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(54) METHOD AND APPARATUS FOR CONTROLLING THE TURNING OF A HYDROFOIL.

(57) Method for controlling the turning of a hydrofoil (1), such method providing for: a first step for detecting a required turn angle (a) and a generation of a corresponding turn signal (SV); a step for detecting the variations of linear acceleration, the variations of angular speed, the tilts and the advancing speed of the hydrofoil (1) and a generation of corresponding acceleration signals, angular speed, tilt and linear speed (SA, SVA, SI, SVL); a first calculation step, as a function of the turn signal (SV), of an ideal turn position (PVI) for each appendage (4) of the hydrofoil (1); a second calculation step, as a function of the acceleration signals, angular speed, tilt and linear speed (SA, SVA, SI, SVL), of first corrective factor (FC1) for each appendage (4); a processing step, in which each ideal turn position (PVI) is corrected by the first corrective factor (FC1) in order to obtain a corrected turn position (PVC) for each said appendage (4); a step for driving first actuator means (5) to move each appendage (4) around a corresponding first rotation axis (Y) in order to reach the corresponding corrected turn position (PVC).

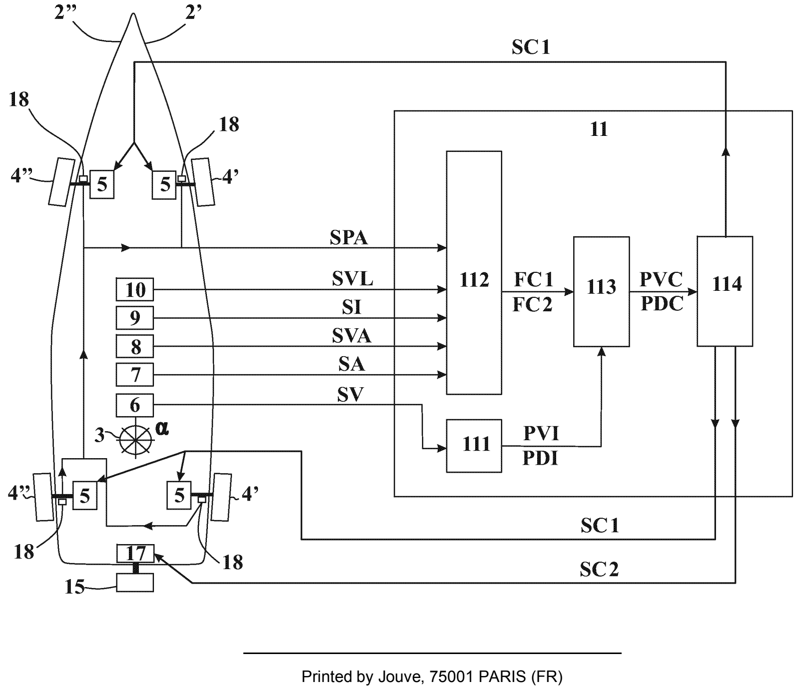

Fig. 5

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Description

Field of application

[0001] The present invention regards a method for controlling the turning of a hydrofoil, a hydrofoil and an apparatus for controlling the turning of said hydrofoil, according to the preamble of the respective independent claims.

[0002] The method, the hydrofoil and the control apparatus of the present invention are intended to be advantageously employed in the nautical field for automatically controlling the turning of the hydrofoil itself.

[0003] More particularly, the method, object of the present invention, allows the automatic control of the course and it is advantageously employable for detecting turn requests executed by a pilot of the hydrofoil and for automatically driving a corresponding movement of the appendages of the hydrofoil itself so as to execute the requested turning.

[0004] The invention is therefore inserted in the industrial field of the nautical industry, both in the context of production of hydrofoils and accessories thereof and in the context of the use of such hydrofoils.

State of the art

[0005] Known on the market are new boats, also termed "hydrofoils", which are provided with appendages mounted on the hull of the boat and projecting below with respect to such hull for the purpose of being at least partially immersed in water.

[0006] During use, such appendages are capable of interacting with a water flow in which they advance, converting the pressure resulting from the relative speed between that of advancement of the hydrofoil and that of the water flow into a lift force directed upward. In particular, the greater the advancing speed of the hydrofoil on which such appendages are mounted, the greater the resulting lift force applied to the appendages, which lifts the hull from the free surface of the water.

[0007] More in detail, once a predetermined value of advancing speed has been exceeded, the generated lift force exceeds the weight force of the hydrofoil and the hull of the latter if lifted from the free surface of the water up to completely emerging and obtaining a navigation condition termed "foilborne".

[0008] Such foilborne navigation allows numerous advantages. In particular, during foilborne navigation, only the appendages are immersed in water and the hydrofoil navigates with a smaller surface area with respect to a "conventional" navigation, in which also the hull is at least partially immersed in water.

[0009] The aforesaid smaller immersed surface area involves a lower hydrodynamic resistance of the water on the hydrofoil and allows the hydrofoil to reach higher navigation speeds, given the same installed motor power.

[0010] One example of hydrofoil of known type is described in the document US 3886884. The hydrofoil described herein is provided, in a per se conventional manner, with a hull intended to advance on the water in a first navigation condition of conventional type, i.e. with at least one portion of such hull immersed in water.

[0011] The aforesaid hydrofoil of known type also comprises two appendages, intended to be immersed in water in order to allow the hydrofoil to navigate also in a second condition, i.e. in foilborne condition.

[0012] More in detail, the hydrofoil of known type is provided with a bow appendage and with a stern appendage, which are mounted on the hull so as to project below the hull itself in order to be immersed in water and they are spaced from each other along a main extension direction of the hull itself.

[0013] In particular, the bow appendage is rigidly mounted on the rudder blade of the hydrofoil and it is intended to always be immersed.

[0014] Otherwise, the stern appendage is rotatably mounted on the hull in proximity to its stern and is susceptible of being moved with respect to the hull itself. More in detail, the stern appendage is extended transversely to the hull, from port to starboard, and is movable around a rotation axis orthogonal to the main extension axis of the hull itself and substantially horizontal.

[0015] In particular, the aforesaid stern appendage is movable between a lifted position, in which the appendage is substantially side-by-side the hull and the hydrofoil is susceptible of navigating in a conventional manner, and a lowered position, in which the appendage projects below with respect to the hull and the hydrofoil is susceptible of navigating, once the speed threshold value has been exceeded, in foilborne condition.

[0016] More in detail, in the aforesaid lifted position, the stern appendage of the hydrofoil of known type is horizontal, side-by-side the hull and it completely emerges from the water so as to not interact with the water flow lines and not generate lift.

[0017] In this situation, the hull remains at least partially immersed, allowing the aforesaid navigation of conventional type.

[0018] Otherwise, in the lowered position, the stern appendage is vertical, projects below the bottom wall of the hull and is completely immersed in water so as to interact with the water flow lines and generate lift.

[0019] In order to allow a greater control of the stability of the hydrofoil, i.e. so as to maintain it substantially always horizontal during the entire navigation, the hydrofoil described in US 3886884 is also provided with movable terminations mounted on the bow and stern appendages. More in detail, each bow and stern appendage has substantially flat shape, and is placed horizontal when the appendage is immersed in water. The aforesaid terminations comprise plates mounted on the appendages at a rear edge thereof, i.e. directed towards the stem, during use in opposite direction with respect to the advancement direction. In addition, the aforesaid terminations are hinged to the corresponding appendage and are susceptible of being moved in order to vary an incidence profile (i.e. the substantially horizontal profile of the appendage which interacts with the water flow in order to convert the pressure of the water into the aforesaid lift force) of the appendage itself with the water flow lines.

