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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 October 2015 (08.10.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/152807 A1

(51) International Patent Classification:
F03B 13/26 (2006.01) *F03B 13/10* (2006.01)

(21) International Application Number:
PCT/SE2015/050392

(22) International Filing Date:
31 March 2015 (31.03.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1400183-8 4 April 2014 (04.04.2014) SE

(71) Applicant: **AKTIEBOLAGET SKF** [SE/SE]; S-415 50 Göteborg (SE).

(72) Inventor: **LINDÉN, Hans**; Gustavsbergsvägen 12, S-442 94 Ytterby (SE).

(74) Agent: **GENTZEL, Marcus**; SKF Patebt Department, S-415 50 Göteborg (SE).

(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, BN, 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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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, ST, 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, KM, ML, MR, NE, SN, TD, TG).

Published:

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

— *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))*

(54) Title: SUBMERGED SYSTEM FOR CONVERTING A TIDAL WATER FLOW TO ELECTRICAL ENERGY

(57) Abstract: The present invention is based on the idea to utilize forces arising from predictable tidal water flows changing direction every six hours. The present invention relates to a submerged system for converting a tidal water flow to electrical energy comprising a load-carrying module, an electrical generating module comprising a generator and being operatively connected to the load- carrying module and a transmission unit allowing rotational motion about the central axis of the load-carrying module to be transmitted to rotational motion about the axis of the electrical generating module being parallel to the central axis. The present invention provides a submerged system allowing for extended service life and simplified maintenance work.

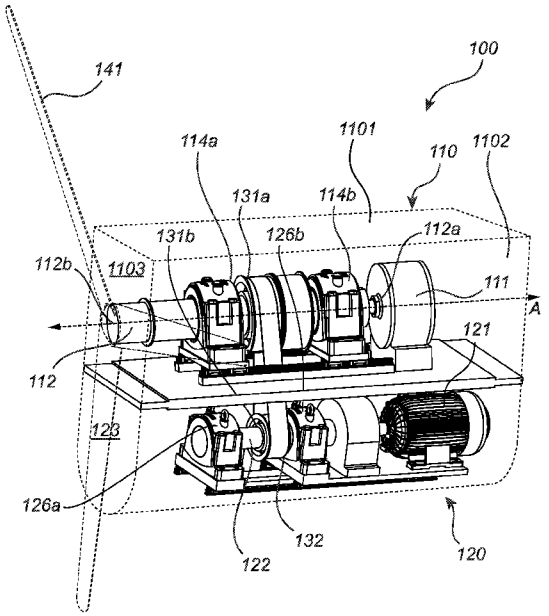


Fig. 1

WO 2015/152807 A1

SUBMERGED SYSTEM FOR CONVERTING A TIDAL WATER FLOW TO ELECTRICAL ENERGY

Technical field of invention

The present invention relates to a submerged system for converting tidal water flow to electrical energy. The submerged system comprises a load-carrying module, an electrical generating module and a transmission unit.

Background

Submerged power applications that make use of tidal water flows, continuously changing mean direction every six hours, have been proposed as commercially interesting in order to meet at least part of the energy demand in today's society. However, submerged power applications can be very demanding in many aspects. For instance, installation of submerged power applications is often costly and maintenance work is complicated due to harsh environment conditions, such as low visibility and high pressure due to the water depth. Thus, it is a need in the art to provide submerged power applications allowing for simplified maintenance work.

Further, submerged power applications making use of tidal water flow, typically, comprise a rotatable component that may be driven by the tidal water flow. In order to achieve a relatively smooth operation mode of the submerged power applications, the rotatable component may be connected to an axial bearing. However, conventional axial bearings, such as thrust bearings, are subjected to wear in the harsh conditions present in a submerged state. For instance, penetration of water into thrust bearings causes corrosion, resulting in damages of the bearing and in the end a breakdown of the submerged power application. Thus, it is also a need in the art to provide submerged power applications with extended service life and minimized failure mode.

Summary

The present invention is based on the idea to utilize forces arising from a predictable tidal water flow changing mean direction every six hours. By arranging a submerged system in a water system having a significant predictable tidal water flow, an axial load arising from the tidal water flows will apply to the submerged system. The axial load applied to the submerged system will consequently also change mean direction every six hours.

As stated above, it is a purpose of the present invention to at least partly overcome the drawbacks of the conventional submerged power applications.

Conventional submerged power applications try to minimize the water penetration as much as possible, however, the present invention provides an arrangement not completely dependent on minimized water penetration. The inventor has realized the importance of providing a submerged system being capable of, at least to a certain degree, handling water penetration, thereby prolonging the service life of the submerged system.

The inventor has also realized the importance of providing a submerged system allowing for simplified maintenance work, thereby prolonging the service life of the submerged system. The present invention provides a submerged system which is capable of varying its position in the water system into which it is arranged, e.g. by being buoyant. The submerged system may be arranged in an operation mode at a level where the water flows are powerful. In the operation mode, the submeregd system is typically in a completely submerged state. The submerged system may be arranged in a maintenance mode where the system is easy to handle. In the maintenance mode, the submerged system is typically in a partly submerged state at the water surface.

According to a first aspect, the present invention relates to a submerged system for converting a tidal water flow to electrical energy. The submerged system comprises a load-carrying module, an electrical generating module and a transmission unit. The load-carrying module comprises an axial load-carrying unit configured to carry axial load relative to a central axis, and a first main shaft moveably arranged along the central axis and rotatably arranged about the central axis. The first main shaft has a first end portion connected to the axial load-carrying unit and a second end portion connectable to a rotor. The electrical generating module is operatively connected to the load-carrying module and comprises a subshaft rotatably arranged about an axis parallel to the central axis, a generator capable of converting a rotational motion to electrical energy, and a housing at least partly enclosing the subshaft and the generator. The generator is connected to the subshaft. The first main shaft is operatively connected to the subshaft via a transmission unit, whereby the transmission unit allows rotational motion about the central axis to be transmitted to rotational motion about the axis being parallel to the central axis. An arrangement comprising a first (and single) main shaft is called a single arrangement.

The central axis herein refers to the central axis of the load-carrying module. The main shaft extends along the central axis. The central axis is typically arranged along the mean direction of the mean water flow of the water system into which the submerged system is arranged.

In an example, the housing of the electrical generating module may be made of a water impermeable material, or a combination of materials being water impermeable. For instance, the housing comprises a non-porous material, e.g. glass fibers. Alternatively, the housing may be made of aluminum.The housing serves to minimize the water penetration into the submerged system. The housing may further allow for creation of a closed environment having a controllable pressure, which may e.g. be advantageous for a buoyant submerged system.

Typically, the walls, i.e. the sidewalls and the walls of the end portions, of the load-carrying module are made in a rigid material, such as a metallic material, for instance steel, e.g. stainless steel.

The transmission unit may typically be a pulley-belt assembly. Alternatively, the transmission unit may comprise chains or gears fulfilling the same function as a pulley-belt assembly.

According to an embodiment, the axial load-carrying unit may be a hydraulic axial load-carrying unit comprising a housing member and a piston member. The piston member may be moveably arranged along the central axis and rotatably arranged about the central axis relative to the housing member. The first end portion of the first main shaft may be connected to the piston member. Alternatively, the axial load-carrying unit may be a thrust bearing, a rolling bearing, a slide bearing, or a hydrostatic bearing.

By providing the submerged system with a hydraulic axial load-carrying unit, the submerged system is more resistant to water penetration as the hydraulic axial load-carrying unit is much less sensitive to water than e.g. conventional thrust bearings. By optimizing the parameters of the hydraulic axial load-carrying unit, a submerged system comprising a hydraulic load-carrying unit may be smaller in size and allow for a smoother operation than a submerged system comprising a conventional thrust bearing. The hydraulic axial load-carrying unit is described in detail further below.

