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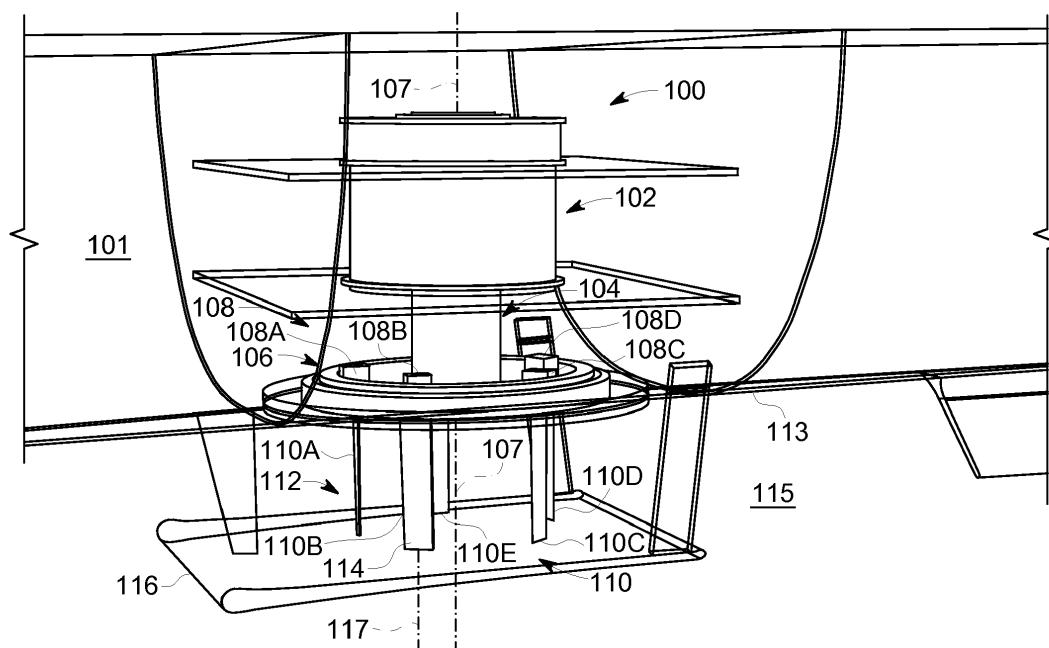
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(54) **Cycloidal marine-propulsion system**

(57) A cycloidal marine-propulsion system (100) is disclosed. The system comprises a blade-mounting disc (106) and a plurality of propeller blades (110A-E). Each of the plurality of propeller blades has a respective primary blade axis (117) and is connected to the disc (106) in a manner allowing the blade (110) to be rotated about its primary blade axis (117) independent of any about-

axis rotation of every other one of the propeller blades. The system also includes a plurality of electric actuators (108A-E), each actuator being connected to a respective one of the propeller blades (110A-E). The system further includes a controller in communication with the electric actuators (108A-E) for controlling selectively each of the electric actuators.



**FIG. 1**

## Description

### I. Technical Field

[0001] The present technology relates generally to a cycloidal-marine propulsion system. In some embodiments, the technology relates more particularly to a cycloidal marine-propulsion system comprising multiple electric motors for controlling individually each of multiple respective cycloidal blades.

### II. Background

[0002] A cycloidal-drive propeller system is a specialized marine propulsion system allowing high maneuverability. The system allows change of vessel thrust to a direction and magnitude per command.

[0003] Cycloidal-drive propeller systems are used widely in vessels for which station keeping and high maneuverability at lower speeds are central functions, such as tugboats, ferries, and offshore support vehicles. A conventional type of cycloidal-drive propeller system is a Voith-Schneider propeller (VSP) system.

[0004] Conventional cycloidal propeller systems use heavy-duty drive engines such as a diesel motor drive. The drive provides input power and torque for a relatively complex group of intermediary structures leading to a complex mechanical gearbox and crosshead arrangement.

[0005] The drive engine of conventional systems is also connected to the mechanical gearbox and slider arrangement by way of a series of relatively intermediate structures and a main, vertical, system shaft. The intermediate structures include, for instance, couplings (e.g., displaceable coupling), intermediate drive shafts such as a Cardan shaft, and step-down gears, with or without one or more clutches.

[0006] During vessel movement, and especially high-vessel-speed operation, the vertical propeller blades of a cycloidal drive create undesirably high drag in the water. The drag is particularly high under certain conditions, such as during continuous running of the vessel at high power. The drag slows the vehicle, limiting speed and thus vessel efficiency. The drag also lowers fuel economy, requiring more power and so fuel to overcome the drag.

[0007] Due to the relatively complex intermediate structures, mechanical gearbox, and crosshead arrangement described, response time between a triggering input - e.g., a signal transmitted in response to a captain pulling a lever - and the desired response is also undesirably high. The complex mechanical drive is also noisy and causes unwanted vibration due to unbalanced forces and couples.

### III. Summary of the Embodiments

[0008] Given the aforementioned deficiencies, there is

a need for a cycloidal marine-propulsion system that reduces significantly drag formed at vertical propeller blades of the system during high-vessel-speed operation.

[0009] The present technology accomplishes this and other goals in various embodiments. In one embodiment, the system includes multiple electric drives connected to respective cycloidal-propeller blades for controlling the respective blades selectively. Each electric drive allows complex and fine control of position and movement of the blade to which it is connected.

[0010] Each blade can be moved, independent of movement of each of the other blades, and independently of a rotational position of the vertical main assembly. Both independences are distinctions compared to the conventional mechanical drive system.

[0011] Each blade can be moved in any of a variety of ways to reduce drag and accomplish other desired functions such as creating, increasing, and/or re-directing thrust.

[0012] One way each blade can be repositioned or moved selectively is by rotating the blade about a primary, longitudinal (extending along a primary length, usually generally vertical of the blade - reference axis 117 in FIG. 1).

[0013] In a contemplated embodiment, each blade can also be tilted, or pitched, whereby an angle of a blade axis (e.g., axis 117) is changed. This embodiment is described more below.

[0014] In still another contemplate embodiment, all of the blade axis can be moved toward or away from a main system axis (e.g., axis 107, FIG. 1). And each blade can be moved in more than one manner at a time - e.g., tilted, while being rotated about its blade axis, and both at the same time that the blade is being moved with the other blades about the main system axis. These aspects are also described more below.

[0015] In addition to providing increased ability to reduce drag and in some instances increase thrust, the individual blade control of the present technology improves response time between desired blade action (e.g., positioning or motion) resulting from input signals - e.g., an input signal from the controller or a vessel captain to increase speed and/or operate in a low-drag, or energy-efficient, mode, and can also reduce noise (e.g., underwater, or underwater and noise passing to the air) and vibrations (e.g., underwater and into the vessel).

[0016] In some embodiments, efficiency, as well as fine control, are further promoted by a direct electric drive. The electric drive is linked directly to a main system axis shaft and, thereby, to a disc or plate holding the propeller blades. The direct electric drive also promotes quick response time between input and resulting propeller action.

[0017] Further features and advantages, as well as the structure and operation of various embodiments, are described in more detail below with reference to the accompanying drawings. The technology is not limited to the specific embodiments described herein. The embodi-

ments are presented herein for illustrative purposes only. Additional embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

**[0018]** In one embodiment, the present invention can provide a cycloidal marine-propulsion system, comprising: a blade-mounting disc; a plurality of propeller blades, each having a respective primary blade axis and being connected to the disc in a manner allowing the blade to be rotated about its primary blade axis independent of any about-axis rotation of every other one of the propeller blades; a plurality of electric actuators, each actuator being connected to a respective one of the propeller blades; and a controller in communication selectively with each of the electric actuators for controlling each of the actuators.

**[0019]** The controller can include computer-executable instructions, comprising a control map, that, when executed by a processor of the controller, cause the processor to control separately each of the electric actuators according to the control map.

**[0020]** The cycloidal marine-propulsion system can further comprise a primary vertical-axis drive shaft connected to the lower disc and a primary-axis drive connected to the drive shaft for turning the shaft and, thereby, turning the lower disc. The computer-executable instructions, comprising the control map, when executed by the processor, can cause the processor to control operation of the primary-axis drive according to the control map.

