. 5.

Fig. 10 shows a cross-sectional view of another chamber 210 in a rotational element 200, 206 according to yet another embodiment of the invention. With reference to Fig. 6, the rotational element 200, 206 comprises an opening 270 providing access to the chamber 210 as discussed with reference to Fig. 7.

The thixotropic balancing substance 230 may be a thixotropic tyre balancing composition disclosed in EP patent application no. 0 281 252 and corresponding US patent no. 4,867,792, which are hereby incorporated by reference in their entirety, having a yield stress value between 1 Pa and 260 Pa being capable of balancing tyres by being able to flow under the influence of the vibrations induced when a heavy spot on the tyre hits the road surface.

The thixotropic balancing substance 230 may be a tyre gel balancing composition disclosed in European patent no. 0 557 365 and US corresponding patent no. 5,431,726, which are hereby incorporated by reference in their entirety, having a storage modulus of between 3000 and 15000 Pa and the specific gravity less than 1000 kg/m^3 in the temperature range between -20 and +90 °C, preferably its storage modulus is about 9000 Pa, being capable of balancing tyres by being able to flow under the vibrations caused by imbalance in a wheel assembly. The composition preferably comprises a mixture of: 1) paraffinic oils, polybutene oils, polyolesters or polyol ethers; 2) hydrophobic or hydrophilic fumed silica; 3) polyalkyl-methacrylates, styrene-ethylene-propylene block copolymers or polyhydroxycarboxylic acid derivatives; and optionally corrosion inhibitors and antioxidants.

The thixotropic balancing substance 230 may be one of the tyre balancing compositions disclosed in European patent no. 1 196 299 B1 and corresponding US publication nos US-2005-0159534-A1 and US-2010-0252174-A1, which are hereby incorporated by reference in their entirety, having improved balancing properties and comprise a visco-plastic gel and solid bodies having an average smallest dimension in the range of 0.5-5 mm; preferably 1-4 mm, more preferably around 3 mm. When applied in a layer to the inside of a motor vehicle tyre, the compositions act by allowing the solid bodies move through the gel and to concentrate in areas to counteract imbalances. The solid bodies preferably have an average ratio alpha between their smallest and their largest dimension of alpha <=2, more preferably alpha <=1.5, especially around 1. The visco-plastic gel preferably has a storage modulus (G') between 1000 Pa and 25000 Pa at 22 °C, a loss modulus (G'') smaller than the storage modulus, and a critical yield stress above 3 Pa at 22 °C. The bodies may be shaped as prolate or oblate ellipsoids, cylinders, rectangular parallelipipeds, or spheres, or mixtures of such bodies; they may have an apparent specific gravity in the range of 500-3000 kg/m^3, preferably 600-2000 kg/m^3, in particular 700-1000 kg/m^3, especially 800-900 kg/m^3; they may be made from polyolefins, polystyrene, polyvinyl chloride, polyamide, rubber or glass. The weight ratio between the solid bodies and the gel is from 10:1 to 1:10, preferably from 5:1 to 1:5, in particular from 2:1 to 3:1, such as from 1:1 to 1:2.

The thixotropic balancing substance 230 may be one of the visco-elastic tyre balancing compositions disclosed in international patent application WO 2010/055097, which is hereby incorporated by reference in its entirety, comprising 1) 85 to 97 % by weight of a glycol ether component comprising one or more ethylene/propylene glycol copolymer ethers of the general formula (I) or the general (II) or mixtures thereof R-O {[CH(C_{1-13})CH_2-O-]$_m$ [CH_2-CH_2-O-]„}H (I) R,-(O- {[CH(CHOCH_2-O-]$_m$ [CH_2-CH_2-O-]$_n$}H)$_2$ (II) wherein R is hydrogen or an alkyl group of 2-8 carbon atoms; R i is an alkylene moiety of 2-8 carbon atoms in which the two substituents are not carried on the same carbon atom; m is the mole percentage of propylene glycol in the ethylene/propylene glycol copolymer moiety or moieties; and n is the mole percentage of ethylene glycol in the ethylene/propylene glycol copolymer moiety or moieties, wherein the ratio n: m is in the range from 35:65 to 80:20; each glycol copolymer compound having a number average molecular weight in the range of 2000-10000; and 2) 3 to 15 % by weight of a fumed silica gel former; said balancing compositions being visco-elastic and having a Storage Modulus (G') between 1500 Pa and 5000 Pa at 22 °C, a Loss Modulus (G") smaller than the Storage Modulus up to a Cross Over Frequency of 10-40 Hz, and a Critical Yield Stress exceeding 2 Pa.