[0020] In particular, the variation of the incidence profile involves a different interaction of the appendage with the water flow lines and then involves a different lift force developed by the appendage itself.

[0021] The hydrofoil described in US 3886884 is also provided with an electronic control apparatus programmed for automatically modifying the position of the aforesaid terminations of each appendage, in a manner such to control the stability of the hydrofoil itself.

[0022] More in detail, such control apparatus of known type is provided with a plurality of sensors adapted to detect the distance of the hull from the free surface of the water, the accelerations and the tilts of the hull with respect to the three axes of rolling, pitch and yaw.

[0023] In addition, on the basis of such detected information, the control apparatus is programmed for calculating the position in which the terminations of each appendage are to be placed so as to vary the lift generated by each appendage itself and thus maintain the hydrofoil substantially horizontal during navigation.

[0024] The hydrofoil of known type described briefly up to now and the control method of known type provided in such hydrofoil have in practice demonstrated that they do not lack drawbacks.

[0025] A first drawback lies in the fact that, in foilborne conditions, such hydrofoil of known type is unable to execute sudden turns, e.g. in case of danger.

[0026] Indeed, in foilborne condition, in order to execute the turns it is necessary to vary the lift generated by the appendages in a manner such to slightly submerge the side of the hull towards which it is intended to turn so as to obtain the aforesaid turning.

[0027] In foilborne condition, the appendages of the hydrofoil of known type are fixed with respect to the hull and, in order to vary the lift that they generate, it is possible to move only their respective terminations. Given the reduced size of such terminations with respect to the entire appendage and with respect to the hull, it is clear that a movement of the single terminations does not involve sufficient lift variations to allow sudden turns. Consequently, the turns executed by only moving such terminations result quite slow.

[0028] A further drawback of the control method employed in such hydrofoil is tied to the fact that the movement of the terminations is only calculated as a function of the orientation of the hydrofoil and of its distance with respect to the free surface of the water. Therefore, such method for controlling the turning of known type is unable to also evaluate further factors which affect the turning of the hydrofoil itself.

[0029] In this situation, the control method of known type employed in such hydrofoil provides for varying the position of the terminations always in the same manner, regardless of any other factor, whether inside or outside the hydrofoil, resulting in poor reliability of the control method itself and hence greater accident risk.

[0030] In addition, the movement of the terminations independently with respect to the conditions outside the hydrofoil can lead to amplifying natural jolts to which the hydrofoil is subjected, for example caused by waves which the hydrofoil can intercept during its navigation. It is clear that such amplification of the jolts involves an unpleasant ride for the people on board the hydrofoil, subjected to shakes and jolts.

[0031] In addition, the above-described hydrofoil of known type requires the constant intervention of a pilot, who is capable of evaluating the different conditions inside and outside the hydrofoil and who is capable of intervening during navigation in order to regulate the position of the terminations, as well as for driving an exit from the foilborne condition in case of emergency.

Presentation of the invention

[0032] In this situation, the problem underlying the present invention is therefore that of overcoming the drawbacks manifested by the hydrofoils of known type, by providing a method for controlling the turning of a hydrofoil, a hydrofoil and an apparatus for controlling the turning of said hydrofoil which allow executing turns of the hydrofoil itself in an automatic and reliable manner.

[0033] A further object of the present invention is to provide a method for controlling the turning of a hydrofoil, a hydrofoil and an apparatus for controlling the turning of said hydrofoil which allow executing sudden turns.

[0034] A further object of the present invention is to provide a method for controlling the turning of a hydrofoil, a hydrofoil and an apparatus for controlling the turning of said hydrofoil which allow limiting the jolts to which the hydrofoil is subjected during navigation thereof.

[0035] A further object of the present invention is to provide a method for controlling the turning of a hydrofoil, a hydrofoil and an apparatus for controlling the turning of said hydrofoil which allow even less expert pilots to drive such hydrofoils.

[0036] A further object of the present invention is to provide a method for controlling the turning of a hydrofoil which allows executing turns in a safer manner, even at considerable speeds of the hydrofoil. Indeed, as is known, the hydrofoils of known type, provided with the aforesaid appendages and terminations, must limit the advancing speed so as to ensure a limiting turning space.

[0037] A further object of the present invention is to provide a hydrofoil and an apparatus for controlling the turning of said hydrofoil which is entirely efficient and reliable in operation.

Brief description of the drawings

[0038] The technical characteristics of the invention, according to the aforesaid objects, can be clearly seen in the contents of the below-reported claims and the advantages thereof will be more evident in the following detailed description, made with reference to the enclosed drawings, which represent a merely exemplifying and non-limiting embodiment of the invention, in which:

- Fig. 1 shows a perspective view of a hydrofoil, object of the present invention, in which the hydrofoil is represented with the appendages placed in a lifted position in order to execute a non-foilborne navigation;
- Fig. 2 shows a further perspective view of a hydrofoil, object of the present invention, in which the hydrofoil is represented with the appendages placed in a lowered position in order to execute a foilborne navigation;
- Figs. 3A and 3B respectively show a plan view and a side view of a hydrofoil and of a control apparatus thereof, both the object of the present invention, in which the position is visible at which several sensors of the present control apparatus are mounted;
- Figs. 4A and 4B respectively show a plan view and a side view of a hydrofoil and of a control apparatus thereof, both the object of the present invention, in which the position is visible at which a linear speed sensor of the present control apparatus is mounted;
- Fig. 5 shows a functional block diagram of the control apparatus, object of the present invention.

Detailed description of a preferred embodiment

[0039] With reference to the enclosed drawings, reference number 1 overall indicates a hydrofoil, according to the present invention.

[0040] The hydrofoil 1, during use, is advantageously intended to advance on a body of water along a navigation course, which is intended to be controlled by means of a method for controlling the turning according to the present invention.

[0041] The hydrofoil 1 comprises a hull 2 provided with at least one main extension axis X, which preferably coincides with an advancement direction of the hydrofoil 1 itself along the navigation course.

[0042] The hydrofoil 1 also comprises at least one helm 3, mechanically mounted on the hull 2 and movable into a plurality of positions, each defining a corresponding turn angle α with respect to the main extension axis X.

[0043] In particular, with the term "helm" it must be intended hereinbelow a turn request member, preferably mounted at a driving zone of the hydrofoil 1, e.g. a driving cabin of the hydrofoil 1, and manipulatable by a pilot so as to drive a turning of the hydrofoil 1 with respect to the advancement direction.

[0044] The hydrofoil 1 also comprises at least two appendages 4, rotatably mounted on the hull 2 and projecting below with respect to the hull 2 itself. In particular, such appendages 4 are intended, during use, to be at least partially immersed in water for generating a lift force and lifting the hull 2 from the free surface of the water, allowing the hydrofoil 1 to navigate in foilborne condition.

[0045] With the term "lift" it must be intended in the present text a lifting force, substantially directed upward, resulting from the fluid-dynamic forces that the water imparts on the aforesaid appendages 4.

[0046] The hydrofoil 1 also comprises first actuator means 5 mechanically connected to the appendages 4 in order to move them with respect to the hull 2 as will be better described hereinbelow. According to the invention, the present control method provides for a first detection step, in which at least one turn sensor 6 operatively connected to the helm 3 detects each turn angle α and generates corresponding turn signals SV.

[0047] The present control method also comprises a second detection step, in which at least one accelerometer 7 mechanically mounted on the hull 2 detects variations of linear acceleration of the hull 2 itself along three detection axes that are orthogonal to each other and generates corresponding acceleration signals SA.

[0048] Preferably, the aforesaid three detection axes coincide with the axes of rolling R, pitch B and yaw I of the hydrofoil 1, illustrated in the enclosed figure 1.