**[0021]** The cycloidal marine-propulsion system can further comprise a primary vertical-axis drive shaft connected to the lower disc and a primary axis drive connected to the drive shaft for turning the shaft and, thereby, the lower disc. The primary-axis drive can include an electric motor connected directly to the primary vertical-axis drive shaft.

**[0022]** The cycloidal marine-propulsion system can further comprise a primary vertical-axis drive shaft connected to the lower disc a primary axis drive connected to the drive shaft for turning the shaft and, thereby, the lower disc. The controller can be in communication with the primary-axis drive for controlling the drive according to the control map.

**[0023]** Each of the plurality of propeller blades can be connected to the disc in a manner allowing the blade to tilt independent of any tilting of every other one of the propeller blades. The controller can include computer-executable instructions, comprising a control map, that, when executed by a processor of the controller, cause the processor to control separately each of the electric actuators, to control blade tilt independently, according to the control map.

**[0024]** The control map can include code that, when executed by the processor, produces output, used in controlling separately each of the electric actuators, based on at least one data input selected a group consisting of: on-blade sensor data; adjacent-blade-angle-sensor data; main-assembly-angle-sensor data; present system-

power data; available-system-power data; present vessel-speed data; requested-vessel-speed data; wind-speed data; ambient-water-temperature data; present-vessel-heading data; requested-vessel-heading data; present-vessel position data; requested-vessel-position data; water-depth data; water-current data; vessel-type data; propulsion-layout data; vessel-captain command; and controller auto-generated command.

**[0025]** The cycloidal marine-propulsion system can further comprise a primary vertical-axis drive shaft connected to the lower disc. Each of the plurality of propeller blades can be connected to the disc in a manner allowing the blade to be rotated about its primary blade axis independent of any about-axis rotation, non-rotation, and position of the primary vertical-axis drive shaft.

**[0026]** In another embodiment, the present invention can provide a method, for controlling a cycloidal-machine-propulsion system being used in a marine vessel, comprising: obtaining, by a processor of a controller, a vessel-kinematic command; accessing, by the processor, a control map; obtaining, by the processor, input data indicative of at least one present condition associated with the vessel; determining, using the vessel-kinematic command, the control map, and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades; and transmitting the blade-control commands to multiple actuators connected to respective ones of the cycloidal propeller blades.

**[0027]** Each of the actuators can include an electric motor.

**[0028]** The vessel-kinematic command can indicate a request to stop the vessel, maintain a present motion characteristic of the vessel, or to maintain a present non-motion characteristic of the vessel.

**[0029]** The vessel-kinematic command can be a previous vessel-kinematic command. In this case, the method can further comprise determining whether a new vessel-kinematic command is present, and acting on the new vessel-kinematic command if present.

**[0030]** The method can further comprise determining, using the vessel-kinematic command, the control map, and input data, a main-axis-drive-control command for controlling a main-axis drive of the system, and transmitting the main-axis-drive-control commands to the main-axis drive.

**[0031]** The blade-control commands can request at least one change selected from a group consisting of: a change of position of the respective blade; a change to a blade rotation about a blade-axis; and a tilting of the blade.

**[0032]** The vessel can include a primary vertical-axis drive shaft. Each of the plurality of propeller blades can be connected to the disc in a manner allowing the blade to be rotated about its primary blade axis independent of any about-axis rotation, non-rotation, and position of the primary vertical-axis drive shaft. The step of determining, using the vessel-kinematic command, the control map,

and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades, can include determining blade-control commands for controlling the blades wherein each blade is not limited mechanically to only one blade position based on about-axis rotational movement, non-movement, and position of the primary drive shaft.

**[0033]** In another embodiment the present invention can provide a method, for controlling a cycloidal-machine-propulsion system being used in a marine vessel, comprising: accessing, by the processor, a control map; obtaining, by the processor, input data indicative of at least one present condition associated with the vessel; determining, using the control map and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades; and transmitting the blade-control commands to multiple actuators connected to respective ones of the cycloidal propeller blades.

**[0034]** The method can further comprise determining, using the control map and the input data, a main-axis-drive-control command for controlling a main-axis drive of the system, and transmitting the main-axis-drive-control commands to the main-axis drive.

**[0035]** The vessel can include a primary vertical-axis drive shaft. Each of the plurality of propeller blades can be connected to the disc in a manner allowing the blade to be rotated about its primary blade axis independent of any about-axis rotation, non-rotation, and position of the primary vertical-axis drive shaft. The step of determining, using the vessel-kinematic command, the control map, and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades, can include determining blade-control commands for controlling the blades wherein each blade is not limited mechanically to only one blade position based on about-axis rotational movement, non-movement, and position of the primary drive shaft.

**[0036]** The blade-control commands can request at least one of a change to a blade rotation about a blade-axis and/or a tilting of the blade.

#### IV. Brief Description of the Drawings

**[0037]** Exemplary embodiments may take form in various components and arrangements of components. Exemplary embodiments are illustrated in the accompanying drawings, throughout which like reference numerals may indicate corresponding or similar parts in the various figures.

**[0038]** The drawings are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the technology. Given the following enabling description of the drawings, novel aspects of the present technology will be evident to a person of ordinary skill in the art.

FIG.1 is a perspective view of the cycloidal marine

propulsion system positioned in a marine vessel.

FIG. 2 is a side cut-away view of the system of FIG. 1.

FIG. 3 is a schematic diagram of a computing device for use in performing functions of the present technology.

FIG. 4 is a flow chart showing operations of a method performed by the present technology.

#### V. Detailed Description of the Embodiments

**[0039]** While exemplary embodiments are described herein with illustrative embodiments for particular implementations, it should be understood that the technology is not limited thereto. Those skilled in the art with access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof, and additional fields in which the cycloidal marine-propulsion system described herein would be of significant utility.

##### Figure 1 - System Components

**[0040]** FIG.1 is a perspective view of a cycloidal marine propulsion system 100, positioned in a marine vessel 101, according to embodiments of the present technology. The system 100 includes a primary drive 102.

**[0041]** In one embodiment, the primary drive 102 is a fully electric drive.

**[0042]** The drive 102 is in one embodiment linked directly (e.g., without complex intermediary components such as clutches, step down or up gears) to a main vertical system shaft 104 of the system 100. The drive 102 is in this case referred to as a direct drive - e.g., a direct electric drive.

**[0043]** The main shaft 104 is connected rigidly to a blade-mounting disc 106, and the two rotate about a main system axis 107 in operation.

**[0044]** The system 100 also includes at least one angle sensor (not shown in detail) positioned on or adjacent the main shaft 104.

**[0045]** A direct-drive arrangement promotes efficiency and fine control of the system 100, as losses from intermediate structure (e.g., couplings, such as a displaceable coupling, intermediate drive shafts such as a Cardan shaft, and step-down gears, with or without one or more clutches) that would otherwise be present are avoided or greatly limited.

**[0046]** A direct drive arrangement, e.g., a direct electric drive, also allows very fast system response. By limiting intermediate structure between the drive 102 and the propeller disc 106, time between an input signal, initiated by a system controller or vessel operator, and resulting propeller action - e.g., rotation of propeller disc 106. A system controller is described further below.

**[0047]** An electric motor 102 is in one embodiment a synchronous motor. The motor 102 may be a wound-field or permanent-magnet type of motor. In one embodiment, the motor 102 is an induction-type motor. And in another,

the motor 102 is a reluctance-type motor.

**[0048]** In contemplated embodiments, the main drive 102 is not electric, or not entirely electric, being, e.g., a type of diesel engine or other internal combustion engine (e.g., Otto, petrol, gas turbine, etc.) The drive 102 can include hydraulic or pneumatic features, and connect directly or indirectly to the main shaft 104. The drive 102 is described further below, including in connection with FIG. 2.

**[0049]** In one contemplated embodiment, the main assembly drive 102 includes or is connected to a geared system (not shown) for turning the main shaft 104. The geared system can include a gear ring, located on a periphery of the main shaft 104, connected to one or more pinion gears driven by one or more high speed motors.