The thixotropic balancing substance 230 may be a composition for balancing a rotary system disclosed in international patent application no. WO 2011/042549, which is hereby incorporated by reference in its entirety, comprising an amount of a thixotropic balancing substance; characterized by an amount of hydrophobic particles or nanoparticles distributed in said amount of said thixotropic balancing substance.

The thixotropic balancing substance 230 may comprise a plurality of balls. The balls may comprise metal, such as steel, titanium, copper or aluminium, composite material, such as aluminiumoxide or ceramics, or plastics. The balls may be polished or coated, for example polytetrafluoroethylene- (PTFE)- coated. The balls may have a diameter between approximately 1 mm and approximately 50 mm, for example approximately 15 mm.

Embodiments of the inventions comprise a corresponding apparatus that may carry out the method.

Embodiments of the inventions comprise a corresponding system that may carry out the method, possibly across a number of devices.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art, that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. It is to be understood, that the above description is intended to be illustrative and not restrictive. This application is intended to cover any adaptations or variations of the invention. Combinations of the above embodiments and many other embodiments will be apparent to those of skill in the art upon reading and understanding the above description. The scope of the invention includes any other embodiments and applications in which the above structures and methods may be used. The scope of the invention is, therefore, defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

Claims

1. A method of reducing vibration in a rotary system (120, 130, 140, 150) of a power generator (100), comprising:

- balancing said rotary system (120, 130, 140, 150),

characterized by

- providing a rotational element (120, 124, 130, 135, 140, 144, 150; 200) comprising a chamber (210) having a fulcrum on a rotational axis (240) of said rotational element (120, 124, 130, 135, 140, 144, 150; 200), comprising a circumferential balancing area (220) and being partially filled with an amount of a thixotropic balancing substance (230).

2. The method of claim 1, further comprising:

- rotating said rotational element (120, 124, 130, 135, 140, 144, 150; 200) about the rotational axis (240), such that said thixotropic balancing substance (230) liquefies and distributes itself along the circumferential balancing area (220), and an imbalance of said rotational element (120, 124, 130, 135, 140, 144, 150; 200) is reduced.

3. The method of claim 1 or 2, wherein:

- said rotational axis (240) is oriented horizontally; or
- said rotational axis (240) is oriented vertically.

4. The method of claim 1 or 2, wherein:

- said rotational element (120, 124, 130, 135, 140, 144, 150; 200) is an original element of said rotary system (120, 130, 140, 150), a replacement element of said rotary system (120, 130, 140, 150), or a supplemental element to said rotary system (120, 130, 140, 150);
- said rotational element (130) is a hollow shaft or tubular shaft;
- said rotational element (130) is an articulated shaft, for example a cardan shaft; or
- a combination thereof.

5. The method of claim 4, wherein:

- the supplemental element is disc-shaped; or

- the supplemental element is ring-shaped.

6. The method of claim 1 or 2, wherein:

- said rotational element (120, 124, 130, 135, 140, 144, 150; 200) is a shaft (130);
- said rotational element (120, 124, 130, 135, 140, 144, 150; 200) is a rotor (144) of said power generator (100);
- said rotational element (120, 124, 130, 135, 140, 144, 150; 200) is a gear wheel;
- said rotational element (120, 124, 130, 135, 140, 144, 150; 200) is a bearing (135); or
- a combination thereof.

7. The method of claim 1 or 2, wherein:

- said chamber (210) is annular or ring-shaped, or cylindrical;
- said chamber (210) has a cross section being rectangular, square, semicircle-shaped, bell-shaped or circular;
- said chamber (210) has a diameter of between 0.005 m and 2 m, or between 0.01 m and 1 m, or between 0.02 m and 0.5 m, or between 0.05 m and 0.2 m, or 0.1 m;
- said chamber (210) has a length of between 0.01 m and 1 m, or between 0.02 m and 0.5 m, or between 0.05 m and 0.2 m, or 0.1 m; or
- a combination thereof.