According to an embodiment, the load-carrying module may be provided with a first opening configured to encircle a cross-section of the second end portion of the first main shaft. The load-carrying module may further comprise a first sealing member radially arranged about the first main shaft such as to seal the first opening. The first sealing member serves to minimize the water penetration into the submerged system via the first main shaft, by closing tight to the first main shaft. The first sealing member may have an optimized

function if the pressure inside the submerged system is close to, e.g. substantially equal to, the pressure outside the submerged system. The first sealing member may for instance be a lip sealing, such as a lip sealing comprising rubber.

According to an embodiment, the load-carrying module may further comprise at least two radial load-carrying units configured to carry radial load relative to the central axis. The at least two load-carrying units may be arranged about the first main shaft. Any radial load-carrying unit known to the person skilled in the art and suitable for the present purpose may be used.

According to an embodiment, the submerged system may further comprise a first rotor capable of converting a tidal water flow to a rotational motion. The first rotor may be connected to the second end portion of the first main shaft and rotatably arranged about the central axis. The first rotor may be e.g. an impeller or a screw. The shape of the rotor is typically optimized for the water flows of the water system into which the submerged is arranged. For instance, the rotor may have a very different shape than rotors for wind power applications due to the difference in density between air and water.

According to an embodiment, the load-carrying module may further comprise a second main shaft. The second main shaft may be moveably arranged along the central axis and rotatably arranged about the central axis. The second main shaft may have a first end portion connected to the piston member and a second end portion connectable to a rotor. The second main shaft may be arranged to rotate in the same direction about the central axis as the first main shaft. An arrangement comprising a first main shaft and a second main shaft is called a double arrangement. In a double arrangement, the first main shaft and the second main shaft are typically interconnected via the axial load-carrying unit.

It may be advantageous to provide the load-carrying module with two main shaft as each of the main shafts are connectable to a rotor, and thereby the potential capacity of the submerged system may increase with a double arrangement compared to a single arrangement. When each of the two main shafts is connected to a rotor, the utilization of the water flow of the water system into which the submerged system is arranged may increase during operation (e.g. due to an increased total surface area of the rotors) and thus, the frequency of the rotational motion of the main shafts may increase. A submerged system comprising two rotors arranged on opposite sides of the load-carrying module along the central axis may more efficiently convert tidal water flow whichever the axial direction of the tidal water flow.

According to an embodiment, the load-carrying module may further be provided with a second opening configured to encircle a cross-section of the second end portion of the second main shaft. The load-carrying module may further comprise a second sealing member radially arranged about the second main shaft such as to seal the second opening. Similarly to the first sealing member, the second sealing member serves to minimize the water penetration into the submerged system via the second main shaft, by closing tight to the second main shaft. The second sealing member may have an optimized function if the pressure inside the submerged system is close to, e.g. substantially equal to, the pressure outside the submerged system.

According to an embodiment, the submerged system may further comprise at least two radial load-carrying units configured to carry radial load relative to the central axis. The at least two load-carrying units may be arranged about the second main shaft. Any radial load-carrying unit known to the person skilled in the art and suitable for the present purpose may be used.

According to an embodiment, the submerged system may further comprise a second rotor capable of converting a tidal water flow to a rotational motion. The second rotor may be connected to the second end portion of the second main shaft and rotatably arranged about the central axis. The second rotor may be e.g. an impeller or a screw. The second rotor is adapted to rotate in the same direction as the first rotor. By including a second rotor to the submerged system, the potential capacity of the submerged system may increase.

According to an embodiment, the submerged system may further comprise at least two radial load-carrying units configured to carry radial load relative to the axis parallel to the central axis. The at least two load-carrying units may be arranged about the subshaft. Any radial load-carrying unit known to the person skilled in the art and suitable for the present purpose may be used.

According to an embodiment, the electrical generating module may further comprise a pump. Typically, the pump is fully enclosed by the housing of the electrical generating module. Alternatively, the pump may be integrated in the housing.

Even if the system is adapted to prevent as much water as possible to enter the system, the service life of the system may be prolonged by the arrangement of a pump in the lowest electrical generating module (i.e. the electrical generating module being arranged operatively closest to the bottom

of the water system into which the submerged system is arranged, e.g. closest to the sea bed). The pump serves to remedy the water penetration in an efficient way. The pump may be either an active pump, such as an electrical pump, or a passive pump. For instance, the pump may be activated by a sensor, which, continuously or periodically, indicates the present water level inside the lowest electrical generating module.
Typically, the pump is connected to a valve, e.g. a non-return valve, arranged in the housing of the lowest electrical generating module.

It is highly advantageous to provide the submerged system with a pump in combination with the sealing member(s) in order to both minimize the water penetration into the system and to efficiently remove yet penetrated water out from the system, thereby minimizing the need of maintenance work and prolonging the service life of the submerged system. Preferably, all of the outer surfaces of the submerged system, i.e. all of the surfaces facing the surroundings, are water-impermeable.

According to an embodiment, the electrical generating module may further comprise a gear box arranged about the subshaft between the transmission unit and the generator. Any gearbox known to the person skilled in the art and suitable for the present purpose may be used. The gearbox serves to amplify the number of revolutions of the subshaft (about which it is arranged) per time unit in order to increase the efficiency of the generator, and thereby of the submerged system. The gearbox may amplify the number of revolutions per time unit about 10 to 1000 times, such as from 20 to 100 times.

In an example, the electrical generating module may further comprise a sensor. The sensor may, continuously or discontinuously, sense any of the parameters selected from the non-exhaustive list of: the frequency of the rotor(s), the frequency of the transmission unit, the frequency of the gearbox, the temperature inside the load-carrying module, the degree of vibrations of the main shaft(s), the degree of vibrations of the subshaft(s), the axial load on the main shaft(s), the radial load on the main shaft(s), the radial load on the subshaft(s), the water level inside the lowest electrical generating module, the position of the piston member relative to the housing member of the hydraulic axial load-carrying unit, the pressure inside the hydraulic axial load carrier, et cetera. It would be known to the person skilled in the art where to arrange the different types of sensors in the submerged system.

According to an embodiment, the submerged system may further comprise at least one additional electrical generating module operatively connected to the load-carrying module. Preferably, the submerged system comprises one

electrical generating module arranged at each sidewall of the load-carrying module.

For instance, if the load-carrying module has the shape of a square prism or a rectangular prism, the submerged system preferably comprises four electrical generating modules allowing the housing of each of the four electrical generating modules to tightly enclose the entire submerged system, only the two end portions of the load-carrying module excluded, in a waterproof manner. However, the two end portions of the load-carrying module are typically also made of water-impermeable material(s).

According to an embodiment, the submerged system may include means for attaching the submerged system to the bottom of the water system in which it is arranged. For instance, the submerged system may be adapted to be attached to a rigid structure, to a watercraft, or to the bottom of the water in which the system is submerged. The system may, for instance, be arranged on a frame arranged on the sea bed, allowing maintenance work to be performed from the sea bed.

According to an embodiment, the submerged system may be a buoyant system. A water impermeable housing, preferably enclosing the entire submerged system with only the end portions of the load-carrying module excluded, and an ability to pressurize the system (e.g. by airbags additionally provided inside the electrical generating module(s)) allows for buoyancy.

The buyoant system may be fully submerged, and thus completely surrounded by water. Alternatively, the system may be buyoant at the water surface, and thus partly surrounded by water. A buoyant system may provide for simplified maintenance work, as the maintenance work may be performed from the water surface, such as from a ship.

The conversion of tidal water flow to electrical energy of the submerged system may, in its simplest way, be summarized as follows. The first rotor and/or second rotor may generate a rotational motion of the first main shaft and/or second main shaft from the water flow energy, whereby the rotational motion of the first main shaft and/or second main shaft has a first frequency. The transmission unit may transfer the rotational motion of the first main shaft and/or second main shaft having a first frequency to a rotational motion of the at least one subshaft having a second frequency. The at least one generator may generate electrical energy from the rotational motion of the at least one subshaft, either directly (thus, from rotational motion having the second frequency) or via a gearbox (thus, from a rotational motion having a third

frequency). Typically, the second frequency is higher than the first frequency. Similarly, the third frequency is generally higher than the second frequency.

In an alternative example, the system may be used in a watercourse having a water flow of a substantially constant direction. In this situation, the submerged system (instead of the water flow) may change direction regularly. For instance, the system may be arranged on a rotatable structure, e.g. a rotatable frame.