**[0050]** The blade-mounting disc 106 can be referred to by other names, such as main rotating assembly, or lower, inner, structure. The disc 106 rotates with respect to a lower, outer, structure or frame described further below in connection with FIG. 2, and reference numeral 210.

**[0051]** The drive 102 - e.g., direct drive - is in some embodiments controlled by a controller using a control map. The map comprises at least one algorithm according to which the main shaft can be controlled. The map can use as inputs, to determine main shaft operation, any of a wide variety of input data, such as any of output from the on-blade or adjacent-blade angle sensors, output from main assembly angle sensor(s), system power being used, system power available, present vessel speed, vessel attitude (e.g., roll or pitch), vessel speed desired or requested (by command of a vessel operator or the controller 300 (FIG. 3), for instance), wind speed, ambient water temperature, water depth present heading and/or position, heading and/or position desired or requested (by, e.g., command of a vessel operator or the controller), a type or characteristic of the vessel 101, a propulsion layout, vessel-captain command, controller auto-generated command, etc.

**[0052]** The type of vessel will influence the method and type of control, since it is important for certain vessels to have accurate station-keeping characteristics, for example, platform supply vessels, or to have fast transit times, but still require improved maneuverability, such as in the case of ferry boats.

**[0053]** The propulsion layout, relative to the vessel center of gravity, or other vessel handling parameter, will require the control map to take into account those characteristics and parameters. For example, a tug customarily has two propulsion units at the furthest aft section of the hull, whereas a ferry could have the propulsion unit at the forward and after parts of the ship.

**[0054]** The shaft 104 is controlled to accomplish desired vessel dynamics, such as vessel speed, vessel speed vector, vessel thrust, and vessel attitude.

**[0055]** The control map can also be configured to control the system 100 in a manner that lowers or minimizes drag created by one or more of the blades, thereby im-

proving fuel efficiency. The control can also be performed to maintain or produce more thrust, and can be effected in less time than conventional systems, as mentioned above.

**[0056]** The control can include controlling movement of the main shaft 104. These control features are described further below in connection with FIGs. 3 and 4.

**[0057]** The system 100 further includes multiple actuators 108, such as electric motors, mounted locally to the propeller disc 106. Each actuator 108 is connected to respective system propeller blades 110.

**[0058]** Each blade 110 includes a distal end 112 that is positioned below a bottom 113 of the vessel 101 and, during operation of the system 100, positioned in the water 115 in which the vessel 101 is positioned.

**[0059]** Each actuator 108 is controlled by control signals received from a system controller, for instance, as described further below. While actuators 108 can be controlled to move their respective blades 110 according to some relationships (e.g., each blade is controlled to be

positioned 20 degrees further in its rotation, about its blade axis, than a preceding adjacent blade on the disc 106), each actuator 108 is controlled to drive its respective blade 110 to move, or not move, independent of any motion of any of the other blades. That is, each actuator/blade pair can be controlled to move while each other actuator/blade is moved in any way, or kept from moving.

**[0060]** Thus, while one of the blades 110 can be rotated by a first angle in a first direction (e.g., clockwise) about its longitudinal (e.g., usually vertical) axis, for instance, another of the blades 110 can be controlled to move in any way, according to the control map, which can contain one or more algorithms for these purposes, such as by rotating in the same or an opposite direction by the same or another angle, or controlled to not move.

**[0061]** The system 100 also includes angle sensors on or adjacent each blade 110. These sensors are in one embodiment a part of the actuators 108. For simplicity, the sensors considered illustrated by the components 108 in the figures, though the sensors may be physically distinct from and/or connected to the actuators 108.

**[0062]** In the illustrated embodiment, the system 100 includes five actuators 108 (labeled respectively in the figures as 108A-E) connected to five respective propeller blades 110 - 110A-E. While five blades linked to five actuators are shown by way of example, it should be appreciated that the system 100 can include any number of actuators and respective blades.

**[0063]** The actuators 108 in some embodiments are controlled by, or include, or are, one or more electric motors. These electric motors are considered shown by the same structure 108 in the figures. The actuators 108 in some embodiments include or are controlled by one or more other types of drives, such as pneumatic or hydraulic drives, considered shown by the same structure 108 in the figures.

**[0064]** The actuators 108 in some embodiments include electric stepper motors. In one embodiment, the

actuators are reluctance-type motors. Considerations in selecting or designing a motor of the actuators 108 include any or all of responsiveness (e.g., response time), strength, robustness, durability, and noise reduction.

**[0065]** The actuators 108 can be operated to control velocity - speed and direction of movement, angular and/or linear - of the respective blades 110.

**[0066]** In operation, position of each blade 110 changes in a rotation phase of the system 100 in which the rotating disc 106 is being rotated. The blades 110 being rotated by the disc 106 can create vectored thrust.

**[0067]** Disc rotation and/or individual blade rotations can be, as mentioned above, controlled separately by a controller implementing a control map, or algorithm therein. The control map can use as inputs, to determine main shaft operation, any of various inputs, such as any of output from the on-blade or adjacent-blade angle sensors, output from main assembly angle sensor(s), system power being used, system power available, present vessel speed, vessel speed desired or requested (by, e.g., command of a vessel operator or the controller 300 (FIG. 3)), wind speed, ambient water temperature, water depth present heading and/or position, heading and/or position desired or requested (by, e.g., command of a vessel operator or the controller), a type or characteristic of the vessel 101, a propulsion layout, vessel-captain command, controller auto-generated command, etc.

**[0068]** Angular speed of any of the blades 110, about a respective blade axis 117 can be increased during the rotation phase to increase thrust. Angular speed of any blade, about its axis 117, can also be changed to decrease drag of the blade 110 in the water 115 when the vessel 101 is moving.

**[0069]** The blades 110 are controlled individually to accomplish desired vessel dynamics - e.g., vessel speed vector, thrust, and attitude. The map, or algorithm, can also be configured to control the vessel to lower or minimize drag created by one or more of the blades 110 against the water 115, to improve fuel efficiency, and the like.

**[0070]** In a contemplated embodiment, thrust created by each blade 110, and/or an amount of drag caused by each blade 110 moving through the water 115, can also be affected by posture or position of the blade 110 with respect to the disc 106 - e.g., tilt angle of the blade axis 117. Any one or more of the blades 110 can be moved selectively so that a lower, distal, tip 114 of the blade 110 moved radially outward, farther from the main system axis of rotation 107.

**[0071]** Each blade can be moved in more than one manner at a time, as mentioned. A blade can be tilted (i.e., changing an angle of the blade axis 117 with respect to the main system axis 107), e.g., while it is being rotated about its blade axis 117. And the blade can be tilted while being rotated about its blade axis, and both at the same time that the blade is being moved with the other blades about the main system axis. The blade can also be translated, as a whole, toward or away from the main system

axis 107 while the blade is being moved in another way, such as being rotated about its axis 117 and/or by tilting - changing an angle of the blade axis 107 with respect to the system main axis 117.

**[0072]** In one embodiment, the system 100 or at least the vessel 101 includes a thrust plate 116. The plate 116 is in the illustrated embodiment suspended below the vessel 101 and positioned just below the tips 114 of the blades 110.

**[0073]** In a particular contemplated embodiment, posture of each blade 110 can also be controlled by the controller, implementing the control map, or algorithm, based on any of the controller inputs described herein. The controller and control map or algorithm are described further below regarding FIGs. 3 and 4.

**[0074]** The individual cycloidal-system blade control of the present technology, using an electric drive controlling each of multiple cycloidal propeller blades, e.g., allows complex and fine control of blade angles. The blades can be controlled to accomplish benefits including desired vessel dynamics, such as mooring, translating, or linear movement - e.g., straight forward, reverse, or sideways motion.

**[0075]** The blade control can, as referenced above, be performed, according to the control map, in ways to reduce drag. Drag can be reduced, e.g., by controlling individual blades separately so that each blade 110 creates a limited amount of friction with the water 115 through which the blades 110 are moving.

**[0076]** The map can be configured to cause each blade 100 to, at every instance, be positioned and/or moved to create a desired thrust while minimizing drag created by the blade. The map can be configured to cause each blade 100 to, at every instance, be positioned and/or moved to minimize drag while not performing a thrust-creating action at the moment.