[0049] The present control method also comprises a third detection step, in which at least one gyroscope 8 mechanically mounted on the hull 2 detects variations of angular speed of the hull 2 itself along the aforesaid three detection axes and generates corresponding angular speed signals SVA.

[0050] According to the idea underlying the present invention, the present control method comprises a fourth detection step, in which at least one tilt sensor 9 mechanically mounted on the hull 2 detects the tilt of the hull 2 itself with respect to the aforesaid three detection axes and generates corresponding tilt signals SI.

[0051] The present control method also comprises a fifth detection step, in which at least one linear speed sensor 10 mechanically mounted on the hull 2 detects the advancing speed of the hull 2 itself at least along the main extension axis X and generates at least one corresponding linear speed signal SVL.

[0052] The present control method then provides for a first calculation step, in which an electronic control unit 11 receives the turn signal SV from the turn sensor 6 and calculates a corresponding ideal turn position PVI for each appendage 4.

[0053] In addition, the present control method provides for a second calculation step, in which the electronic control unit 11 receives each acceleration signal SA, each angular speed signal SVA, each tilt signal SI and the linear speed signal SVL and calculates a corresponding first corrective factor FC1 for each appendage 4.

[0054] The present control method also provides for a processing step, in which the electronic control unit 11 corrects the ideal turn position PVI by applying the first corrective factor FC1 and obtains a corresponding corrected turn position PVC for each appendage 4.

[0055] The present control method also provides for a driving step, in which the electronic control unit 11 generates a first driving signal SC1 for driving the first actuator means 5 to move each appendage 4 around a corresponding first rotation axis Y orthogonal to the main extension axis X.

[0056] In addition, the present control method comprises a moving step in which the first actuator means 5 move each appendage 4 in order to reach the corresponding corrected turn position PVC independently with respect to the other appendages 4.

[0057] Preferably, the aforesaid first, second, third, fourth and fifth detection steps are executed substantially simultaneously with each other, in particular at a detection frequency comprised between 200Hz and 6000Hz.

[0058] More in detail, the detection frequency increases with the increase of the progression speed of the hydrofoil 1.

[0059] In particular, the detection frequency is comprised between about 800Hz and 1200Hz and preferably about 1000Hz with the aforesaid progression speed of about 60 knots. Otherwise, the detection frequency is preferably comprised between 3500Hz and 4500Hz and in particular of about 4000Hz with the aforesaid progression speed of about 120 knots.

[0060] Preferably, the above-described signals, and in particular the turn signal SV, the acceleration signal SA, the angular speed signal SVA, the tilt signal SI, the angular speed signal SVL and the first driving signal SC1 are signals of electric type, susceptible of being processed both in reception and in emission by the electronic control unit 11.

[0061] Preferably, in addition, the first corrective factor FC1 calculated in the second calculation step is reversely proportional to the accelerations and to the speeds of the hull 2 detected by the accelerometer 7, by the gyroscope 8 and by the linear speed sensor 10. Advantageously, in this manner, greater speeds and accelerations of the hull 2 correspond with lesser movements of the appendages 4, so as to prevent sudden turns at considerable navigation speed, which can lead to the loss of the control of the hydrofoil 1.

[0062] More in detail, in accordance with a preferred embodiment illustrated in the enclosed figure 1, the hull 2 of the hydrofoil 1 intended to be controlled with the present method is divided by a median plane M, comprising the main extension axis X, into a port half-hull 2' and a starboard half-hull 2".

[0063] In accordance with the preferred embodiment illustrated in the enclosed figures, the aforesaid at least two appendages 4 of the hydrofoil 1 comprise at least one port appendage 4' mounted on the port half-hull 2' and at least one starboard appendage 4" mounted on the starboard half-hull 2". Still more preferably, the appendages 4 comprise two port appendages 4' and two starboard appendages 4", placed aligned along the respective port and starboard half-hulls 2', 2". Advantageously, in the aforesaid first detection step, the turn sensor 6 detects the turn angle α oriented with respect to the median plane M (and which lies on a plane substantially transverse to the median plane M itself). In particular, with "oriented angle" it must be intended hereinbelow an angle with which a positive value is associated when, starting from the median plane M, this corresponds with a counter-clockwise rotation, and with which a negative value is associated when, starting from the median plane M, this corresponds with a clockwise rotation. Advantageously, in this manner, the turn signal SV indicates not only the requested turn angle α, but also the direction towards which the aforesaid turn is requested, i.e. towards port or starboard.

[0064] Advantageously, in the aforesaid first calculation step, the electronic control unit 11 associates a positive parameter with one of the aforesaid appendages 4 between the port appendage 4' and the starboard appendage 4" directed in the same direction as the turn angle α and associates a negative parameter with the other of the aforesaid port and starboard appendages 4', 4" directed in the same direction opposite the turn angle α in order to calculate separate ideal turn positions PVI for the port and starboard appendages 4', 4".

[0065] Advantageously, in the aforesaid processing step, the control unit 11 corrects the positive parameter and the negative parameter by applying the first corrective factor FC1 thereto. Advantageously, in this manner, the control unit 11 associates each appendage 4 with a corresponding ideal turn position PVI identifying not only the turn angle requested by the helm 3 but also the exact spatial position of each appendage 4, which can vary with respect to standard design conditions due to movements of the hull 2 which can be verified during navigation and which are included in the first corrective factor FC1.

[0066] In accordance with the preferred embodiment of the present hydrofoil 1, illustrated in the enclosed figure 2, each said appendage 4 comprises at least one first foil 41 that is substantially sheet-like and mainly extended along a first lying plane.

[0067] More in detail, the first foil 41 is shaped in a manner such to allow generating the aforesaid lift, for example shaped with a NACA profile.

[0068] In operation, the first actuator means 5 are adapted to move each appendage 4 around the first rotation axis Y, in a plurality of increasing lift positions between a minimum lift position and a maximum lift position.

[0069] In particular, in the minimum lift position, the first foil 41 is placed with its first lying plane substantially parallel to the main extension axis X of the hull 2, and during use it is substantially parallel to the water flow lines in which the first foil 41 is immersed, so as to develop the least possible lift force.

[0070] Advantageously, in the maximum lift position the first foil 41 of the corresponding appendage 4 is placed with the first lying plane tilted by a maximum tilt angle with respect to the main extension axis X of the hull 2, and during use it is tilted with respect to the water flow lines in which the first foil 41 is immersed, by an angle such to develop the greatest possible lift force. The maximum tilt angle is comprised preferably between 2° and 20°. The value of the maximum tilt angle depends on the particular profile of the first foil 41, in particular it depends on the type of NACA profile used, it depends on the dimensions of the first foil 41. During use, in addition, the value of the maximum tilt angle advantageously depends on the maximum progression speed of the hydrofoil 1.

[0071] In operation, each position of the appendages 4, comprised between the aforesaid positions of minimum lift and maximum lift, corresponds to a different tilt angle of the first lying plane with respect to the main extension axis X comprised between 0 degrees (corresponding to the minimum lift position) and the value of the maximum tilt angle, and in particular, increasing tilt angles correspond to increasing lift forces.

[0072] Advantageously, in the aforesaid driving step, the electronic control unit 11 drives the actuator means 5 to move the appendage 4 with which the positive parameter is associated to rotate into a smaller lift position with respect to the other appendage 4 with which the negative parameter is associated.

[0073] In other words, the appendages 4 mounted on the half-hull 2', 2" directed in the same direction as the turn angle α are advantageously moved into a position such to generate a lower lift force with respect to the appendages mounted on the half-hull 2', 2" directed in a direction opposite the turn angle α.