Brief description of the drawings

These and other aspects of the present invention will now be described in more detail, with reference to the appended drawings showing embodiments of the invention.

In Fig. 1, a submerged system according to an example embodiment of the present invention is schematically shown in a side view.

In Fig. 2, an end portion of the load-carrying module according to the example embodiment in Fig. 1 is schematically shown in a cross-sectional side view.

In Fig. 3, a submerged system according to another example embodiment of the present invention is schematically shown in a partly exploded side view.

In Fig. 4, the double arrangement of the load-carrying module according to the example embodiment in Fig. 3 is schematically shown in a partly cross-sectional side view.

In Fig. 5, a submerged system according to another example embodiment of the present invention being arranged on a rigid structure is schematically shown in a side view.

In Fig. 6, the axial hydraulic load-carrying unit of the load-carrying module in Figs. 3-4 is shown in detail in a partly cross-sectional side view.

Detailed description of the invention

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which currently preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided for

thoroughness and completeness, and fully convey the scope of the invention to the skilled person.

The present invention relates to a submerged system 100 for converting a tidal water flow to electrical energy, which is schematically shown in a first embodiment in Figs. 1 and 2. The submerged system comprises a load-carrying module 110, an electrical generating module 120, and a transmission unit operatively connecting the load-carrying module and the electrical generating module together.

In Fig. 1, the load-carrying module 110 has the shape of a rectangular prism with four sidewall surfaces (of which two are shown 1101, 1102) and two end surfaces (of which one is shown 1103). Alternatively, the load-carrying module may have the shape of e.g. a circular cylinder, a square prism or a triangular prism. The load carrying module 110 is herein arranged symmetrically about a central axis A. The central axis A passes through the both end surfaces 1103 of the load-carrying module.

The load-carrying module 110 comprises a single main shaft, herein called a first main shaft 112. A load-carrying module comprising one main shaft forms a, herein called, single arrangement. The first main shaft 112 has a first end portion 112a connected to an axial load-carrying unit 111, and a second end portion 112b connectable, and herein also connected, to a first rotor 141. The first main shaft 112 is moveably arranged along the central axis A. The first main shaft 112 is rotatably arranged about the central axis A. The first main shaft is typically made in steel, e.g. stainless steel.

The first main shaft may move in the range of from 0.01 to 2 meter in either axial direction along the central axis, typically from 0.5 to 1.5 m, such as from 0.75 to 1.25 m, typically about 1 m, during operation.

The first main shaft may rotate in the range of from 5 to 25 revolutions per second about the central axis, typically from 10 to 25, such as from 15 to 20, during operation. The transmission unit may amplify the number of revolutions of the first main shaft about 2 to 5 times.

In Fig. 1, the second end portion 112b is connected to the first rotor 141. The rotor is adapted to and arranged to rotate due to a water flow, typically a tidal water flow. The rotor is rotatable about the central axis A. Typically, the rotor is arranged substantially perpendicular to the mean direction of the water flow. The relatively high density of water (e.g. in comparison to the density of air which is of interest in wind power applications) allows use of rotors of

many different shapes. The first rotor 141 is herein shown as an impeller, but may alternatively be e.g. a screw. For instance, the speed of the water flow may be within the range of from 0.1 to 20 meter per second (m/s), such as from 0.5 to 10 m/s, typically from 1 to 5 m/s.

The axial load-carrying unit 111 is herein shown as a hydraulic axial load-carrying unit comprising a piston member (not explicitly shown, however further shown in Fig. 6) and a housing member (not explicitly shown, however further shown in Fig. 6). In detail, the first end portion 112a is connected to the piston member. The piston member is moveably arranged along the central axis and rotatably arranged about the central axis. In contrast, the housing member is fixedly arranged, thus neither moveable along the central axis nor rotatable about the central axis. Alternatively, the axial load-carrying unit may be a thrust bearing, a rolling bearing, a slide bearing, or a hydrostatic bearing.

In Fig. 1, the submerged system 100 comprises a single electrical generating module 120. However, as will be described lateron, the submerged system may comprise from 1 to 4 electrical generating modules when the load-carrying module has the shape of a rectangular prism. One electrical generating module may be connected to each of the four sidewalls of the load-carrying module. Typically, the walls, i.e. the sidewalls and the walls of the end portions, of the load-carrying module are made in a rigid material, such as a metallic material, for instance steel, e.g. stainless steel.

The electrical generating module 120 comprises a subshaft 122 being connected to a generator 121 in one of its end portions. The generator 121 is capable of converting rotational motion to electrical energy. The subshaft 122 is rotatably arranged about an axis, at least substantially, parallel to the central axis A. The subshaft is typically made in steel, e.g. stainless steel.

The electrical generating module 120 further comprises a housing 123 arranged to at least partly enclose the generator 121 and the subshaft 122. Typically, the housing is made of a water-impermeable material adapted to minimize water penetration into the submerged system. For instance, the housing comprises a non-porous material, e.g. glass fibers. Alternatively, the housing may be made of aluminum. Typically, the housing 123 is closing tightly to the load-carrying module 110, whereby penetration of water into the system 100 may be avoided.

The portion of the electrical generating module 120, not being enclosed by the housing 123, may be enclosed by a sidewall of the load-carrying module

110 made in a rigid material, such as a metallic material, for instance steel, e.g. stainless steel. Typically, the sidewall of the load-carrying module comprises guide rails adapted for radial load-carrying units and/or the transmission unit (both described more in detail below).

In Fig. 1, the transmission unit is herein shown as a pulley-belt assembly. The pulley-belt assembly comprises a first pulley 131a arranged about the first main shaft 112, a second pulley 131b arranged about the subshaft 122, and a belt 132 arranged about the first pulley and the second pulley, thereby the pulley-belt assembly allows rotational motion of the first main shaft 112 to be transmitted to rotational motion of the subshaft 122. Alternatively, the transmission unit may comprise chains or gears fulfilling the same function as the pulley-belt assembly.

The load-carrying module further comprises at least two, herein two, radial load-carrying units 114a, 114b configured to carry radial load relative to the central axis A. The two radial load-carrying units 114a, 114b are arranged about the first main shaft 112, one on each side of the first pulley 131a of the transmission unit 130. The radial load-carrying units 114a, 114b suitably carry radial load arising from at least one of the first rotor 141 and the transmission unit 130.

The electrical generating module further comprises at least two, herein two, radial load-carrying units 126a, 126b configured to carry radial load relative to the axis, at least substantially, parallell the central axis A. The two radial load-carrying units 126a, 126b are arranged about the subshaft 122, one on each side of the second pulley 131b of the transmission unit 130. The radial load-carrying units 126a, 126b suitably carry radial load arising from the transmission unit 130.

In Fig. 2, a portion of the load-carrying module 110 is shown in more detail. The load-carrying module is provided with a first opening 113. The first opening 113 is provided at one of the end surfaces 1103 of the load-carrying module 110. The first opening 113 is configured to encircle a cross-section 112c of the first main shaft 112, such as a cross-section of the second end portion 112b of the first main shaft. Typically, the second end portion 112b is arranged outside the load-carrying module 110 and the first end portion 112a is arranged inside the load-carrying module 110, as shown in Fig. 1.

In Fig. 2, a first sealing member 151 is radially arranged about the first main shaft such as to seal the first opening. The sealing member is provided to seal a potential gap between the first main shaft 112 and the end surface

1103. The sealing member may allow a closed chamber to be formed inside the load-carrying module 110. Herein, the first sealing member 151 is shown as a bushing being further attached to the wall of the end portion of the load-carrying module 110 provided with the opening 113.

The first sealing member 151 is configured to minimize the water penetration into the load-carrying module 110 along the first main shaft 112, and is preferably robust. The first sealing member 151 is capable to handle both axial motion and rotational motion of the first main shaft 112, and is preferably flexible. In order to optimize the function of the first sealing member 151, the first main shaft 112 typically has a smooth, e.g. polished, surface area. A smooth surface area of the first main shaft 112 may allow the first sealing member 151 to tightly close the gap between the first main shaft 112 and the wall of the load-carrying module 110 to which the first sealing member 151 is attached.