**[0077]** An individual-blade-control arrangement also improves system response by limiting intermediate structure between the drive 102 and the lower disc 106, such as the complex mechanical gearing and sliders of the conventional VSP arrangements. In this way, time is limited between an input signal, initiated by a system controller or vessel operator, and resulting blade positioning or motion.

#### Figure 2 - Cycloidal Propulsion System in More Detail

**[0078]** FIG. 2 is a cut-away of the system 100 of FIG. 1. The embodiment shown includes upper bearings 202 and lower bearings 204.

**[0079]** The upper bearings 202 facilitate turning of the main shaft 104, or structure connected rigidly to the axis 104, with respect to adjacent static structure. The upper bearings 202 are positioned between an upper inner edge 206 connected rigidly to the main shaft 104 and an upper outer edge 208 connected to framing of the vessel 101.

**[0080]** The lower bearings 204 facilitate turning of the

main axis 104, or moving structure connected rigidly to the main shaft 104, with respect to adjacent static structure. The lower bearings 204 are positioned between, for instance, a lower inner edge 210 connected rigidly to the main shaft 104 or disc 106, and a lower outer edge 212 connected to adjacent framing of the vessel 101.

Figure 3 - Computer System

**[0081]** FIG. 3 is a schematic diagram of a computing device 300 for use in performing functions of the present technology. The device 300 is configured to control various functions of the system 100, and can also be referred to as a controller.

**[0082]** Although connections are not shown between all of the components illustrated in FIG. 3, the components can interact with each other to carry out computer system functions.

**[0083]** The computer device 300 includes a memory, or computer-readable medium 302, such as volatile medium, non-volatile medium, removable medium, and non-removable medium. The term computer-readable media and variants thereof, as used in the specification and claims, refer to tangible or non-transitory, computer-readable storage devices.

**[0084]** In some embodiments, storage media includes volatile and/or non-volatile, removable, and/or non-removable media, such as, for example, random access memory (RAM), read-only memory (ROM), electrically erasable programmable read-only memory (EEPROM), solid state memory or other memory technology, CD ROM, DVD, BLU-RAY, or other optical disk storage, magnetic tape, magnetic disk storage or other magnetic storage devices.

**[0085]** The computer device 300 also includes a computer processor 304 connected or connectable to the computer-readable medium 302 by way of a communication link 306, such as a computer bus.

**[0086]** The processor could be multiple processors, which could include distributed processors or parallel processors in a single machine or multiple machines. The processor can be used in supporting a virtual processing environment. The processor could include a state machine, application specific integrated circuit (ASIC), programmable gate array (PGA) including a Field PGA, or state machine. References herein to processor executing code or instructions to perform *operations, acts, tasks, functions, steps*, or the *like*, could include the processor performing the operations directly and/or facilitating, directing, or cooperating with another device or component to perform the operations.

**[0087]** The computer-readable medium 302 includes computer-executable instructions, or code 308. The computer-executable instructions 308 are executable by the processor 304 to cause the processor, and thus the computer device 300, to perform any combination of the functions described in the present disclosure.

**[0088]** The instructions 308 include instructions or

code 309 for controlling operation of the system 100 (FIGs. 1 and 2). The code 309 routes, or maps, various conditions, indicated by conditions of the vessel 101 to output commands for one or more controllable components of the system 100. The code 309 may be referred to as a control map, mapping code, routing code, decision, and includes various algorithms defining any desired relationships between conditions and respective commands.

**[0089]** Example input to the control map 309 includes those referenced above, such as any one or combination of: output from the on-blade or adjacent-blade angle sensors; output from main assembly angle sensor(s); system power being used; system power available; present vessel speed; vessel speed desired or requested (by, e.g., command of a vessel operator or the controller 300); wind speed; ambient water temperature; water depth; heading or position desired or requested (by, e.g., command of a vessel operator or the controller 300); a type or characteristic of the vessel 101; a propulsion layout; vessel-captain command; controller auto-generated command, etc.

**[0090]** The control map 309 in one embodiment includes mapping, to one or more appropriate outputs, any of various combinations of such inputs and indications communicated by the inputs. Example indications include whether a device or condition is present/not present, on/off, percentages (e.g., percentage of vessel power being used or available), levels (e.g., vessel speed, water temperature), amounts (e.g., remaining batter power), and/or other values (e.g., angular, linear, or other position relating to the main axis 104 or any propeller blade(s) 110).

**[0091]** Outputs include commands or signals instructing operation of one or more components of the system 100. The controllable components can include the main system drive 102 controlling rotation of the main axis 104. As mentioned, the main drive 102 in one embodiment includes an electric drive linked directly to the main axis 104. Aspects of the main axis 104 controlled include primarily direction of rotation and speed of rotation. The main axis rotation affects directly rotation of the blade-mounting disc 106, and so rotation of all of the blades 110, about the main system axis 107.

**[0092]** The controllable components can also include each of the propeller blades 110. In these embodiments, the blades 110 are configured and connected to the mounting structure or disc 106 to be moved independently of any motion or non-movement of any of the other blades. For instance, the configuration and arrangement allows the controller 300 to affect counter-clockwise rotation, about its axis 117, of a first of the blades 110, at a first speed, while adjacent blades 110 are kept from rotating about their axes 117, rotated clockwise, or rotated counter-clockwise at a different speed, etc.

**[0093]** The blades 110 are in some embodiments also configured and connected to the mounting structure or disc 106 to be moved independently of any motion, non-

movement, or rotational position of the vertical main assembly

**[0094]** The mapping code 309 can be arranged in any manner connecting various inputs (e.g., vessel-captain commands and water conditions) with pre-set corresponding outputs (operational signals to system components). The mapping code 309 is in one embodiment arranged in an array format, such as a matrix, connecting various conditions (e.g., inputs) to corresponding outputs (e.g., component-specific control commands).

**[0095]** As a simple example of an output (e.g., control command) corresponding in the map 309 to a base condition (e.g., inputs), the input can include the controller 300 or the vessel operator issuing, while the vessel is not creating, or not to be creating, thrust (e.g., gliding to a dock), a command requesting or relating to a desire to limit drag. The command can include or be related to a request for power or energy savings. Output in this example could include a command to the main drive 102 to stop (if not already stopped) and a command to one or any combination including all blades 100 to align to a present or desired vessel direction (i.e., so that main lateral portions of the blade(s) are facing perpendicular to the present or desired direction) so that the blades create limited drag as they are moving through the water 115 with the vessel 101. This may be an appropriate request, and resulting command, for situations in which a vessel (e.g., ferry) is approaching a stop at a slow speed sufficient for the vessel to reach a destination (e.g., dock being approached) if drag is minimized. In this scenario, power and energy (e.g., fuel) are saved.

**[0096]** As another power/energy-saving example, a vessel operator, or the controller 300, can issue a command for power or energy saving vessel movement. The movement can include starting vessel movement in any desired direction - linear and/or turning. In the linear-movement example, the cycloid system 100 can be used to create linear vessel movement in any direction.

**[0097]** Because drag limits vessel movement, vessel speed can be maintained or reached with less thrust if drag is lowered. Thus, for energy saving mode, the vessel speed can be increased simply by reducing drag, without increasing rotation speed of the main axis (and so discs 106 and blades 110 in their collective rotation about the axis 107). Reducing drag can be accomplished by controlling each blade 110, independently, to at all times have a position that limits drag under the circumstances, such as to limit drag while also being moved to create the existing thrust level.

**[0098]** While a control variable can include a rotational position of the blade 110 about the main axis 107, the system is in some embodiments, as mentioned also configured so that each blade can be moved independently of any motion, non-movement, or rotational position of the vertical main assembly.

**[0099]** One or more of the blades may at times be moved in the same manner, but generally each blade would be controlled to move and be positioned differently

in this scenario. Such independent control is impossible using conventional cycloidal systems in which operation of each cycloid blade is linked to movement of the other blades by complex mechanical gearing.

**[0100]** Blade adjustment can include controlling direction and rate of blade rotation about its axis 117.

**[0101]** Blade adjustment can instead or also include controlling a pitch or tilt of the blade 110 - e.g., tilting the blade and its axis 117, such as by moving a lower tip of the blade outward, away from the main system axis 107.