[0074] In operation, in this manner, the present control method provides for more greatly submerging the half-hull 2', 2" directed in the same direction as the turn angle α, thus involving a corresponding turning of the hydrofoil 1.

[0075] Advantageously, the method according to the invention provides for modifying, on the basis of the aforesaid tilt angle value, the power of propulsor means (described in detail hereinbelow) so as to maintain the advancing speed of the hydrofoil within a predetermined speed limit value. Preferably, the propulsor means comprise two propellers, each rotatably mounted below the hull 2. In particular, a first propeller is mounted on the port half-hull and a second propeller is mounted on the starboard half-hull.

[0076] In this manner, the method according to the invention advantageously provides for modifying, based on the value of the aforesaid tilt angle, the power of the first and of the second propeller of the propulsor means in an independent manner.

[0077] More in detail, the method provides for slowing the rotation of the propeller mounted on the half-hull directed in the same direction as the turn angle α and accelerating the rotation of the propeller mounted on the half-hull directed in the opposite direction with respect to the turn angle α.

[0078] Advantageously, in addition, the present control method provides that the difference between the tilt of the first lying plane of the first foil 41 of the port appendage 4' with respect to the main extension axis X and the tilt of the first lying plane of the first foil 41 of the starboard appendage 4" with respect to the aforesaid main extension axis X is proportional to the turn angle α, and still more preferably it is directly proportional to the turn angle α. Advantageously, the aforesaid tilt difference between the port appendage 4' and the starboard appendage 4" is corrected on the basis of the first corrective factor FC1. In this manner it is therefore advantageously possible to correct the lift variation generated by the appendages 4 on the basis of the navigation conditions of the hydrofoil 1, detected by the accelerometer 7, by the gyroscope 8, by the tilt sensor 9 and by the linear speed sensor 10.

[0079] Advantageously, in order to prevent sudden lift variations generated by each appendage 4, the present control method provides that, during the moving step, each appendage 4 is continuously moved up to reaching the corrected turn position PVC.

[0080] In particular, the aforesaid detection, calculation, processing and driving steps are preferably executed at a frequency comprised between 200 Hz and 2 kHz and more preferably of about 1 kHz.

[0081] In this manner, at each second, a number of corrected turn positions PVC are advantageously calculated, comprised between 200 and 2000, which substantially allow continuously moving the appendages 4 between the plurality of corrected turn positions PVC calculated. Of course, it is possible to move the appendages 4 continuously even in the event in which the aforesaid detection, calculation, processing and driving steps are executed at lower frequencies with respect to those indicated above, without exiting from the protective scope of the present patent. In accordance with the preferred embodiment illustrated in the enclosed figure 2, each appendage 4 comprises a second foil 42, that is substantially sheet-like and extended starting from the first foil 41 along a second lying plane that is tilted with respect to the first lying plane of the first foil 41. In other words, the first and the second foil 41, 42 of each appendage 4 are placed mechanically constrained to each other to form a substantially "C" profile and they are joined together by an elbow 43, placed to join together the first and the second foil 41, 42, acting as a connector between the first and the second lying plane.

[0082] Preferably, each appendage 4 comprises at least one support leg 14 placed as a mechanical connection between the elbow 43 and the hull 2. More in detail, each support leg 14 is extended between a first end, fixed to the elbow 43, and a second end, rotatably mounted on the hull 2. The present control method advantageously provides that, in order to move each appendage 4 towards a direction with greater lift, the first actuator means 5 move the corresponding support leg 14 to rotate the first end thereof towards the bow of the hydrofoil 1. Similarly, in order to move each appendage 4 towards a direction with smaller lift, the first actuator means 5 move the corresponding support leg 14 to rotate the first thereof end towards the stern of the hydrofoil 1.

[0083] In accordance with the preferred embodiment, the hydrofoil 1 comprises propulsor means adapted to move a water flow along a thrust direction, such propulsor means are per se of known type and therefore they are not illustrated in detail and will not be described in detail hereinbelow.

[0084] Advantageously, the hydrofoil 1 comprises at least one deflector member 15, known in the technical jargon of the field also with the term "rudder blade", which is rotatably mounted on the hull 2, below the latter and placed along the thrust direction to intercept the water flow moved by the propulsor means, in proximity to the latter.

[0085] In particular, the deflector member 15 is mounted on the hull 2 interposed between the stern of the hull 2 and the aforesaid propulsor means.

[0086] Otherwise, the deflector member 15 can be provided mounted on the hull 2 in distal position with respect to the propulsor means, without exiting from the protective scope of the present patent.

[0087] Advantageously, the hydrofoil 1 comprises second actuator means 17 operatively connected to the helm 3 and to the deflector member 15 in order to move it into a plurality of positions corresponding to the requested turn angles α.

[0088] Advantageously, the present control method provides that in the aforesaid first calculation step, the electronic control unit 11 calculates an ideal deflection position PDI in which the deflector member 15 has to be moved in order to obtain the turn angle α.

[0089] In the second calculation step, advantageously the electronic control unit 11 then calculates a second corrective factor FC2 for the deflector member 15.

[0090] Advantageously, in addition, in the processing step, the electronic control unit 11 corrects the ideal deflection position PDI by applying the second corrective factor FC2 and obtains a corresponding corrected deflection position PDC for the deflector member 15. Advantageously, the present method provides that in the driving step, the electronic control unit 11 generates a second driving signal SC2 for driving the second actuator means 17 to move the deflector member 15 into the corrected deflection position PDC. Advantageously, in addition, in the moving step the second actuator means 17 move the deflector member 15 in order to reach the corrected deflection position PDC.

[0091] Advantageously, the present method also provides for a step for controlling the position of the deflector member, in which a further position sensor (not illustrated in the enclosed figures), which is operatively connected with the deflector member 15, detects the position of the latter and sends a corresponding position signal to the electronic control unit 11, which controls that the deflector member 15 actually reaches the corrected deflection position PDC calculated.

[0092] In accordance with the preferred embodiment illustrated in the enclosed figures 1 and 2, the first actuator means 5 are adapted to move each appendage 4 at least in partial rotation also around a second rotation axis Z, substantially parallel to the main extension axis X of the hull 2, and in particular perpendicular to the first rotation axis Y.

[0093] More in detail, such rotation around the second rotation axis Z occurs between a lowered position, in which the corresponding appendage 4 projects below with respect to the hull 2 (illustrated in the enclosed figure 2), and a lifted position, in which the appendage 4 is placed side-by-side the hull 2 (illustrated in the enclosed figure 1).

[0094] In a per se known manner, the aforesaid lowered position corresponds with a navigation of the hydrofoil 1 in foilborne condition and the aforesaid lifted position corresponds with a navigation of the hydrofoil 1 not in foilborne condition.

[0095] Advantageously, the above-described method for controlling the turning is executed with the appendages 4 placed in the lowered position, i.e. with the hydrofoil 1 which navigates in foilborne condition. In this situation, the appendages 4 generate a lift force such to lift the hull 2 and such to allow varying the course of the hydrofoil 1 by varying the lift force that each of these generates.

[0096] It is of course possible to execute the above-described control method also with the appendages 4 placed in the lifted position, or in any one position interposed between the lowered position and the lifted position. In such positions, the force developed by each appendage is however different from the lift force developed in lowered position. Advantageously, the present control method then provides for a sixth detection step, in which a position sensor 18, operatively connected to each appendage 4, detects the position of the corresponding appendage 4 with respect to the second rotation axis Z and generates corresponding appendage position signals SPA.

[0097] Advantageously, the position sensor 18 comprises a position encoder mechanically associated with the first actuator means 5, for example associated with a piston slidably inserted in a cylinder and configured for reading the relative travel thereof during the movement of the appendages 4.