The first sealing member 151 may be any kind of conventional sealing capable to reduce and/or avoid water penetration along the first main shaft 112 into the load-carrying module 110. For instance, the first sealing member 151 may be a lip sealing, e.g. comprising rubber, or a mechanical sealing, e.g. comprising silicon carbide. The first sealing member 151 may, additionally or alternatively, include grease, e.g. silicon grease, or oil.

The present invention relates to a submerged system 200 for converting a tidal water flow to electrical energy, which is schematically shown in a second embodiment in Figs. 3 and 4 comprising a double arrangement of the load-carrying module. The submerged system 200 comprises a load-carrying module 210, four electrical generating modules 220a, 220b, 220c, 220d, four transmission units 230a, 230b, 230c, 230d each operatively connecting the load-carrying module 210 to one of the electrical generating modules. The submerged system 200 may further comprise a first rotor 241 and a second rotor 242, however not shown in Figs. 3-4.

In Fig. 3, the load-carrying module 210 comprises two main shafts, herein called a first main shaft 212 and a second main shaft 215, respectively. A load-carrying module comprising two main shafts forms a, herein called, double arrangement. Both the first main shaft 212 and the second main shaft 215, are each moveably arranged along and rotatably arranged about the central axis A. The first main shaft 212 and the second main shaft 215 are rotatable about the central axis in the same direction simultaneously. The two main shafts 212, 215 are interconnected via an axial load-carrying unit 211. Nevertheless, as long as the two main shafts do not counteract each other,

the two main shafts may with time rotate both clockwise and counterclockwise with regard to the central axis.

In Fig. 3, the submerged system 200 comprises four electrical generating modules 220a, 220b, 220c, 220d being arranged on one of the four sidewalls of the load-carrying module 210 each. Each of the four electrical generating modules 220a, 220b, 220c, 220d comprises a subshaft 222c, 222d being connected to a generator 221c, 221d in one of its end portions. Each of the four subshafts 222c, 222d is rotatably arranged about an axis. Each of these axes being, at least substantially, parallel to the central axis A. Each of the four electrical generating modules 220a, 220b, 220c, 220d further comprises a housing 223a, 223b arranged to at least partly enclose the generator and the subshaft. Each of the electrical generating modules may further comprise a gear box 227c, 227d. The gearbox is typically arranged about a subshaft 222c, 222d and between the second pulley of the transmission unit 230c, 230d and the generator 221c, 221d. The gearbox serves to amplify the number of revolutions of the subshaft (about which it is arranged) per time unit in order to increase the efficiency of the system. The gearbox may amplify the number of revolutions per time unit about 10 to 1000 times.

In Fig. 3, a transmission unit is arranged between each subshaft 222c, 222d and the main shaft 212, thus, in total, four transmission units 230a, 230b, 230c, 230d are present. The transmission units are herein shown as pulley-belt assemblies, each comprising a first pulley arranged about the first main shaft 212, or alternatively the second main shaft 215, a second pulley arranged about one of the four subshafts, and a belt arranged about the first pulley and the second pulley, thereby allowing the pulley-belt assemblies to transmit rotational motion of the first and second main shaft, respectively, to rotational motion of each of the subshafts.

Similar to the arrangement shown in Figs. 1-2, the load-carrying module 210 of the embodiment illustrated in Figs. 3-4 is provided with a first opening configured to encircle a cross-section of the first main shaft, typically a cross-section of the second end portion of the first main shaft, and a second opening configured to encircle a cross-section of the second main shaft, typically a cross-section of the second end portion of the second main shaft. Typically, the second end portions may be arranged outside the load-carrying module and the first end portions may be arranged inside the load-carrying module, as shown in Fig. 3. A first sealing member 251 is radially arranged about the first main shaft such as to seal the first opening. A second sealing member is radially arranged about the second main shaft such as to seal the second opening.

In Fig. 3, the electrical generating module being arranged most far away from the water surface and closest to the bottom of e.g. the sea, the lake or the watercourse, herein called the lowest electrical generating module 230a, further comprises a pump (not explicitly shown). The pump may be an electrical pump, adapted to remove water, which has undesirably penetrated into the submerged system, out from the electrical generating module. The pump is connected to a valve, such as a non-return valve, provided in the housing 223a of the lowest electrical generating module 220a allowing water to be removed from the electrical generating module.

The double arrangement of the load-carrying module in Fig. 3, described above, is shown in more detail in Fig. 4. The first main shaft 212 has a first end portion 212a connected to a hydraulic axial load-carrying unit 211, more in detail to the piston member 211a of the hydraulic axial load-carrying unit, and a second end portion 212b connectable to a first rotor. The second main shaft 215 has a first end portion 215a connected to the hydraulic axial load-carrying unit 211, more in detail to the piston member 211a of the hydraulic axial load-carrying unit, and a second end portion 215b connectable to a second rotor. The first rotor and the second rotor may be impellers, or alternatively e.g. screws. The first rotor and the second rotor are rotatable about the central axis in the same direction simultaneously. Nevertheless, as long as the two rotors do not counteract each other, the two rotors may with time rotate both clockwise and counterclockwise with regard to the central axis.

As further shown in Fig. 4, each of the first pulleys are arranged between a couple of radial load-carrying units 214a, 214b, 214c, 214d being arranged about the first main shaft 212 and the second main shaft 215, respectively. The radial load-carrying units arranged about any of the main shafts serve to carry radial load arising from both the motion of the rotors and the transmission unit.

Also, each of the second pulleys are arranged between a couple of radial load-carrying units, being arranged about each of the subshafts (not shown in Fig. 4). The radial load-carrying units arranged about any of the subshafts are configured to carry load relative to the axis along which the subshaft is arranged, this axis being parallel to the central axis A.

Thus, whether the submerged system comprises a single arrangement (as shown in Fig. 1) or a double arrangement (as shown in Figs. 3-4), the conversion of tidal water flow to electrical energy of the submerged system

may, in its simplest way, be summarized as follows. The first rotor 141, 241 and/or second rotor 242 may generate a rotational motion of the first main shaft 112, 212 and/or second main shaft 215 from the water flow energy, whereby the rotational motion of the first main shaft 112, 212 and/or second main shaft 215 has a first frequency. The transmission unit 130, 230a-d may transfer the rotational motion of the first main shaft 112, 212 and/or second main shaft 215 having a first frequency to a rotational motion of the at least one subshaft 122, 222a-d having a second frequency. The at least one generator 121, 221a-d may generate electrical energy from the rotational motion of the at least one subshaft 122, 222a-d, either directly (thus, from rotational motion having the second frequency) or via a gearbox 227c-d (thus, from a rotational motion having a third frequency). Typically, the second frequency is higher than the first frequency. Similarly, the third frequency is generally higher than the second frequency.

In Fig. 5, the submerged system 200 shown in Fig. 3 and described above is placed on a solid structure 260 arranged on the bottom 270 of e.g. the sea, the lake or the watercourse. In Fig. 5, the submerged system comprises both a first rotor 241 and a second rotor 242. The structure 260, shown herein, has the shape of a frame and constitutes a means for attaching the submerged system to the bottom of the water system into which the system is submerged. Alternatively, the submerged system could have been attached to e.g. a bridge, a ship, or to the sea ground, the bottom of a lake or a watercourse by an anchor.

If the submerged system is not placed on a solid structure, it may preferably be buyoant. In a buyoant submerged system, the housing preferably encloses the entire submerged system, the end portions of the load-carrying module excluded. The housing and the end portions of the load-carrying module serve to avoid water to penetrate into the submerged system.

The submerged system may be buyoant e.g. by pressurization of the load-carrying module and/or the electrical generating module(s). By pressurizing the load-carrying module and/or the electrical generating module(s), the submerged system may be arranged at a certain depth in the water. The relation between the pressure inside the submerged system and the pressure outside the submerged system will determine the depth. For instance, the water flows may be most suitable at a certain depth and the submerged system may be arranged at this certain depth during operation. On the other hand, the maintenance work may suitably be performed at the water surface, and the submerged system may be arranged at the water surface when not in operation. The submerged system may either be pressurized before

installation or after installation. For instance, the submerged system may be pressurized by airbags, such as crash bags, being installed within the system.