**[0102]** Thrust created by a blade 110 can be increased by adjusting or controlling any one or more of blade movement or position about its axis 117, its movement or position about the main axis 107, and a tilt angle of the blade (e.g., tilting the blade so a lower tip is moved away from or toward the main system axis 107).

**[0103]** At the same time or separately, drag created by a blade 110, moving through the water 115, can be reduced by adjusting or controlling any one or more of blade movement or position about its axis 117, its movement or position about the main axis 107, and a tilt angle of the blade (e.g., tilting the blade so a lower tip is moved away from or toward the main system axis 107).

**[0104]** In a contemplated embodiment, system 100 is configured so that the blade 110 may be moved in its entirety away from the main axis to accomplish desired results (e.g., increasing thrust and/or reducing drag). The disc 106 or structure connected thereto would in this case be arranged to that each blade, or every blade together, can be moved away from the main axis 107. The lower tip of the blade 110 can be moved away from or toward the main axis 107 by an equal amount that an upper tip of the blade 110 is moved away from or toward the axis 107, so that the blade axis 117 angle is kept constant in the motion. Or the blade axis 117 can angle can change in the motion, such as by the lower tip 114 being moved out more slowly than an upper tip of the blade 110.

**[0105]** Drag created by each blade 110 is reduced when, e.g., each blade 110 is controlled to an optimum rotational position (i.e., about its axis 107) vertical position according to an absolute rotational position of the main assembly relative to the intended thrust direction. The reduction of drag can be achieved by modifying the local blade rotational position as the main assembly absolute position alters.

**[0106]** As a related energy-saving example, linear vessel speed can be maintained while less power/energy is used. Due to the drag characteristics mentioned above, linear speed of the vessel 100 can be maintained while one or more aspect of the system 100 can be slowed, e.g., rotation of the main axis 104, simply by adjusting the blades in real time to reduce drag.

**[0107]** The control map is configured to optimize the drag reduction according to factors such as vessel direction, speed, and desired speed based on inputs such as those from ship sensors including those sensing parameters including attitude in roll, pitch, and yaw. In some implementations, a greatest drag reduction effect is gen-

erated as part of providing, by blade control, steering and speed required. It will be appreciated that the blades providing thrust are not limited to providing thrust and steering functions - e.g., the blades moving in a forward direction, meaning returning towards the thrust provision position, can be used to provide direction thrust. This division of duties means that the blades may be more or less active during main assembly vertical axis positional change. In some instances, such as when the vessel is in deep water, or at full-away, the position of the vessel will need correcting without reduction in thrust.

**[0108]** The term 'full-away' refers to conditions, when operating a ship, wherein the ship is clear of navigation obstacles, and the propulsion system of the ship can be operated to any desired power level desired - e.g., a level to match a mission profile. On ferries, full-away can involve the conditions allowing the ferry to operate at full power. Full-away can also refer to such operation of the ship (e.g., without limits, at full power, etc.). On liners, full-away could include the liner operating according to a schedule at a power level of between about 30 and about 100% of full load depending on factors such as distance between ports, weather, and so on. Full-away can also refer to operation of the propulsion system under conditions will not change notably in substantive ways during the voyage (e.g., during a full-away portion of the voyage) until nearing shore or navigation obstacles.

**[0109]** The computer system 300 further comprises an input/output (I/O) device 310, or communication interface, such as a wireless transceiver and/or a wired communication port. The processor 304, executing the instructions 308, receives input from any of a wide variety of input sources 312 and provides output to any of a wide variety of outputs 314.

**[0110]** Example input devices 312 include a temperature sensor (air, water, engine, motor, etc.), main-axis-shaft rotation-speed sensor, blade-position sensor, blade-rotation-speed sensor, other blade-position or movement sensor, vessel-speed sensor, the controller itself (providing, e.g., a command or other input by the processor from one portion of instructions (e.g., map 309 or other code 308) to another (e.g., the map 309), system power sensor or indicator, (by, e.g., a command of a vessel operator or the controller 300 (FIG. 3)), wind-speed sensor, water-depth sensor, vessel-heading or position (e.g., GPS) sensor or indicator, data indicating a characteristic (e.g., an intrinsic feature) or type of the vessel 101, a sensor or indicator expressing data about vessel propulsion layout, data from a vessel-captain, etc.

**[0111]** Communications to/from the device 310 can be in the form of signals, messages, or packetized data, for example. The device 310 can include one or more transceivers, transmitters, and/or receivers. The device 310 can include wired and/or wireless interfaces for communicating with the input and output components 312, 314.

Figure 4 - Methods of Operation

**[0112]** FIG. 4 is a flow chart showing operations of a method 400 performed by the present technology, according to an embodiment of the present disclosure.

**[0113]** Operations, or steps, of the method 400 are not necessarily presented in any particular order and that performance of some or all the steps in an alternative order is possible and is contemplated. The steps have been presented in the demonstrated order for ease of description and illustration. Steps can be added, omitted and/or performed simultaneously without departing from the scope of the appended claims.

**[0114]** The illustrated method 400 can be ended at any time. In certain embodiments, some or all steps of this process, and/or substantially equivalent steps are performed by execution of computer-readable instructions, such as the instructions 308 including the control map 309, stored or included on a computer readable medium, such as the memory 302 of the controller 300.

**[0115]** The method 400 begins 401 and flow proceeds to block 402, whereat the controller obtains a vessel-kinematic, or motion or movement, command. Though the command is termed a kinematic, or movement or motion, command, and while the command can include initiating a vessel motion different than a current motion, the vessel-kinematic command can also be configured to (i) maintain an existing vessel motion, such as a current speed or direction, to (ii) stop the vehicle in any one or more directions (angular or linear), or to (iii) maintain a non-motion state.

**[0116]** The obtaining operation can include receiving the command, being pushed to the processor 304. In one implementation, the obtaining includes the processor 304 retrieving the command - e.g., requesting and receiving the command.

**[0117]** The command in some cases is generated by the controller 300 - i.e., by the processor 304 executing instructions 308. The command can be generated, e.g., in response to a determination by the controller 300 that a vessel speed and/or direction change is needed, such as to maintain a pre-set vessel course or to avoid an obstacle.

**[0118]** The command can also be initiated by an order of a vessel operator, such as from a vessel captain selecting a hard or soft button indicating a power-saving or energy-saving mode, moving a soft or hard control for changing vessel direction, and/or moving a soft or hard vessel control for changing vessel speed.

**[0119]** At step 404, the controller accesses and processes the control map 309. At step 406, the processor 304, executing the control map 309, obtains (e.g., receives or retrieves) input data to be used in processing the control map 309. Some or all of the inputs may already be present before or when the processor 304 accesses the control map 309, and some or all of the inputs may be retrieved by the processor 304 in response to determining the input(s) is/are needed in processing the con-

trol map.

**[0120]** The inputs may be received from any of a wide variety of sources without departing from the scope of the present technology. The inputs can be received from the processor 304 executing certain aspects of the instructions, even of the control map 309. The inputs can be received from other electronic components of the vessel 100, such as any of the sensors described herein (vessel-speed, vessel-attitude, vessel-location, blade-rotation-speed, water-temperature, water-depth, etc.), or the like.

**[0121]** The processor 304, executing the control map 309, determines (e.g., generates), based on the inputs received, one or more ways to adjust or maintain operation of at least one vessel component. Block 408 represents an example by which the processor 304, executing the map 309, determines a command for controlling (e.g., changing or maintaining) a rotational velocity of the main axis 104.

**[0122]** Block 410 represents another example, by which the controller, executing the map 309, determines (e.g., generates) one or more commands for controlling (e.g., changing or maintaining) a position and/or rotational velocity (about blade axis 117) of a blade 110. The step 410 is in some implementations performed separately for each blade 110. The separate performance can be made substantially simultaneously.

**[0123]** In some implementations, while each blade 110 is controlled independently, as mentioned, the controller determines the one or more commands for controlling position or rotational velocity of more than one blade at generally the same time.

**[0124]** At block 412, the main-axis command determined (indicating, e.g., an instruction to increase main-axis speed by 2 revs/min.) is provided to the main-axis driver 102 for maintaining or changing a rotational characteristic of the main shaft 104.