8. The method of claim 1 or 2, wherein:

- said amount of said thixotropic balancing substance (230) is between 0.001 kg and 1000 kg, or between 0.002 kg and 500 kg, or between 0.005 kg and 200 kg, or between 0.01 kg and 100 kg, or between 0.02 kg and 50 kg, or between 0.05 kg and 20 kg, or between 0.1 kg and 10 kg, or between 0.2 kg and 5 kg, or between 0.5 kg and 2 kg, or 1 kg;
- said chamber (210) is filled with the amount of said thixotropic balancing substance (230) to between 1 % and 90 %, or between 10 % and 80 %, or between 25 % and 75 %, or 50 %; or
- a combination thereof.

9. An apparatus for reducing vibration in a rotary system (120, 130, 140, 150) of a power generator (100), characterized by:

- a rotational element (120, 124, 130, 135, 140, 144, 150; 200) comprising a chamber (210) having a fulcrum on a rotational axis (240) of said rotational element (120, 124, 130, 135, 140, 144, 150; 200), comprising a circumferential balancing area (220) and being partially filled with an amount of a thixotropic balancing substance (230).

10. The apparatus of to claim 9, wherein said power generator is a:

- steam power generator,
- gas turbine generator,
- hydraulic power generator,
- combustion engine, or
- a combination thereof.

11. The apparatus of to claim 9 or 10, wherein

- said amount of said thixotropic balancing substance (230) is between 0.001 kg and 1000 kg, or between 0.002 kg and 500 kg, or between 0.005 kg and 200 kg, or between 0.01 kg and 100 kg, or between 0.02 kg and 50 kg, or between 0.05 kg and 20 kg, or between 0.1 kg and 10 kg, or between 0.2 kg and 5 kg, or between 0.5 kg and 2 kg, or 1 kg;
- said chamber (210) is filled with the amount of said thixotropic balancing substance (230) to between 1 % and 90 %, or between 10 % and 80 %, or between 25 % and 75 %, or 50 %; or
- a combination thereof.

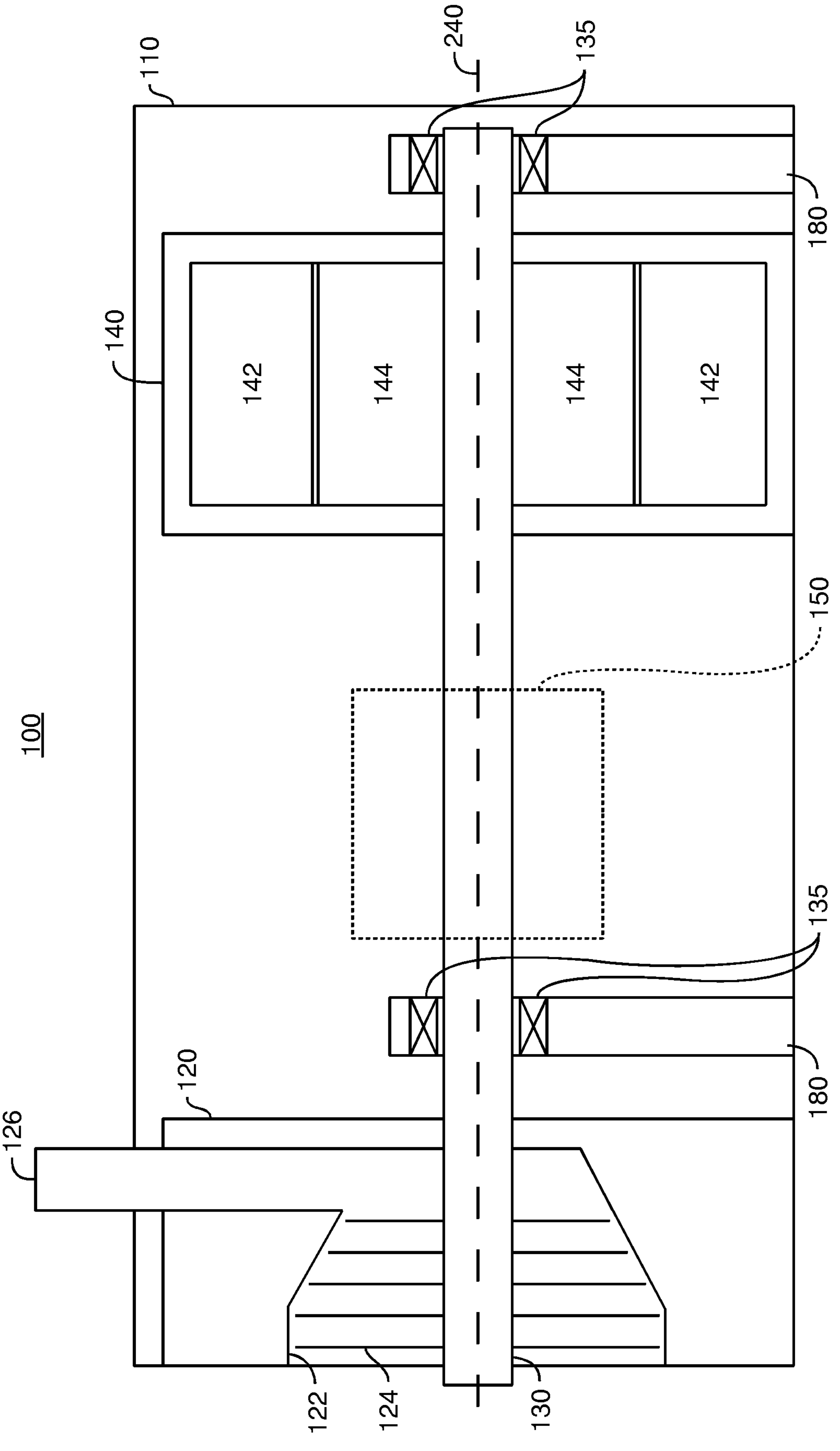
12. A rotary system (120, 130, 140, 150) of a power generator (100), for reducing vibration in said rotary system (120, 130, 140, 150), characterized by:

- a rotational element (120, 124, 130, 135, 140, 144, 150; 200) comprising a chamber (210) having a fulcrum on a rotational axis (240) of said rotational element (120, 124, 130, 135, 140, 144, 150; 200), comprising a circumferential balancing area (220) and being partially filled with an amount of a thixotropic balancing substance (230).

13. The rotary system of claim 12, wherein

- said amount of said thixotropic balancing substance (230) is between 0.001 kg and 1000 kg, or between 0.002 kg and 500 kg, or between 0.005 kg and 200 kg, or between 0.01 kg and 100 kg, or between 0.02 kg and 50 kg, or between 0.05 kg and 20 kg, or between 0.1 kg and 10 kg, or between 0.2 kg and 5 kg, or between 0.5 kg and 2 kg, or 1 kg;
- said chamber (210) is filled with the amount of said thixotropic balancing substance (230) to between 1 % and 90 %, or between 10 % and 80 %, or between 25 % and 75 %, or 50 %; or
- a combination thereof.

14. The rotary system of claim 9 or 12, wherein said power generator is a:
- steam power generator,
- gas turbine generator,
- hydraulic power generator,
- combustion engine, or
- a combination thereof.


100
110
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135
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140
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144
144
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150
135
180
120
126
122
124
130

FIG. 1

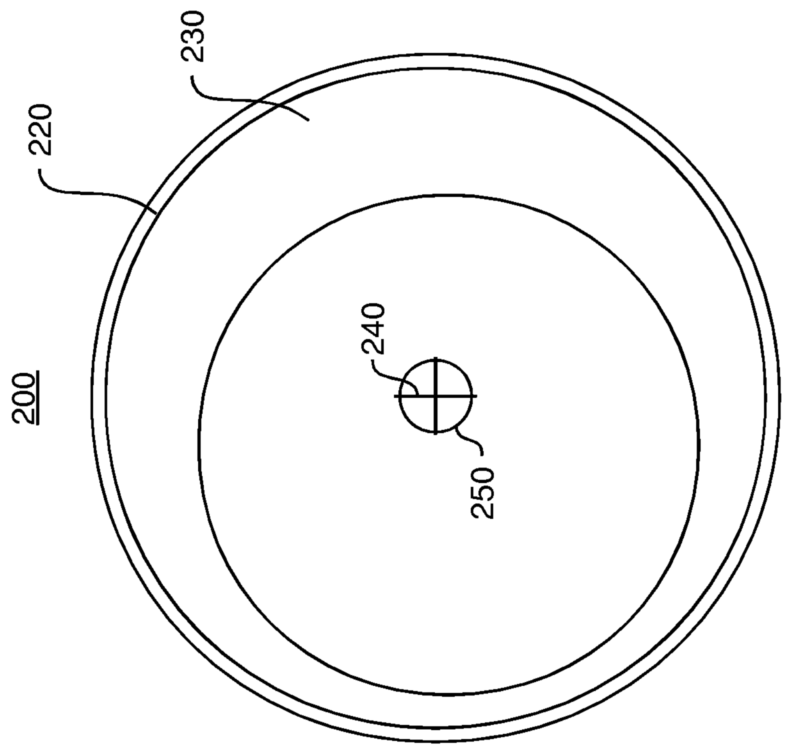

FIG. 3

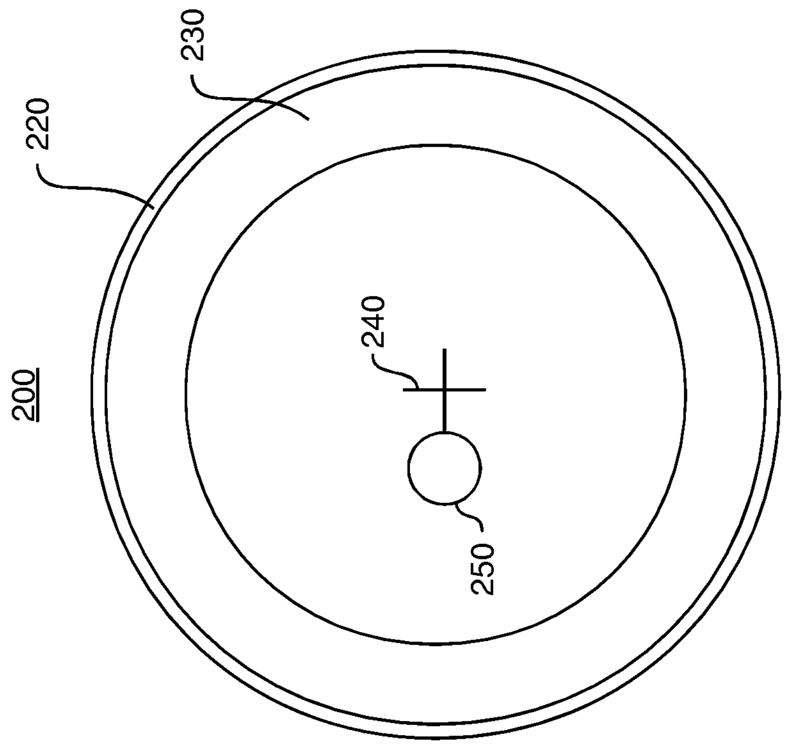

FIG. 2

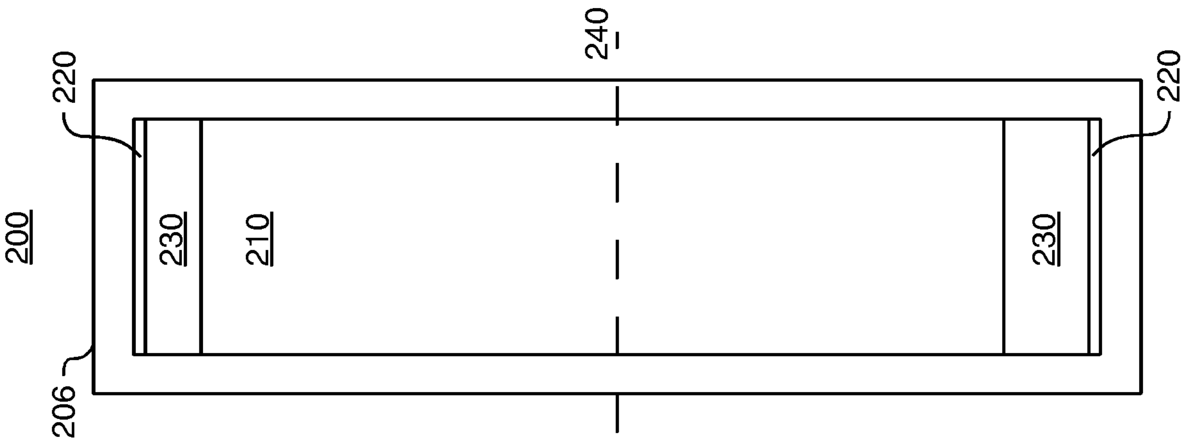

FIG. 6

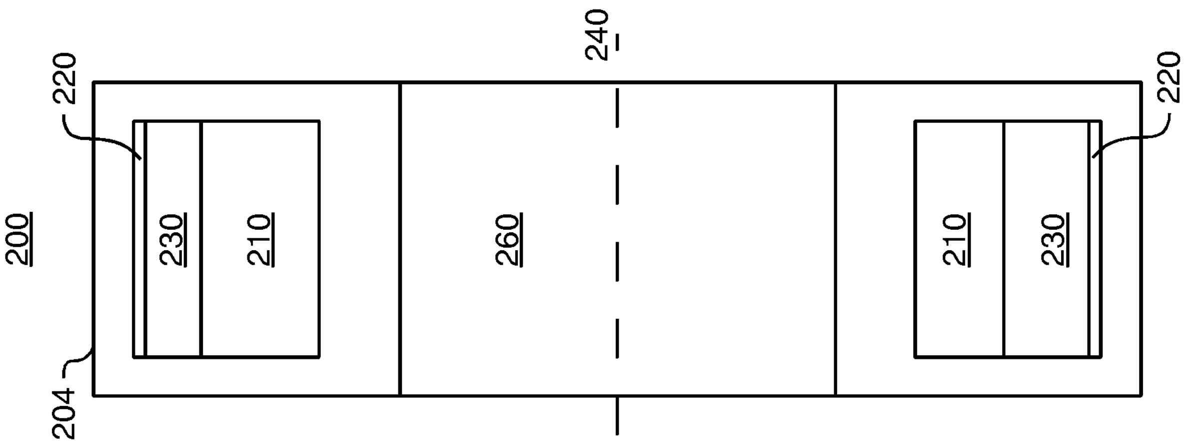

FIG. 5

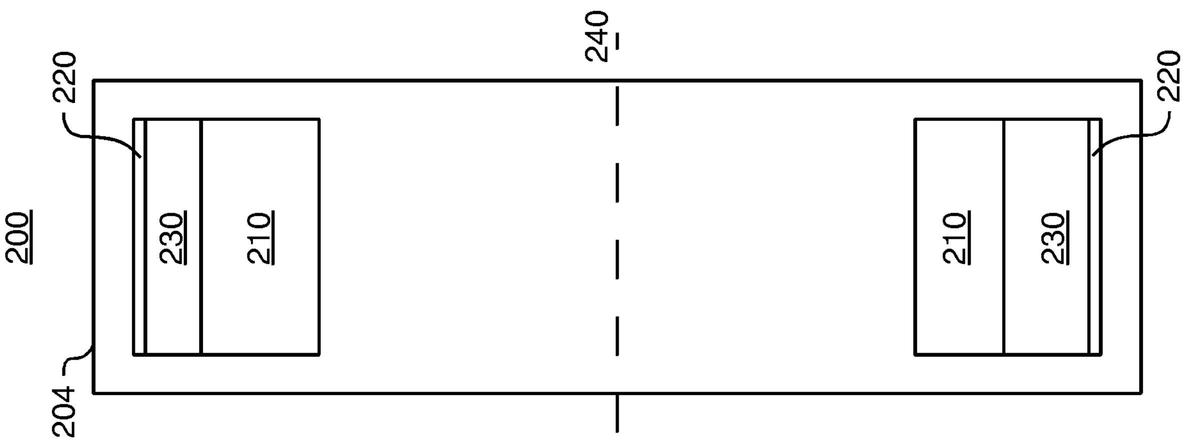

FIG. 4

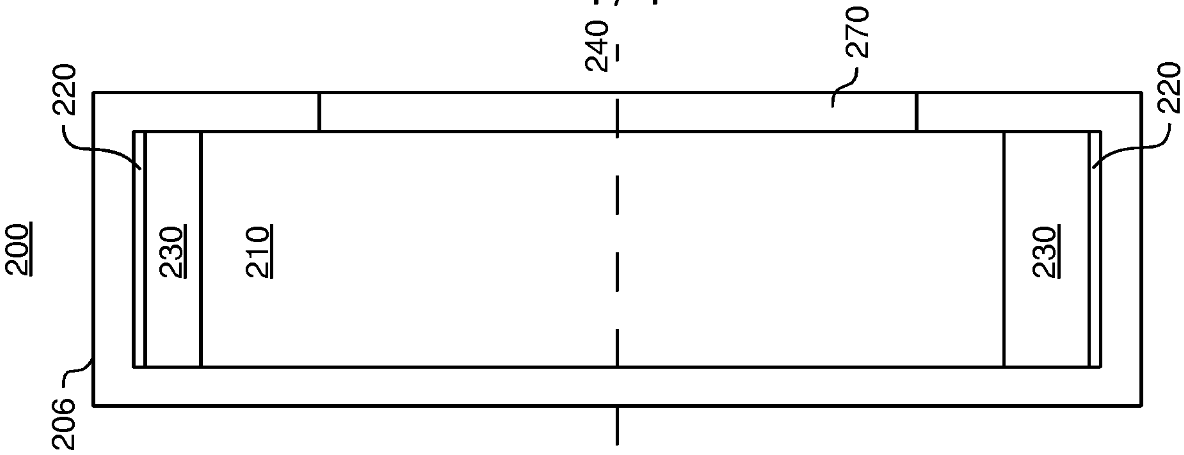

FIG. 10

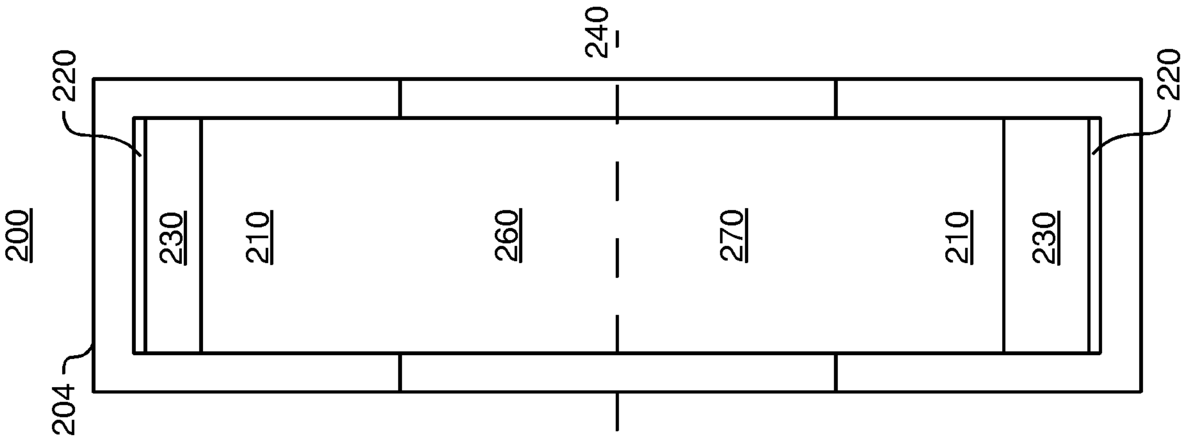

FIG. 9

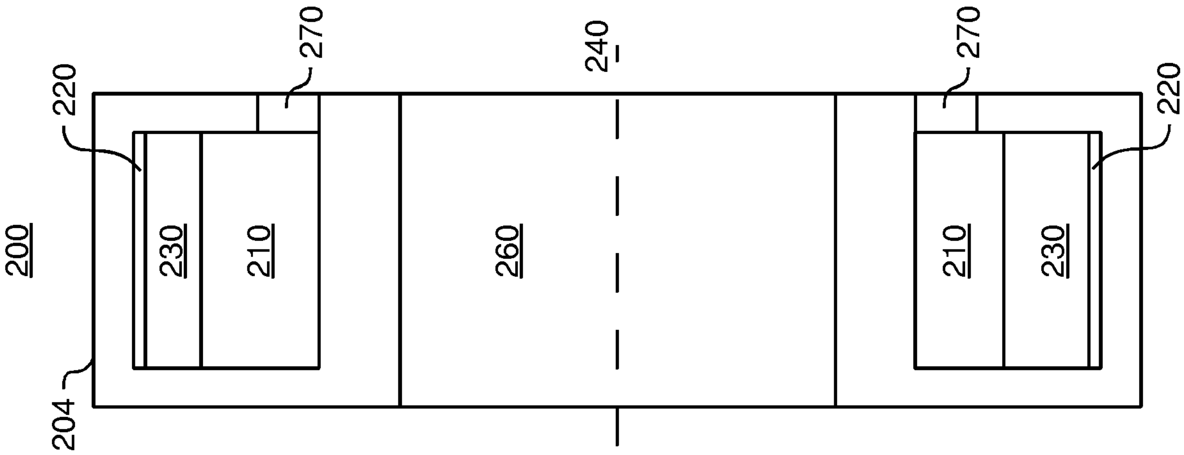

FIG. 8

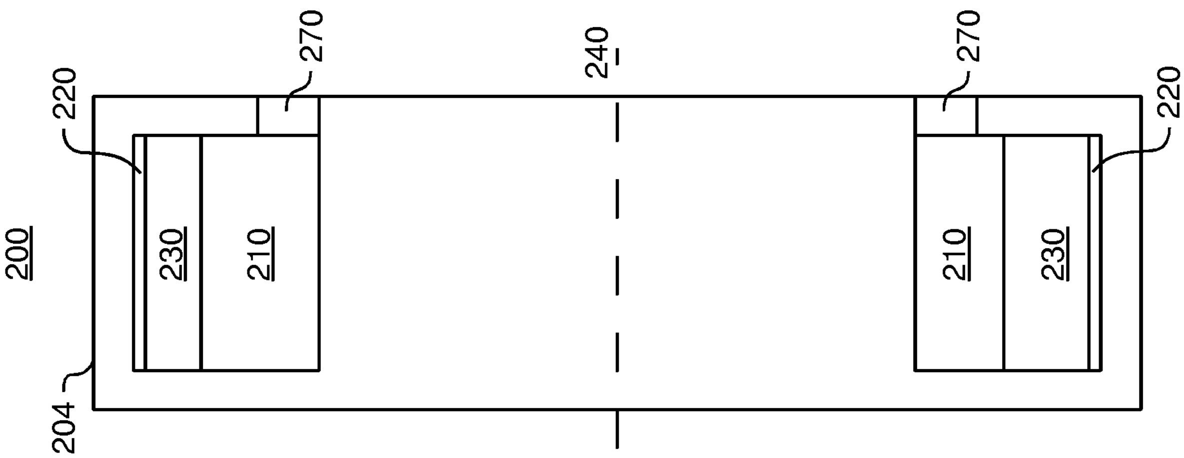

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/060874

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D29/66 F16F15/36 F01D5/02 F03B11/00