In Fig. 6, an hydraulic axial load-carrying unit 111, 211 is shown in more detail. The hydraulic axial load-carrying unit comprises a piston member 111a, 211a and a housing member 111b, 211b.

The housing member 111b, 211b has an inner diameter d_h and an inner cylindrical surface s_h. The housing is hollow, forming a so-called chamber. Hence, by means of the inner diameter and the inner cylindrical surface, an inner housing volume is formed. The inner housing volume here contains a lubricant fluid in form of oil. That is, the inner housing volume is filled with the lubricant fluid. Oil has a suitable viscosity of 0.27 Pa*s, and a suitable density of 870 kg/m^3.

The piston member 111a, 211a is co-axially arranged within the housing member 111b, 211b. The inner housing volume surrounds a major part of the piston member. The piston member 111a, 211a is also configured to be rotatable around an axis A, and movable in the axial direction A upon an external axial force F on the piston member. Herein, the external axial force F may be a periodically constant linear force applied in the axial direction and originating from tidal water forces. The piston member 111a, 211a comprises a piston rod 1111, 2111 and a piston flange 1112, 2112. The piston flange is provided with an outer diameter d_p and an outer cylindrical surface s_p. The piston rod and the piston flange may be separate components which are attached to each other prior to use. For instance, the lower end of the piston rod may be press-fitted to the piston flange. Alternatively, the piston rod and the piston flange are made from the same piece of material.

The outer diameter of the piston flange is smaller than the inner diameter of the housing member such that a radial gap r_{gap} is formed between the inner cylindrical surface of the housing member and the outer cylindrical surface of the piston flange. In this manner, the lubricant fluid is capable of flowing through the radial gap upon an exertion of a tensile force F on the piston member in the axial direction A. The radial gap is formed in the radial direction, which is perpendicular to the axial direction A, but has an extension l_{gap} in the axial direction A corresponding to the thickness of the piston flange. The piston flange should be sufficiently dimensioned to withstand big axial forces and several years in heavy condition without maintenance. For instance, the outer diameter of the piston flange may be 650 mm and the thickness of the piston flange may be 30 mm. The distance of the radial gap may be between 0.05 – 0.5 mm in the radial direction, such as 0.1 mm. The

extension of the radial gap in the axial direction A is equal to the thickness of the piston flange, e.g. 30 mm. However, the shape and the size of the piston flange are ultimately determined by the desired load-carrying characteristics, and it is therefore apparent to the skilled in the art to make any final adjustments of the piston flange dependent on each specific case.

The inner cylindrical housing surface and/or the outer cylindrical surface of the piston flange may be made of friction reducing material, for example plastics material having a low friction co-efficient. The complete components and/or surfaces may also be made from stainless steel or any other suitable material which are capable of being used in this specific environment.

By the provision that the outer diameter of the piston flange d_p is smaller than the inner housing diameter d_h such that a radial gap is formed between the inner housing cylindrical surface and the outer cylindrical surface of the piston flange, it becomes possible to decrease friction between the piston member surface and the inner cylindrical surface of the housing. In this example, the piston member surface refers to the outer cylindrical surface of the piston flange, and the inner cylindrical surface of the housing refers to the inner housing cylindrical surface. This is accomplished due to the radial gap which results in that there is no contact between the piston member surface and the inner cylindrical surface of the housing. Accordingly, the lubricant fluid is capable of flowing from one side of the piston flange to another side of the piston flange via the radial gap. In other words, the radial gap forms a flow channel. To this end, the piston flange is made with a deliberate clearance between the inner housing cylindrical surface and the outer cylindrical surface of the piston flange, which forms an annular gap in the radial direction, i.e. the radial gap. As such, when the surface of the piston flange is pressed towards an inner surface of the housing, the lubricant fluid flow is constricted by the radial gap. The high pressure drop across the radial gap produces a pressure differential across the piston flange, which creates the a damping force. In this regard, the inner housing cylindrical surface s_h and the outer cylindrical surface s_p of the piston flange form a pair of load-carrying surfaces radial opposite to each other with radial gap containing a lubricant fluid there between.

Advantageously, the housing member 111b, 211b should be sealed such that a closed system is obtained which ensures that no oil leaks out from the inner housing volume. Typically, a sealing arrangement 119, 219 is located at the end of the piston rod to seal the annular gaps between the piston rod 1111, 2111 and the housing 111b, 211b such that the inner housing volume forms a closed system.

In an example, the inventor selected the parameters in Table 1 for the hydraulic axial load-carrying unit resulting in a satisfying operation of the system.

Table 1. Parameters for a hydraulic axial load-carrying unit.

Axial load, F	2000 kN
Rotational speed of the first main shaft	25 rpm
Diameter of the piston rod	0.1 m
Diameter of the piston flange, d_p	1 m
Thickness of piston flange, l_{gap}	0.06 m
Number of pistons	1
Radial gap between piston flange and housing member, r_{gap}	0.0001 m
Oil density	870 kg/m^3
Oil viscosity	0.27 Pa·s
Stroking time	6 h

Additionally, the piston member of the hydraulic axial load-carrying unit may have a start position in the housing member, e.g. wherein the piston member is in contact with a first inner surface of the housing member, and an end position, e.g. wherein the piston member is in contact with a second inner surface of the housing member arranged opposite to the first inner surface member as seen in the axial direction.

In an example, the piston member may be moved in the axial direction from the start position to the end position during the tidal water period of six hours, but may be returned substantially faster from the end position back to the start position. In this example, the hydraulic axial load-carrying unit is typically further provided with a spring, being arranged about the piston member on the side of the piston flange being arranged closest to the second inner surface of the housing member, and a check valve.

Additionally, variations to the disclosed example embodiments can be understood and effected by the skilled person in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage.

CLAIMS

1. Submerged system (100, 200) for converting a tidal water flow to electrical energy comprising

a load-carrying module (110, 210) comprising an axial load-carrying unit (111, 211) configured to carry axial load relative to a central axis (A), and a first main shaft (112, 212) moveably arranged along the central axis and rotatably arranged about the central axis, the first main shaft having a first end portion (212a) connected to the axial load-carrying unit and a second end portion (212b) connectable to a rotor,

an electrical generating module (120, 220a) operatively connected to the load-carrying module and comprising a subshaft (122, 222c-d) rotatably arranged about an axis parallel to the central axis, a generator (227c-d) capable of converting a rotational motion to electrical energy, the generator being connected to the subshaft, and a housing (123, 223) at least partly enclosing the subshaft and the generator,

wherein the first main shaft is operatively connected to the subshaft via a transmission unit (230a-d), whereby the transmission unit allows rotational motion about the central axis to be transmitted to rotational motion about the axis being parallel to the central axis.

2. Submerged system according to claim 1, wherein the axial load-carrying unit is a hydraulic axial load-carrying unit comprising a piston member (111a, 211a) and a housing member (111b, 211b), the piston member being moveably arranged along the central axis and rotatably arranged about the central axis relative to the housing member, and wherein the first end portion of the first main shaft is connected to the piston member.

3. Submerged system according to claim 1 or 2, wherein the load-carrying module is provided with a first opening (113) configured to encircle a cross-section (112c) of the second end portion of the first main shaft, and further comprises a first sealing member (151, 251) radially arranged about the first main shaft such as to seal the first opening.

4. Submerged system according to any of claims 1 to 3, wherein the load-carrying module further comprises at least two radial load-carrying units (114a-b, 214a-b) configured to carry radial load relative to the central axis, the at least two load-carrying units being arranged about the first main shaft.

5. Submerged system according to any of claims 1 to 4, further comprising a first rotor (141, 241) capable of converting a tidal water flow to a

rotational motion, the first rotor being connected to the second end portion of the first main shaft and being rotatably arranged about the central axis.