**[0125]** At block 414, the blade command determined (e.g., indicating an instruction to increase blade rotation about the blade axis 117) is provided to a blade actuator 108 (e.g., independent electric motor) for maintaining or changing a positional and/or movement characteristic (e.g., increasing blade rotation) for the blade 110.

**[0126]** As with previous step 410, the present operation 414 is in some implementations performed separately for each blade 110. The separate performance can be made substantially simultaneously. In some implementations, while each blade 110 is controlled independently, via its respective actuator (e.g., independent electric motor), as mentioned, the processor 304 can generate commands for controlling position or rotational velocity of more than one blade at generally the same time, and commands for various blades can be related. As mentioned, for instance, actuators 108 can be controlled to move their respective blades 110 according to some relationships - e.g., each blade is controlled to be positioned 20 degrees further in its rotation, about its blade axis 117, than a preceding adjacent blade 110 of the blades 110

on the disc 106.

**[0127]** At operation 416, the controller determines whether a new vessel-kinematic command (VKC) is present. In some embodiments, the operation 416 includes a passive function of receiving, or not receiving, a new VKC. As provided, while the command (VKC) is termed a kinematic, or movement or motion, command, and while the command can include initiating a vessel motion different than a current motion, the vessel-kinematic command can also be configured to (i) maintain an existing vessel motion, such as a current speed or direction, to (ii) stop the vehicle in any one or more directions (angular or linear), or to (iii) maintain a non-motion state.

**[0128]** If there is no new VKC, flow proceeds along return route 417 to steps 404 *et seq.*, such as for any further processing and any new output determinations that need to be made or provided in order to maintain, reach, or get closer to reaching a desired vessel state. Such subsequent iterations of the method 400 can include obtaining new (e.g., different) and/or updated sensor data at block 406.

**[0129]** In response to a new VKC, such as from the controller or vessel electronics triggered by a vessel operator, at block 418, the new VKC is accepted, stored in cache or other memory as a current VKC, or otherwise processed by the processor 304 to give effect to the new VKC.

**[0130]** Following receiving the new VKC, flow proceeds along return route 419 to steps 404 *et seq.*, such as for any further processing and any new output determinations that need to be made or provided in order to maintain, reach, or get closer to reaching a desired vessel state. As shown by the figures, such subsequent iterations of the method 400 can include obtaining new (e.g., different) and/or updated sensor data at block 406.

**[0131]** The process 400 can be repeated, such as to effect one or more VKCs over time. The process 400 can be ended 421, such as by turning the controller 300 or the system 100 off, or a vessel operator selecting an off or sleep-mode.

#### Benefits and Advantages

**[0132]** This section elaborates on benefits of the present technology described above. Benefits are achieved by the controls described herein. The control features include controlling any or all of individual-blade position, individual-blade motion, main-axis-shaft position, and main-axis-shaft motion.

**[0133]** These controls can be achieved using, e.g., individually-controllable blades, electric-motor blade actuators, and a direct-drive (e.g., electric motor) for main-shaft control.

**[0134]** One of the primary advantages of the present technology is an ability to lower power and energy used by a marine cycloidal-propulsion system. As mentioned, noise (e.g., underwater noise and/or noise passed to the air) can also be reduced, as well as vibrations through

the water, vessel, etc. The savings result in more-efficient fuel consumption, lowered fuel cost (capital cost of operation), lower emissions, and extended ship range on the same amount of fuel.

[0135] Technical advantages of the present technology include an ability to achieve greater speeds, including greater speeds at an equivalent power expenditure, by reducing drag.

[0136] Another technical advantage includes improved vessel maneuverability. Improved vessel maneuverability is achievable by the ability to control each blade 110 individually in real time.

[0137] Another benefit of the technology is a greater flexibility in designing vessels. The flexibility results from the greater maneuverability and speeds achievable by vessels incorporating the present technology. As a result, the vessel can be designed in previously unachievable ways without sacrificing maneuverability or speed.

[0138] The flexibility can also result from an ability to use any of a variety of drives, such one or more diesel and/or electric motors to control the main drive shaft, and a distinct controllable electric motor for each of the plurality of cycloidal propeller blades.

#### Conclusion

[0139] Alternative embodiments, examples, and modifications that would still be encompassed by the technology may be made by those skilled in the art, particularly in light of the foregoing teachings. Further, it should be understood that the terminology used to describe the technology is intended to be in the nature of words of description rather than of limitation.

[0140] Those skilled in the art will also appreciate that various adaptations and modifications of the preferred and alternative embodiments described above can be configured without departing from the scope and spirit of the technology. Therefore, it is to be understood that, within the scope of the appended claims, the technology may be practiced other than as specifically described herein.

#### Claims

1. A cycloidal marine-propulsion system (100), comprising:

a blade-mounting disc (106);  
 a plurality of propeller blades (110A-E), each having a respective primary blade axis (117) and being connected to the disc (106) in a manner allowing the blade (110) to be rotated about its primary blade axis (117) independent of any about-axis rotation of every other one of the propeller blades (110);  
 a plurality of electric actuators (108A-E), each actuator (108) being connected to a respective

one of the propeller blades (110); and  
 a controller (300) in communication selectively with each of the electric actuators (108) for controlling each of the actuators (108).

2. A cycloidal marine-propulsion system (100) according to claim 1, wherein the controller (300) includes computer-executable instructions, comprising a control map, that, when executed by a processor of the controller, cause the processor to control separately each of the electric actuators (108) according to the control map, wherein the control map optionally includes code that, when executed by the processor, produces output, used in controlling separately each of the electric actuators (108), based on at least one data input selected a group consisting of:

on-blade sensor data;  
 adjacent-blade-angle-sensor data;  
 main-assembly-angle-sensor data;  
 present system-power data;  
 available-system-power data;  
 present vessel-speed data;  
 requested-vessel-speed data;  
 wind-speed data;  
 ambient-water-temperature data;  
 present-vessel-heading data;  
 requested-vessel-heading data;  
 present-vessel position data;  
 requested-vessel-position data;  
 water-depth data;  
 water-current data;  
 vessel-type data;  
 propulsion-layout data;  
 vessel-captain command; and  
 controller auto-generated command.

3. A cycloidal marine-propulsion system (100) according to claim 2, further comprising:

a primary vertical-axis drive shaft (104) connected to the lower disc (106); and  
 a primary-axis drive (102) connected to the drive shaft (104) for turning the shaft and, thereby, turning the lower disc (106);  
 wherein the computer-executable instructions, comprising the control map, when executed by the processor, cause the processor to control operation of the primary-axis drive (102) according to the control map; or  
 wherein the controller (300) is in communication with the primary-axis drive (102) for controlling the drive according to the control map.