[0098] More in detail, the first actuator means 5 of each appendage comprise two different encoders of the aforesaid position sensor 18. Such two encoders are configured for detecting a tilt angle of the corresponding appendage 4 and the relative distance between the first foil 41 and the hull 2 of the hydrofoil 1.

[0099] Advantageously, in the second calculation step, the electronic control unit 11 receives the aforesaid appendage position signal SPA and calculates the aforesaid first corrective factor FC1 also as a function of such appendage position signal SPA. Advantageously, in this manner, the ideal turn position PVI is corrected not only as a function of the signals detected by the accelerometer 7, by the gyroscope 8, by the tilt sensor 9 and by the linear speed sensor 10, but also of the actual position of the appendage 4 with respect to the hull 2 and hence of the portion of the first and second foils 41, 42 immersed in water and capable of developing lift force.

[0100] As indicated above, also forming the object of the present invention is a hydrofoil 1, the course of which is advantageously drivable by means of a method for controlling the turning of the above-described type, regarding which the same nomenclature will be maintained together with the same alphanumeric references for the sake of description simplicity.

[0101] The hydrofoil 1 according to the invention comprises at least one hull 2 provided with at least one main extension axis X. In the following present description, reference will always be made to a hydrofoil 1 provided with only one hull 2; nevertheless, an alternative embodiment of the hydrofoil 1 must also be intended as possible, provided with two or more hulls 2, without exiting from the protective scope of the present patent.

[0102] The present hydrofoil 1 comprises at least one helm 3, mechanically mounted on the hull 2 and movable into a plurality of positions, each defining a corresponding turn angle α.

[0103] According to the invention, the hydrofoil 1 comprises at least two appendages 4, rotatably mounted on the hull 2 and projecting below with respect to the hull 2 itself.

[0104] In particular, the hydrofoil 1 comprises preferably at least one port appendage 4' (and more preferably two port appendages 4') and at least one starboard appendage 4" (and more preferably two port appendages 4'), which are respectively mounted on a port half-hull 2' and on a starboard half-hull 2", identified by a median plane M of the hull 2, as is illustrated in the enclosed figure 1.

[0105] The hydrofoil 1 also comprises first actuator means 5 mechanically connected to the appendages 4 in order to move them with respect to said hull 2, as is better described hereinbelow. According to the invention, the hydrofoil 1 comprises a control apparatus comprising a plurality of sensors operatively connected to the hydrofoil 1 and adapted to detect a plurality of measurements, as is better described hereinbelow.

[0106] According to the invention, the aforesaid control apparatus comprises at least one turn sensor 6 operatively connected to the helm 3 and configured for detecting each turn angle α and for generating corresponding turn signals SV.

[0107] In particular, the turn sensor is preferably a transducer and still more preferably an encoder, mounted on a hub of the helm 3 in order to detect the rotation angle of the helm 3 itself, corresponding to the requested turn angle α.

[0108] According to the invention, the control apparatus comprises at least one accelerometer 7 mechanically mounted on the hull 2, preferably along its main extension axis X, and still more preferably in proximity to the bottom of the hull 2 itself, as is illustrated in the enclosed figures 3A, 3B.

[0109] The aforesaid accelerometer 7 is also configured to detect variations of linear acceleration of the hull 2 along three detection axes that are orthogonal to each other and for generating corresponding acceleration signals SA.

[0110] Preferably, the aforesaid three detection axes coincide with the axes of rolling R, pitch B and yaw I of the hull 2.

[0111] In order to detect the variations of linear acceleration along the three detection axes, the control apparatus can advantageously comprise a single accelerometer 7 configured for detecting the aforesaid three variations of linear acceleration, or it can comprise three accelerometers 7, placed orthogonal to each other and each configured for detecting the variation of linear acceleration along a separate detection axis.

[0112] According to the invention, the control apparatus comprises at least one gyroscope 8 mechanically mounted on the hull 2, preferably along its main extension axis X, and still more preferably in proximity to the bottom of the hull 2 itself, as is illustrated in the enclosed figures 3A, 3B.

[0113] The aforesaid gyroscope 8 is configured for detecting variations of angular speed of said hull 2 along the aforesaid three detection axes and for generating corresponding angular speed signals SVA.

[0114] In order to detect the variations of angular speed along the three detection axes, the control apparatus can advantageously comprise only one gyroscope 8 configured for detecting the aforesaid three variations of angular speed, or it can comprise three gyroscopes 8, placed orthogonal to each other and each configured for detecting the variation of angular speed along a separate detection axis.

[0115] According to the invention, the apparatus for controlling the present hydrofoil 1 also comprises at least one electronic control unit 11, mounted on the hull 2 and placed in data communication with the turn sensor 6, with the accelerometer 7, with the gyroscope 8 and with the first actuator means 5.

[0116] More in detail, the electronic control unit 11 is configured for receiving input signals from the turning sensor 6, from the accelerometer 7 and from the gyroscope 8 and for calculating corresponding output signal to send to the first actuator means 5 in order to move the appendages 4, as is better described hereinbelow.

[0117] According to the idea underlying the present invention, the first actuator means 5 are adapted to move each appendage 4 at least in partial rotation around a corresponding first rotation axis Y, orthogonal to the main extension axis X. In addition, the first actuator means 5 are adapted to move each appendage 4 independently with respect to the other appendages 4.

[0118] In particular, the aforesaid first actuator means 5 preferably comprise at least one actuator for each appendage 4 so as to move each appendage 4 independently from the remaining appendages 4. Such actuators can for example be linear actuators and preferably hydraulic pistons.

[0119] The control apparatus also comprises at least one tilt sensor 9 mechanically mounted on the hull 2 and configured for detecting the tilt of the hull 2 with respect to the three detection axes and for generating corresponding tilt signals SI. Preferably, the aforesaid tilt sensor 9 is a sensor of magnetic type, configured for detecting the tilt of the hull 2 as a function of its tilt with respect to the terrestrial magnetic axis.

[0120] Preferably, in addition, the tilt sensor 9 is mounted on the hull 2 along its main extension axis X, and still more preferably in proximity to the bottom of the hull 2 itself, as is illustrated in the enclosed figures 3A and 3B.

[0121] Advantageously, in addition, the accelerometer 7, the gyroscope 8 and the tilt sensor 9 are housed within a single space and are all placed substantially in the same position, so as to detect the measurements of variation of linear acceleration, of variation of angular speed and of tilt with respect to the same system of Cartesian axes, corresponding to the aforesaid three detection axes.

[0122] In accordance with the embodiment illustrated in the enclosed figures, in addition, the containment space of the accelerometer 7, of the gyroscope 8 and of the tilt sensor 9 is placed along the main extension axis X of the hull and spaced with respect to the geometric center G of the hull 2 itself (see for example the enclosed figures 3A, 3B), so as to detect amplified measurements of the variations of linear speed, of the variations of linear acceleration and of the tilts of the hull 2.

[0123] Otherwise, in accordance with a further embodiment not illustrated in the enclosed figures, the containment space of the accelerometer 7, of the gyroscope 8 and of the tilt sensor 9 is placed at the geometric center G of the hull 2 itself.

[0124] Advantageously, in addition, the aforesaid accelerometer 7, gyroscope 8 and tilt sensor 9 can be enclosed in a single inertial platform, configured for detecting the aforesaid variations of linear speed, variations of linear acceleration and tilts of the hull 2, each with respect to the three detection axes.

[0125] The control apparatus comprises at least one linear speed sensor 10 mechanically mounted on the hull 2 and configured for detecting the advancing speed of the hull 2 itself at least along the main extension axis X and for generating at least one corresponding linear speed signal SVL.