6. Submerged system according to any of claims 1 to 5, wherein the load-carrying module further comprises a second main shaft (215), the second main shaft being moveably arranged along the central axis and rotatably arranged about the central axis, the second main shaft having a first end portion (215a) connected to the piston member and a second end portion (215b) connectable to a rotor.

7. Submerged system according to claim 6, wherein the load-carrying module further is provided with a second opening configured to encircle a cross-section of the second end portion of the second main shaft, and further comprises a second sealing member radially arranged about the second main shaft such as to seal the second opening.

8. Submerged system according to claim 6 or 7, further comprising at least two radial load-carrying units (214c-d) configured to carry radial load relative to the central axis, the at least two load-carrying units being arranged about the second main shaft.

9. Submerged system according to any of claim 6 to 8, (when dependent on any of claim 3 to 5,) further comprising a second rotor (242) capable of converting a tidal water flow to a rotational motion, the second rotor being connected to the second end portion of the second main shaft and being rotatably arranged about the central axis.

10. Submerged system according to claim 6 or 9, further comprising at least two radial load-carrying units (126a-b) configured to carry radial load relative to the axis parallel to the central axis, the at least two load-carrying units being arranged about the subshaft.

11. Submerged system according to any of the preceding claims, wherein the electrical generating module further comprises a pump.

12. Submerged system according to any of the preceding claims, wherein the electrical generating module further comprises a gear box (227c-d) being arranged about the subshaft between the transmission unit and the generator.

13. Submerged system according to any of the preceding claims, wherein the electrical generating module further comprises a sensor.

14. Submerged system according to any of the preceding claims, further comprising at least one additional electrical generating module (220b-d) operatively connected to the load-carrying module.

15. Submerged system according to any of the preceding claims, being adapted to be attached to the bottom of the water (270) in which the system is submerged, to a rigid structure (260) or to a watercraft.

16. Submerged system according to any of the preceding claims, being a buoyant system.

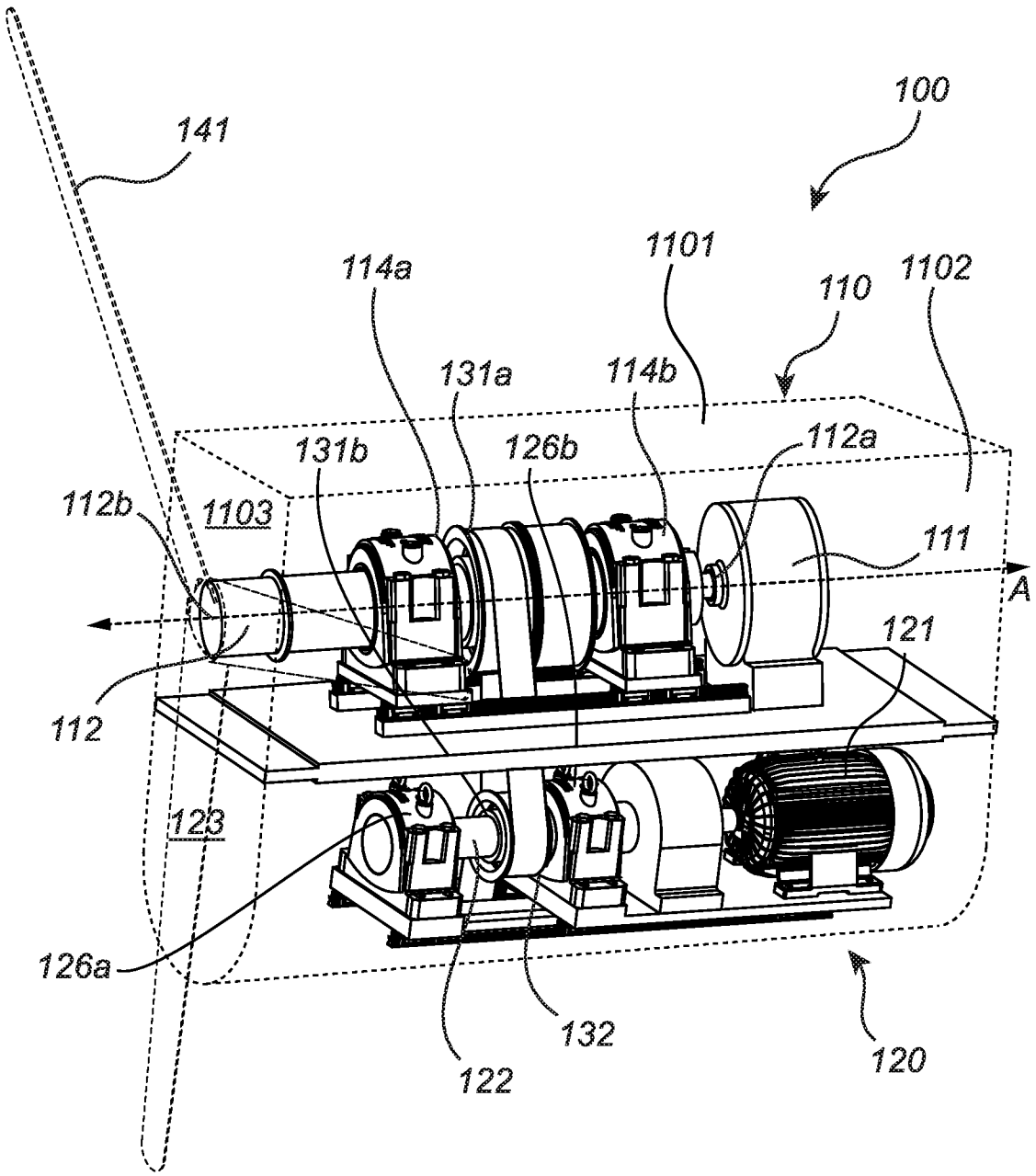

141
100
1101
114a
110
1102
131a
114b
131b
126b
112a
112b
1103
111
A
121
112
123
126a
132
122
120