4. A cycloidal marine-propulsion system (100) according to claim 1 or claim 2, further comprising:

a primary vertical-axis drive shaft (104) connect-

- ed to the lower disc (106); and  
a primary-axis drive (102) connected to the drive shaft (104) for turning the shaft and, thereby, turning the lower disc (106);  
wherein the primary-axis drive (102) includes an electric motor connected directly to the primary vertical-axis drive shaft (104).
- 5
5. A cycloidal marine-propulsion system (100) according to any preceding claim, wherein each of the plurality of propeller blades (110A-E) is connected to the disc (106) in a manner allowing the blade (110) to tilt independent of any tilting of every other one of the propeller blades (110), and wherein the controller (300) optionally includes computer-executable instructions, comprising a control map, that, when executed by a processor of the controller, cause the processor to control separately each of the electric actuators (108), to control blade tilt independently, according to the control map.
- 10
6. A cycloidal marine-propulsion system (100) according to claim 1 or claim 2, further comprising:
- 15
- a primary vertical-axis drive shaft (104) connected to the lower disc (106);  
wherein each of the plurality of propeller blades (110A-E) is connected to the disc (106) in a manner allowing the blade (110) to be rotated about its primary blade axis (117) independent of any about-axis rotation, non-rotation, and position of the primary vertical-axis drive shaft (104).
- 20
7. A method, for controlling a cycloidal-machine-propulsion system (100) being used in a marine vessel, the method comprising the steps of:
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- obtaining, by a processor of a controller (300), a vessel-kinematic command;  
accessing, by the processor, a control map;  
obtaining, by the processor, input data indicative of at least one present condition associated with the vessel;  
determining, using the vessel-kinematic command, the control map, and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades (110A-E); and  
transmitting the blade-control commands to multiple actuators (108A-E) connected to respective ones of the cycloidal propeller blades (110A-E).
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8. A method according to claim 7, wherein the vessel-kinematic command indicates a request to stop the vessel, maintain a present motion characteristic of the vessel, or to maintain a present non-motion characteristic of the vessel.
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9. A method according to claim 7, wherein:
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- the vessel-kinematic command is a previous vessel-kinematic command; and  
the method further comprises determining whether a new vessel-kinematic command is present, and acting on the new vessel-kinematic command if present.
- 45
10. A method according to any of claims 7 to 9, further comprising the steps of:
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- determining, using the vessel-kinematic command, the control map, and input data, a main-axis-drive-control command for controlling a main-axis drive (102) of the system (100); and  
transmitting the main-axis-drive-control commands to the main-axis drive (102).
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11. A method according to any of claims 7 to 10, wherein the blade-control commands requests at least one change selected from a group consisting of:
- a change of position of the respective blade (110);  
a change to a blade rotation about a blade-axis (117); and  
a tilting of the blade (110).
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12. A method according to any of claims 7 to 11, wherein:
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- the vessel includes a primary vertical-axis drive shaft (104);  
each of the plurality of propeller blades (110A-E) is connected to the disc (106) in a manner allowing the blade (110) to be rotated about its primary blade axis (117) independent of any about-axis rotation, non-rotation, and position of the primary vertical-axis drive shaft (104); and  
wherein the step of:  
determining, using the vessel-kinematic command, the control map, and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades (110A-E), includes determining blade-control commands for controlling the blades (110A-E) wherein each blade (110) is not limited mechanically to only one blade position based on about-axis rotational movement, non-movement, and position of the primary drive shaft (104).
- 70
13. A method, for controlling a cycloidal-machine-propulsion system (100) being used in a marine vessel, the method comprising the steps of:
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- accessing, by a processor, a control map;  
obtaining, by the processor, input data indicative

of at least one present condition associated with the vessel;  
determining, using the control map and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades (110A-E), wherein the blade-control commands optionally request at least one of a change to a blade rotation about a blade axis (117) and/or a tilting of the blade (110); and transmitting the blade-control commands to multiple actuators (108A-108E) connected to respective ones of the cycloidal propeller blades (110A-E).

14. A method according to claim 13, further comprising the steps of:

determining, using the control map and the input data, a main-axis-drive-control command for controlling a main-axis drive (102) of the system (100); and transmitting the main-axis-drive-control commands to the main-axis drive (102).

15. A method according to claim 13 or claim 14, wherein:

the vessel includes a primary vertical-axis drive shaft (104);  
each of the plurality of propeller blades (110A-E) is connected to the disc (106) in a manner allowing the blade (110) to be rotated about its primary blade axis (117) independent of any about-axis rotation, non-rotation, and position of the primary vertical-axis drive shaft (104); and wherein the step of:  
determining, using the vessel-kinematic command, the control map, and the input data, distinct blade-control commands for controlling independently each of multiple cycloidal propeller blades, includes determining blade-control commands for controlling the blades (110A-E) wherein each blade (110) is not limited mechanically to only one blade position based on about-axis rotational movement, non-movement, and position of the primary drive shaft (104).

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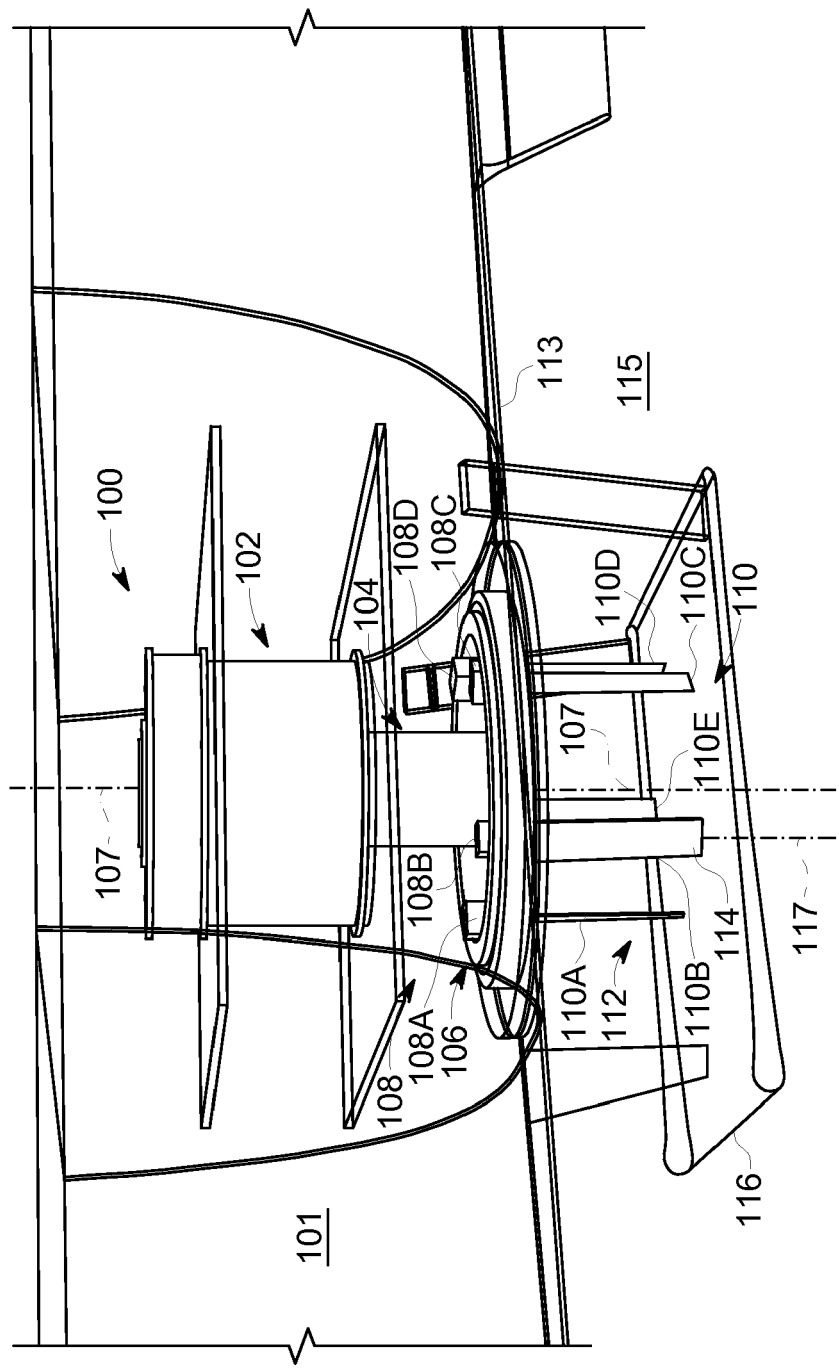
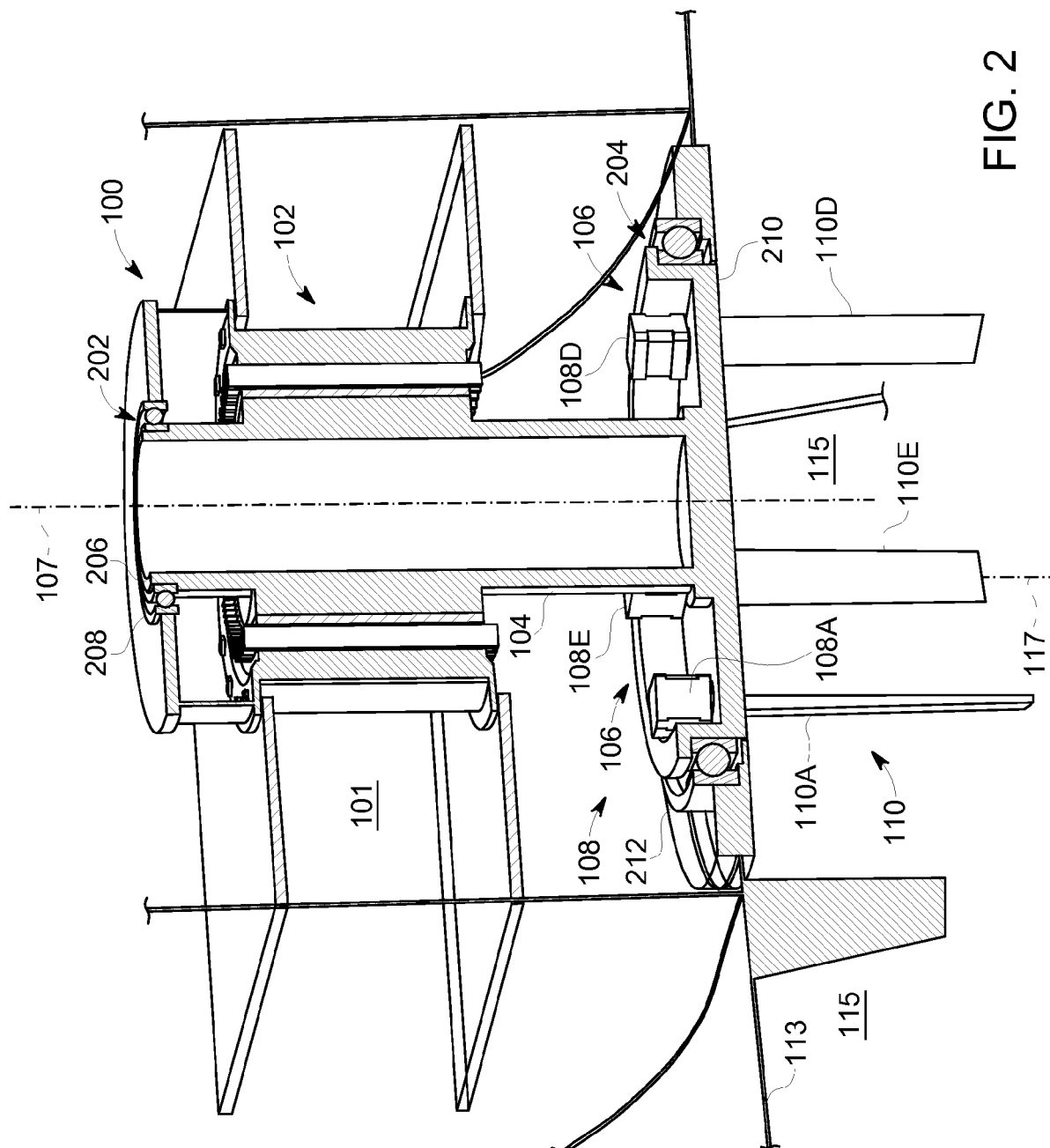