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)
F04D D06F F16F B64C G01M B63H F01D F03B

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 practicable, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 198 57 646 A1 (SEITZ NORBERT [DE]; HOLLBURG UWE [DE]; BARICH GERHARD [DE]) 15 June 2000 (2000-06-15) column 1, line 45 - line 47 column 2, line 21 - line 33 -----	1-14
X	WO 2010/003988 A1 (CARNEHAMMAR LARS BERTIL [CH]; SEITZ NORBERT [DE]) 14 January 2010 (2010-01-14) claims 1,2,6-9,13,14 -----	1-14
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 October 2012	19/10/2012

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	Di Giorgio, F

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	WO 2010/029112 A1 (CARNEHAMMAR LARS BERTIL [CH]; RONLAN ALVIN [SE]; SEITZ NORBERT [DE]) 18 March 2010 (2010-03-18) claims 1,2,4,6,8	1-14
X	US 2 836 083 A (SMITH THOMAS R) 27 May 1958 (1958-05-27) column 4, line 45 - column 5, line 1; figure 1	1-14
X	DATABASE WPI Week 198902 Thomson Scientific, London, GB; AN 1989-013998 XP002662363, -& SU 1 404 938 A1 (ANALYT INSTRM SCI) 23 June 1988 (1988-06-23) abstract column 2, line 23 - line 43; figure 2	1-14

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/060874

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