[0126] In particular, the aforesaid linear speed sensor 10 is preferably a sensor of magnetic-hydrodynamic type, which is mounted on a portion of said hull 2 intended during use to always be placed below the free surface of the water, for example at the support of the propeller of the hydrofoil 1, as is illustrated in the enclosed figures 4A and 4B.

[0127] Alternatively, the linear speed sensor 10 can be any one other sensor, such as a blade sensor, which has the advantage of being less expensive than the above-described magnetic-hydrodynamic sensor, but it has the disadvantage of being less accurate at high advancing speeds of the hull 2.

[0128] Advantageously, the control apparatus comprises two linear speed sensors 10, of which a first sensor 10' is of magnetic-hydrodynamic type and is mounted on the support of the propeller as is indicated above, and a second sensor 10" is of blade type and is mounted on the hull 2 (as is illustrated in the enclosed figures 4A and 4B).

[0129] In this manner, the second sensor 10" is redundant with respect to the first sensor 10' while the hydrofoil 1 navigates in non-foilborne condition and stops measuring the angular speed of the hull when the hydrofoil 1 passes into foilborne condition. Advantageously, therefore, the aforesaid two linear speed sensors 10 allow having a correction of the measurements detected by each of these in non-foilborne navigation condition and also allow detecting the instant of separation of the hull 2 from the water, corresponding to the instant at which the second sensor 10" no longer detects a linear advancing speed.

[0130] The aforesaid electronic control unit 11 is also provided with a plurality of modules, a diagram of which being illustrated in the enclosed figure 5.

[0131] The electronic control unit 11 is provided with a first calculation modulus 111 programmed for receiving the turn signal SV from the turn sensor 6 and for calculating a corresponding ideal turn position PVI for each appendage 4.

[0132] In addition, the electronic control unit 11 is provided with a second calculation modulus 112 programmed for receiving each acceleration signal SA from the accelerometer 7, each angular speed signal SVA from the gyroscope 8, each tilt signal SI from the tilt sensor 9 and the linear speed signal SVL from the linear speed sensor 10.

[0133] In addition, the second calculation modulus 112 is programmed for calculating a corresponding first corrective factor FC1 for each appendage 4.

[0134] The electronic control unit 11 is also provided with a processing module 113, in data connection with the aforesaid first and second calculation modulus 111, 112 and configured for correcting the ideal turn position PVI by means of the application of the first corrective factor FC1, obtaining a corresponding corrected turn position PVC for each appendage 4.

[0135] In addition, the electronic control unit 11 is provided with a driving module 114 configured for receiving each corrected turn position PVC and for generating a corresponding first driving signal SC1 for driving the first actuator means 5 to move each appendage 4 around the corresponding first rotation axis Y in order to reach the corresponding corrected turn position PVC.

[0136] More in detail, in accordance with that reported above in relation to the control method of the hydrofoil 1, the first calculation modulus 111 is programmed for associating a positive parameter with the port and starboard appendages 4', 4" directed in a same direction as the turn angle α and for associating a negative parameter with the port and starboard appendages 4', 4" directed in opposite direction with respect to the turn angle α.

[0137] Advantageously, in addition, the processing module 113 is programmed for correcting the positive and negative parameters associated with each appendage 4 with the first corrective factor FC1.

[0138] In accordance with the preferred embodiment illustrated in the enclosed figure 2, each appendage 4 is provided with a first foil 41 that is substantially sheet-like and extended along a first lying plane.

[0139] Preferably, each appendage 4 is also provided with a second foil 42 that is substantially sheet-like and extended in succession after the first foil 41 along a second lying plane angled with respect to the first lying plane of the first foil 41. Preferably, in addition, the first and the second foil 41, 42 are connected together by means of an elbow 43.

[0140] In accordance with the embodiment of the present invention, both the first and second foils 41, 42 are susceptible of generating a lift force in order to allow the navigation in foilborne mode, since both the first and second foils 41, 42 are configured for being hit by the water. Advantageously, during use, at least the first foil 41 is susceptible of coming into contact with the water in a position such to generate lift and at least partially lifting the corresponding appendage 4 with respect to the free surface of the water.

[0141] In particular, each appendage 4 is movable, by means of the first actuator means 5, between a plurality of variable lift positions, and in particular between a minimum lift position and a maximum lift position.

[0142] More in detail, in the minimum lift position, the first lying plane of the first foil 41 is substantially parallel to the main extension axis X of the hull 2, and in the maximum lift position the first lying plane is tilted by a maximum tilt angle with respect to the main extension axis X itself.

[0143] Advantageously, the first calculation modulus 111 is programmed for calculating, for each appendage 4 with which the positive parameter is associated, an ideal turn position PVI corresponding to a lift position smaller than the ideal turn position PVI calculated for each appendage 4 with which the negative parameter is associated.

[0144] In accordance with the preferred embodiment, the hydrofoil 1 comprises propulsor means adapted to move a water flow along a thrust direction and at least one deflector member 15, rotatably mounted on the hull 2, below the latter and placed along the thrust direction to intercept the water flow in proximity to said propulsor means.

[0145] Advantageously, the hydrofoil 1 comprises second actuator means 17 operatively connected to the helm 3 and to the deflector member 15 in order to move it into a plurality of positions corresponding to the requested turn angles α of the helm 3.

[0146] Advantageously, the first calculation modulus 111 of the electronic control unit 11 is programmed for calculating an ideal deflection position PDI in which the deflector member 15 has to be moved so as to obtain the turn angle α.

[0147] In addition, the second calculation modulus 112 is programmed for calculating a second corrective factor FC2 based on the signals of acceleration SA, angular speed SVA, tilt SI and linear speed SVL received.

[0148] In addition, the processing module 113 is programmed for correcting the ideal deflection position PDI by means of the second corrective factor FC2 and for calculating a corrected deflection position PDC for the deflector member 15.

[0149] In addition, the driving module 114 is configured for generating a second driving signal SC2 for driving the second actuator means 17 to move the deflector member 15 into the corrected deflection position PDC.

[0150] In accordance with the preferred embodiment illustrated in the enclosed figures 1 and 2, the first actuator means 5 are adapted to move each appendage 4 at least in partial rotation around a second rotation axis Z, substantially parallel to the main extension axis X between a lowered position, in which the appendage 4 projects below with respect to the hull 2 (illustrated in figure 2), and a lifted position (illustrated in figure 1), in which the appendage 4 is placed side-by-side the hull 2.

[0151] Advantageously, the control apparatus comprises at least one position sensor 18, preferably a transducer and still more preferably an encoder, operatively connected to each appendage 4 and configured for detecting the position of the latter with respect to the second rotation axis Z. Advantageously, in addition, each position sensor 18 is configured for generating corresponding appendage position signals SPA and for sending such signals to the second calculation modulus 112 of the electronic control unit 11, which is advantageously programmed for calculating the first corrective factor FC1 also as a function of such appendage position signal SPA.

[0152] In particular, the aforesaid position sensor 18 allows the electronic control unit 11 to know the position of each appendage 4 with respect to the hull 2 so as to correct the ideal turn position PVI calculated by the second calculation modulus 112 also as a function of the aforesaid appendage position signal SPA.

[0153] Advantageously, the present hydrofoil 1 comprises a further position sensor (not illustrated in the enclosed figures), which is operatively connected with the deflector member 15, and is configured for detecting the position of the latter and sending a corresponding position signal to the electronic control unit 11.

[0154] Advantageously, the electronic control unit 11 is programmed for verifying that the deflector member 15 actually reaches the corrected deflection position PDC calculated.