FIG. 1



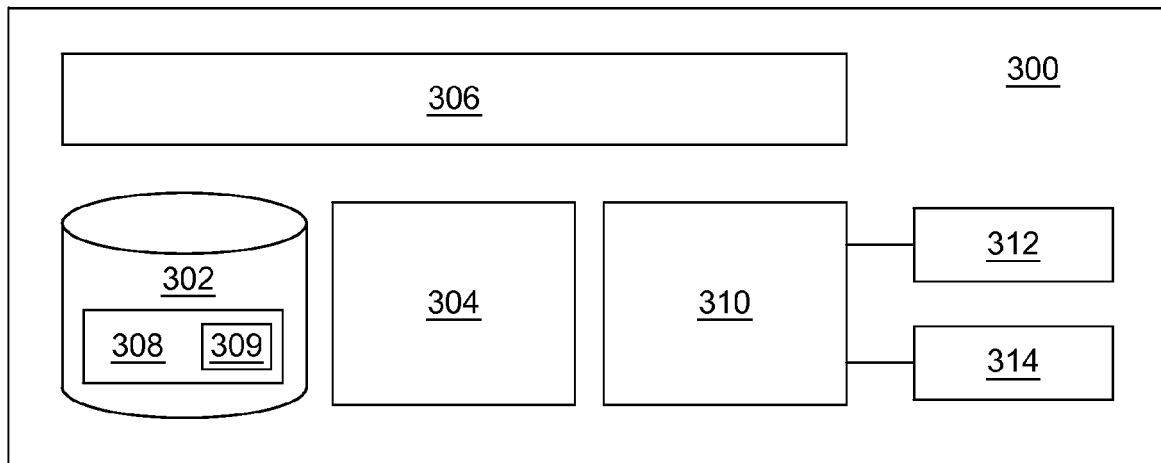


FIG. 3

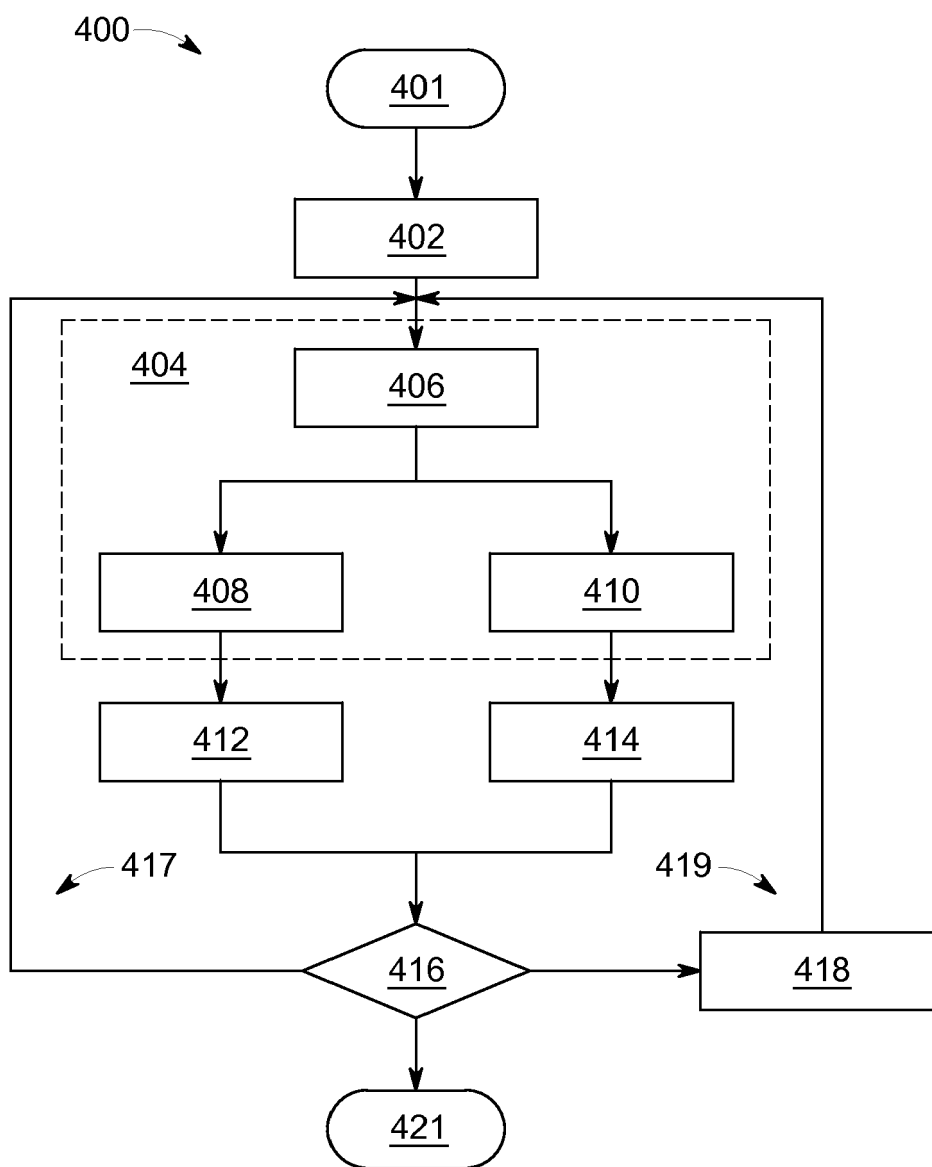


FIG. 4



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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                              |                                  |                                         |
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