Fig. 1

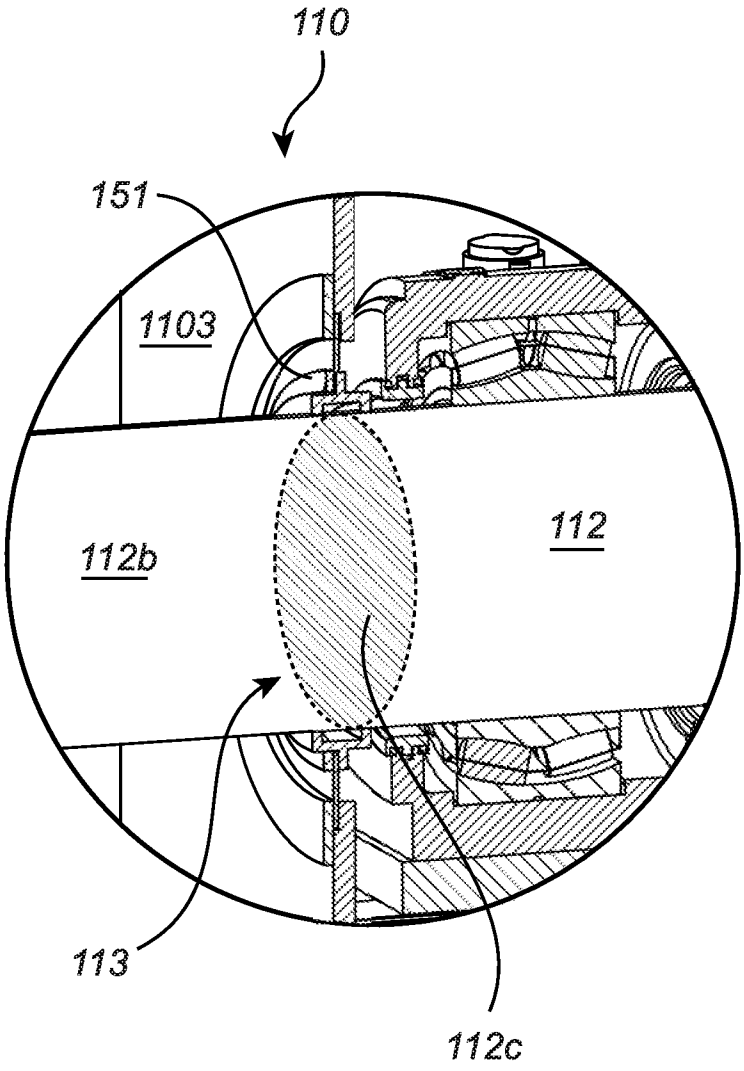


Fig. 2

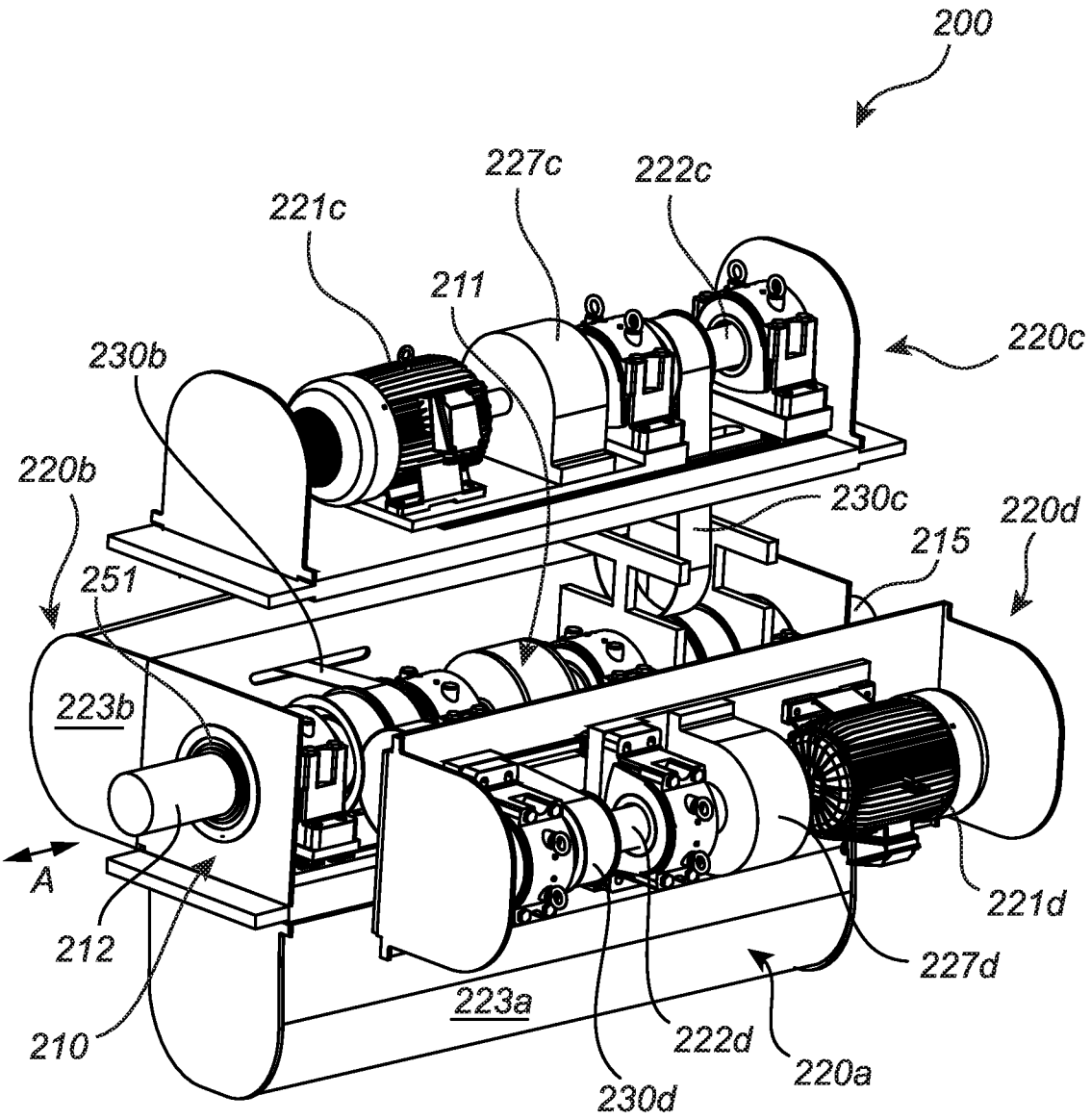

200
227c
222c
221c
211
220c
230b
220b
230c
220d
215
251
223b
A
212
210
223a
222d
230d
220a
227d
221d