[0155] Also forming the object of the present invention is an apparatus for controlling the turning of a hydrofoil preferably of the above-described type, regarding which the same nomenclature will be maintained for the sake of description simplicity.

[0156] The control apparatus according to the invention comprises at least one turn sensor 6 intended to be connected to a helm 3 of the hydrofoil 1 and configured for detecting at least one turn angle α in which the helm 3 is moved. In addition, the turn sensor 6 is configured for generating turn signals SV corresponding to the detected turn angles α.

[0157] In addition, the control apparatus comprises at least one accelerometer 7 intended to be mounted on a hull 2 of the hydrofoil 1 and configured for detecting variations of linear acceleration of the hull 2 itself along three detection axes that are orthogonal to each other and for generating acceleration signals SA corresponding to the detections carried out.

[0158] In addition, the control apparatus comprises at least one gyroscope 8 intended to be mounted on the hull 2 and configured for detecting variations of angular speed of the hull 2 itself along the three detection axes and for generating corresponding angular speed signals SVA.

[0159] In addition, the control apparatus comprises at least one electronic control unit 11, intended to be mounted on the hull 2 and placed in data communication with the turn sensor 6, with the accelerometer 7, with the gyroscope 8 and with first actuator means 5 of at least two appendages 4 of the hydrofoil 1.

[0160] According to the idea underlying the present invention, the present control apparatus also comprises at least one tilt sensor 9 intended to be mounted on the hull 2 and configured for detecting the tilt of the hull 2 with respect to the three detection axes and for generating corresponding tilt signals SI.

[0161] In addition, the control apparatus comprises at least one linear speed sensor 10 intended to be mounted on the hull 2 and configured for detecting the advancing speed of the hull 2 itself at least along a main extension axis X of the hull 2 and for generating at least one corresponding linear speed signal SVL.

[0162] In addition, the electronic control unit 11 is provided with a first calculation modulus 111 programmed for receiving the turn signal SV and for calculating a corresponding ideal turn position PVI for each appendage 4.

[0163] In addition, the electronic control unit 11 is provided with a second calculation modulus 112 programmed for receiving each acceleration signal SA, each angular speed signal SVA, each tilt signal SI and the linear speed signal SVL, and for calculating a corresponding first corrective factor FC1 for each appendage 4.

[0164] In addition, the electronic control unit 11 is provided with a processing module 113 configured for correcting the ideal turn position PVI by means of the application of the first corrective factor FC1, obtaining a corresponding corrected turn position PVC for each appendage 4.

[0165] In addition, the electronic control unit 11 is provided with a driving module 114 configured for receiving each corrected turn position PVC and generating a corresponding first driving signal SC1 for driving the first actuator means 5 of the appendages 4 to independently move each said appendage 4 at least in partial rotation around a corresponding first rotation axis Y, orthogonal to the main extension axis X, in order to reach the corresponding corrected turn position PVC. In particular, the present control apparatus is of the above-described type in relation to the hydrofoil 1 and the same above-reported considerations are also valid for this.

[0166] The method for controlling the turning of a hydrofoil, the hydrofoil 1 and its control apparatus thus conceived therefore attain the pre-established objects.

Claims

1. Method for controlling the turning of a hydrofoil (1), said hydrofoil (1) comprising:

   - a hull (2) provided with at least one main extension axis (X);
   - at least one helm (3), mechanically mounted on said hull (2) and movable into a plurality of positions, each defining a corresponding turn angle (α) with respect to said main extension axis (X);
   - at least two appendages (4), rotatably mounted on said hull (2) and projecting below with respect to said hull (2);
   - first actuator means (5) mechanically connected to said appendages (4) in order to move them with respect to said hull (2);

   said control method providing for:

   - a first detection step, wherein at least one turn sensor (6) operatively connected to said helm (3) detects each said turn angle (α) and generates corresponding turn signals (SV);
   - a second detection step, wherein at least one accelerometer (7) mechanically mounted on said hull (2) detects variations of linear acceleration of said hull (2) along three detection axes that are orthogonal to each other, and generates corresponding acceleration signals (SA);
   - a third detection step, wherein at least one gyroscope (8) mechanically mounted on said hull (2) detects variations of angular speed of said hull (2) along said three detection axes and generates corresponding angular speed signals (SVA);

   said method being **characterized in that** it comprises:

   - a fourth detection step, wherein at least one tilt sensor (9) mechanically mounted on said hull (2) detects the tilt of said hull (2) with respect to

said three detection axes and generates corresponding tilt signals (SI);
- a fifth detection step, wherein at least one linear speed sensor (10) mechanically mounted on said hull (2) detects the advancing speed of said hull (2) at least along said main extension axis (X) and generates at least one corresponding linear speed signal (SVL);
- a first calculation step, wherein an electronic control unit (11) receives said turn signal (SV) and calculates a corresponding ideal turn position (PVI) for each said appendage (4);
- a second calculation step, wherein said electronic control unit (11) receives each said acceleration signal (SA), each said angular speed signal (SVA), each said tilt signal (SI) and said linear speed signal (SVL), and calculates a corresponding first corrective factor (FC1) for each said appendage (4);
- a processing step, wherein said electronic control unit (11) corrects said ideal turn position (PVI) by applying said first corrective factor (FC1) and obtains a corresponding corrected turn position (PVC) for each said appendage (4);
- a driving step, wherein said electronic control unit (11) generates a first driving signal (SC1) for driving said first actuator means (5) to move each said appendage (4) around a corresponding first rotation axis (Y) orthogonal to said main extension axis (X);
- a moving step, wherein said first actuator means (5) move each said appendage (4) in order to reach the corresponding said corrected turn position (PVC) independently with respect to the other of said at least two appendages (4).

2. Control method according to claim 1, wherein said hull (2) is divided by a median plane (M), comprising said main extension axis (X), into a port half-hull (2') and a starboard half-hull (2");
said at least two appendages (4) comprising at least one port appendage (4') mounted on said port half-hull (2') and at least one starboard appendage (4") mounted on said starboard half-hull (2");
said control method being **characterized in that**:

- in said first detection step, said turn sensor (6) detects said turn angle (α) oriented with respect to said median plane (M);
- in said first calculation step, said electronic control unit (11) associates a positive parameter with one of said port and starboard appendages (4', 4") directed in the same direction as said turn angle (α) and a negative parameter with the other of said port and starboard appendages (4', 4") directed in the direction opposite said turn angle (α) in order to calculate separate said ideal turn positions (PVI) for said port and starboard appendages (4', 4");
- in said processing step, said control unit (11) corrects said positive parameter and said negative parameter by applying said first corrective factor (FC1).

3. Control method according to claim 2, wherein each said appendage (4) comprises at least one first foil (41) that is substantially sheet-like and mainly extended along a first lying plane (P); said first actuator means (5) being adapted to move each said appendage (4) around said first rotation axis (Y), in a plurality of increasing lift positions between:

- a minimum lift position, in which said first foil (41) is placed with said first lying plane (P) substantially parallel to the main extension axis (X) of said hull (2), and
- a maximum lift position, in which said first foil (41) is placed with said first lying plane (P) tilted by a maximum tilt angle with respect to the main extension axis (X) of said hull (2);

said control method being **characterized in that** in said driving step, said electronic control unit (11) drives said actuator means (5) to move the appendage (4), with which said positive parameter is associated, to rotate into a smaller lift position with respect to the other appendage (4) with which said negative parameter is associated.

4. Control method according to claim 3, wherein the difference between the tilt of the first lying plane (P) of the first foil (41) of said port appendage (4') with respect to the main extension axis (X) of said hull (2) and the tilt of the first lying plane (P) of the first foil (41) of said starboard appendage (4") with respect to the main extension axis (X) of said hull (2) is proportional to said turn angle (α) and is corrected on the basis of said first corrective factor (FC1).