Fig. 3

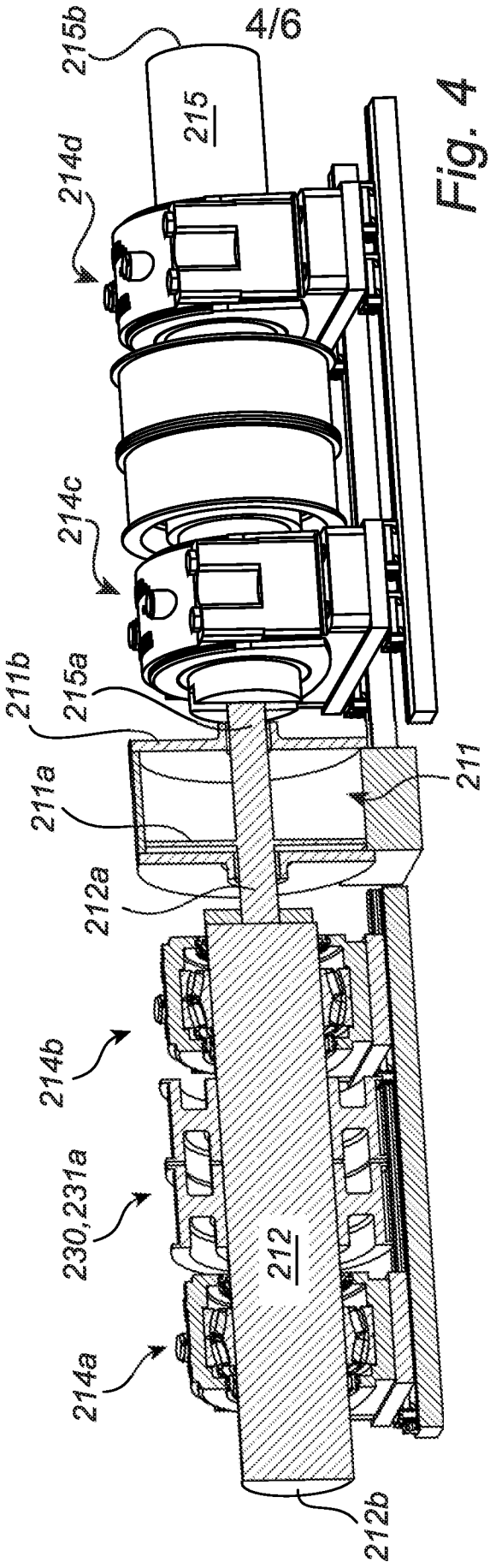

215b
215
214d
214c
211b
215a
211a
211
212a
214b
230,231a
212
214a
212b

Fig. 4

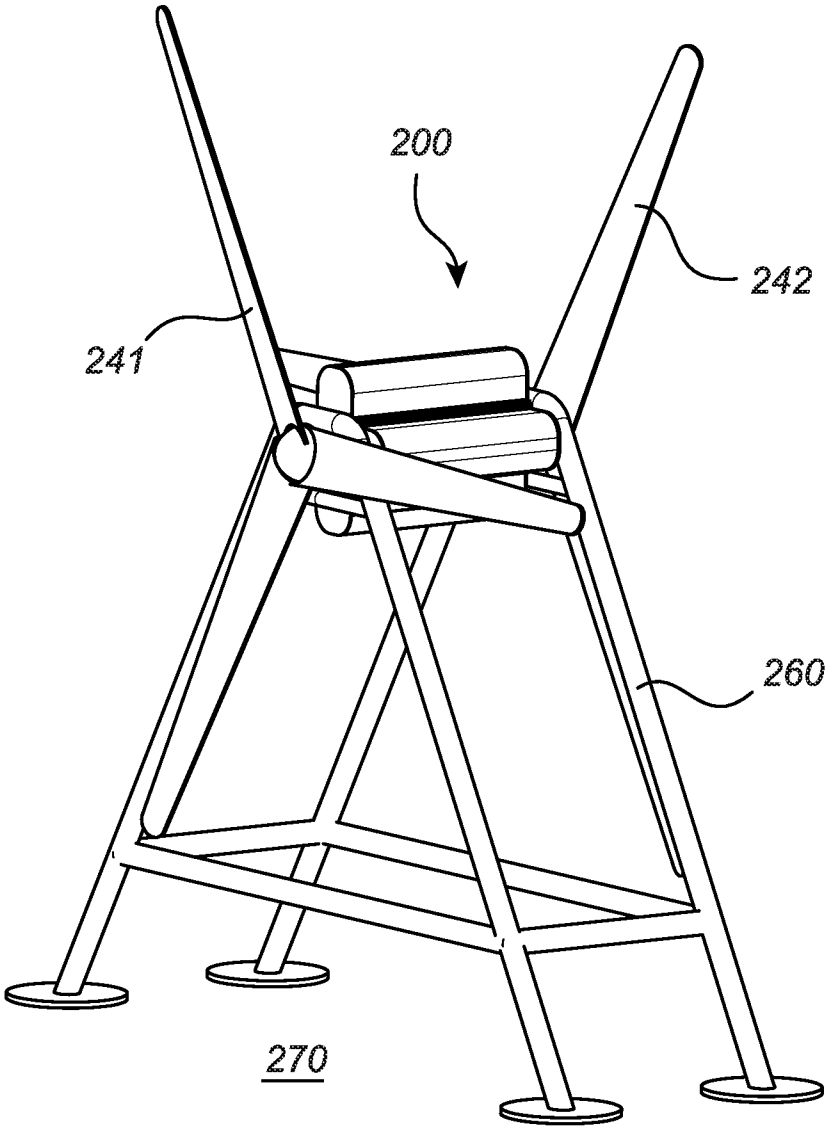


Fig. 5

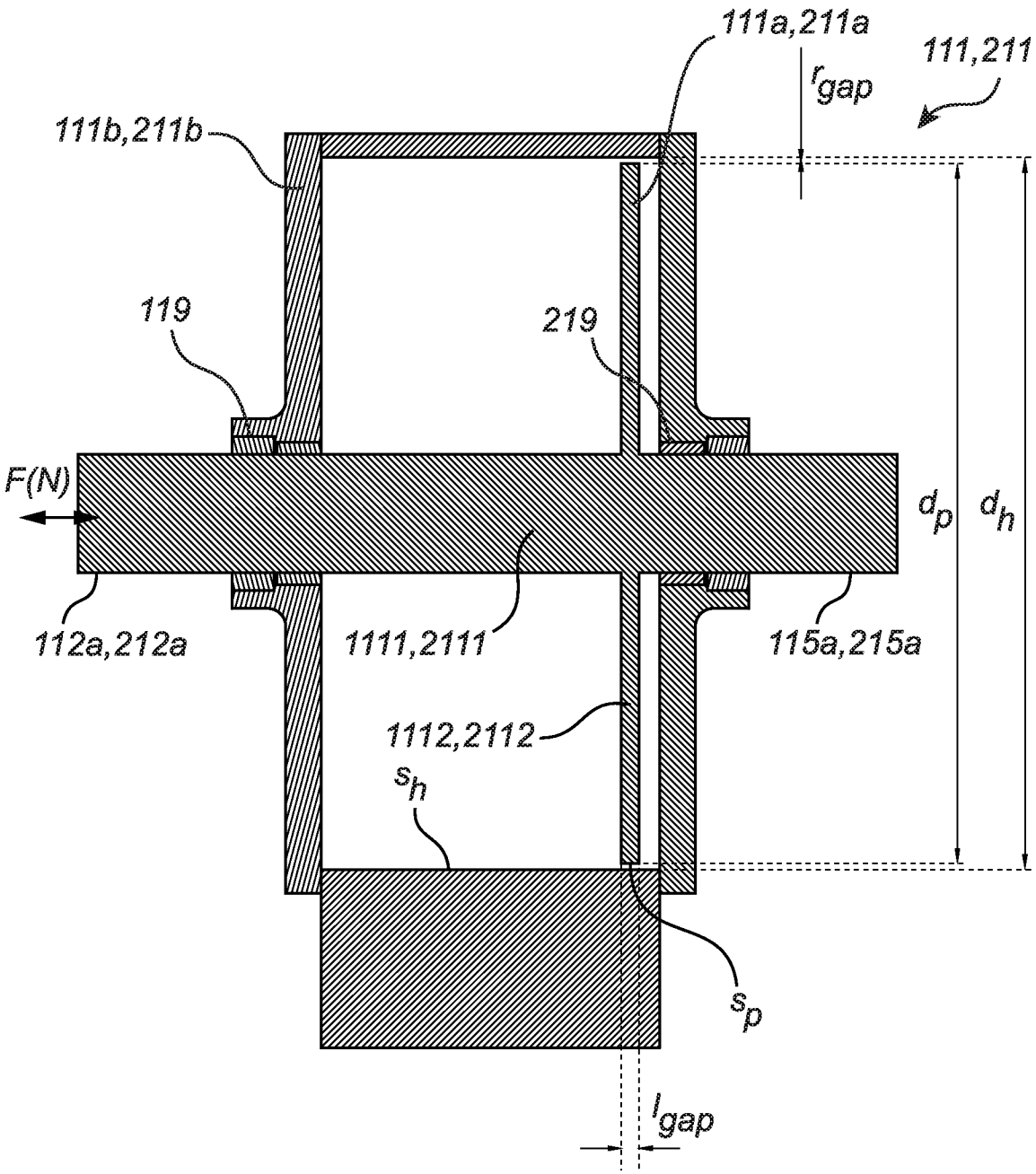

111a,211a
111,211
r_{gap}
111b,211b
119
219
F(N)
d_p
d_h
112a,212a
1111,2111
115a,215a
1112,2112
s_h
s_p
l_{gap}

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2015/050392

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: E02B, F03B, F16F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

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	GB 2470447 A (O'DONNELL JAMES - (B) MICROGEN TECHNOLOGIES LTD [GB]), 24 November 2010 (2010-11-24); pages 3-5; figure 4	1, 3-5, 11-16
	--	
A	US 20060055174 A1 (LANDWEHR WILHELM), 16 March 2006 (2006-03-16); paragraphs [0001]-[0002], [0085]-[0086]; figures 1,6	1-16
	--	
A	JP 57193781 A (KOGYO GIJUTSUIN ET AL), 29 November 1982 (1982-11-29); (abstract) Retrieved from: EPODOC database; figure 2	1-16
	--	

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier 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
23-07-2015	23-07-2015
Name and mailing address of the ISA/SE Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Fredrik Timoteusson Telephone No. + 46 8 782 28 00

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2015/050392

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 102506006 A (HARBIN ELECTRIC MACH CO LTD), 20 June 2012 (2012-06-20); (abstract) Retrieved from: EPODOC database; figure 1 --	1-16
A	KR 101372128 B1 (HYUNDAI ENG & CONSTRUCT CO LTD), 7 March 2014 (2014-03-07); (abstract) Retrieved from: EPODOC database; figure 3 --	1-16
A	CN 202148978 U (UNIV DALIAN TECH), 22 February 2012 (2012-02-22); (abstract) Retrieved from: EPODOC database; figures -- --------	1-16

International application No.
PCT/SE2015/050392

Continuation of: second sheet

International Patent Classification (IPC)

F03B 13/26 (2006.01)
F03B 13/10 (2006.01)

GB	2470447	A	24/11/2010	NONE			
US	20060055174	A1	16/03/2006	US	7498683	B2	03/03/2009
JP	57193781	A	29/11/1982	NONE			
CN	102506006	A	20/06/2012	NONE			
KR	101372128	B1	07/03/2014	NONE			
CN	202148978	U	22/02/2012	NONE			