5. Control method according to any one of the preceding claims, **characterized in that** in said moving step, each said appendage (4) is continuously moved up to reaching said corrected turn position (PVC).

6. Control method according to any one of the preceding claims, **characterized in that** said detection, calculation, processing and driving steps are executed at a frequency comprised between 200 Hz and 6 kHz.

7. Control method according to any one of the preceding claims, wherein said hydrofoil comprises:

- propulsor means adapted to move a water flow along a thrust direction;
- at least one deflector member (15), rotatably

mounted on said hull (2), below with respect to said hull (2), placed along said thrust direction to intercept the water flow in proximity to said propulsor means;

- second actuator means (17) operatively connected to said helm (3) and to said deflector member (15) in order to move it into a plurality of positions corresponding to said turn angles (α);

said control method being **characterized in that**:

- in said first calculation step, said electronic control unit (11) calculates an ideal deflection position (PDI) in which said deflector member (15) has to be moved in order to obtain said turn angle (α);
- in said second calculation step, said electronic control unit (11) calculates a second corrective factor (FC2) for said deflector member (15);
- in said processing step, said electronic control unit (11) corrects said ideal deflection position (PDI) by applying said second corrective factor (FC2) and obtains a corresponding corrected deflection position (PDC) for said deflector member (15);
- in said driving step, said electronic control unit (11) generates a second driving signal (SC2) in order to drive said second actuator means (17) to move said deflector member (15) into said corrected deflection position (PDC);
- in said moving step, said second actuator means (17) move said deflector member (15) in order to reach said corrected deflection position (PDC).

8. Control method according to any one of the preceding claims, wherein said first actuator means (5) are adapted to move each said appendage (4) at least in partial rotation around a second rotation axis (Z), substantially parallel to the main extension axis (X) between:

- a lowered position, wherein said appendage (4) projects below with respect to said hull (2), and
- a lifted position, wherein said appendage (4) is placed side-by-side said hull (2); said method being **characterized in that** it provides for a sixth detection step, wherein a position sensor (18) operatively connected to each said appendage (4) detects the position of the corresponding said appendage (4) with respect to said second rotation axis (Z) and generates corresponding appendage position signals (SPA);

in said second calculation step, said electronic control unit (11) calculates said first corrective factor (FC1) as a function of said appendage position signal (SPA).

9. Hydrofoil (1) comprising:

- a hull (2) provided with at least one main extension axis (X);
- at least one helm (3), mechanically mounted on said hull (2) and movable into a plurality of positions, each defining a corresponding turn angle (α);
- at least two appendages (4), rotatably mounted on said hull (2) and projecting below with respect to said hull (2);
- first actuator means (5) mechanically connected to said appendages (4) in order to move them with respect to said hull (2);
- a control apparatus comprising:

  - at least one turn sensor (6) operatively connected to said helm (3) and configured for detecting each said turn angle (α) and for generating corresponding turn signals (SV),
  - at least one accelerometer (7) mechanically mounted on said hull (2) and configured for detecting variations of linear acceleration of said hull (2) along three detection axes that are orthogonal to each other and for generating corresponding acceleration signals (SA),
  - at least one gyroscope (8) mechanically mounted on said hull (2) and configured for detecting variations of angular speed of said hull (2) along said three detection axes and for generating corresponding angular speed signals (SVA),
  - at least one electronic control unit (11), mounted on said hull (2) and placed in data communication with said turn sensor (6), with said accelerometer (7), with said gyroscope (8) and with the first actuator means (5);

said hydrofoil (1) being **characterized in that:**

- said first actuator means (5) are adapted to move each said appendage (4) at least in partial rotation around a corresponding first rotation axis (Y), orthogonal to said main extension axis (X); said first actuator means (5) being adapted to move each of said at least two appendages (4) independently with respect to the other of said at least two appendages (4);
- said control apparatus comprises:

  - at least one tilt sensor (9) mechanically mounted on said hull (2) and configured for detecting the tilt of said hull (2) with respect to said three detection axes and for generating corresponding tilt signals (SI),

- at least one linear speed sensor (10) mechanically mounted on said hull (2) and configured for detecting the advancing speed of said hull (2) at least along said main extension axis (X) and for generating at least one corresponding linear speed signal (SVL);

- said electronic control unit (11) is provided with:

  - a first calculation modulus (111) programmed for receiving said turn signal (SV) and for calculating a corresponding ideal turn position (PVI) for each said appendage (4),
  - a second calculation modulus (112) programmed for receiving each said acceleration signal (SA), said angular speed signal (SVA), said tilt signal (SI) and said linear speed signal (SVL), and for calculating a corresponding first corrective factor (FC1) for each said appendage (4),
  - a processing module (113) configured for correcting said ideal turn position (PVI) by means of the application of said first corrective factor (FC1), obtaining a corresponding corrected turn position (PVC) for each said appendage (4),
  - a driving module (114) configured for receiving each said corrected turn position (PVC) and generating a corresponding first driving signal (SC1) in order to drive said first actuator means (5) to move each said appendage (4) around the corresponding said first rotation axis (Y) in order to reach the corresponding said corrected turn position (PVC).

10. Apparatus for controlling the turning of a hydrofoil (1), such control apparatus comprising:

- at least one turn sensor (6) intended to be connected to a helm (3) of said hydrofoil (1) and configured for detecting at least one turn angle (α) and for generating corresponding turn signals (SV);
- at least one accelerometer (7) intended to be mounted on a hull (2) of said hydrofoil (1) and configured for detecting variations of linear acceleration of said hull (2) along three detection axes that are orthogonal to each other and for generating corresponding acceleration signals (SA);
- at least one gyroscope (8) intended to be mounted on said hull (2) and configured for detecting variations of angular speed of said hull (2) along said three detection axes and for generating corresponding angular speed signals (SVA);
- at least one electronic control unit (11), intended to be mounted on said hull (2) and placed in data communication with said turn sensor (6), with said accelerometer (7), with said gyroscope (8) and with first actuator means (5) of at least two appendages (4) of said hydrofoil (1);

said control apparatus being **characterized in that** it comprises:

- at least one tilt sensor (9) intended to be mounted on said hull (2) and configured for detecting the tilt of said hull (2) with respect to said three detection axes and for generating corresponding tilt signals **(SI);**
- at least one linear speed sensor (10) intended to be mounted on said hull (2) and configured for detecting the advancing speed of said hull (2) at least along a main extension axis (X) of said hull (2) and for generating at least one corresponding linear speed signal (SVL);

and **in that** said electronic control unit (11) is provided with:

- a first calculation modulus (111) programmed for receiving said turn signal (SV) and for calculating a corresponding ideal turn position (PVI) for each appendage (4) of said hydrofoil (1);
- a second calculation modulus (112) programmed for receiving each said acceleration signal (SA), each said angular speed signal (SVA), each said tilt signal (SI) and said linear speed signal (SVL), and for calculating a corresponding first corrective factor (FC1) for each said appendage (4);
- a processing module (113) configured for correcting said ideal turn position (PVI) by means of the application of said first corrective factor (FC1), obtaining a corresponding corrected turn position (PVC) for each said appendage (4);
- a driving module (114) configured for receiving each said corrected turn position (PVC) and generating a corresponding first driving signal (SC1) in order to drive the first actuator means (5) of said appendages (4) to independently move each said appendage (4) at least in partial rotation around a corresponding first rotation axis (Y), orthogonal to the main extension axis (X) in order to reach the corresponding said corrected turn position (PVC).

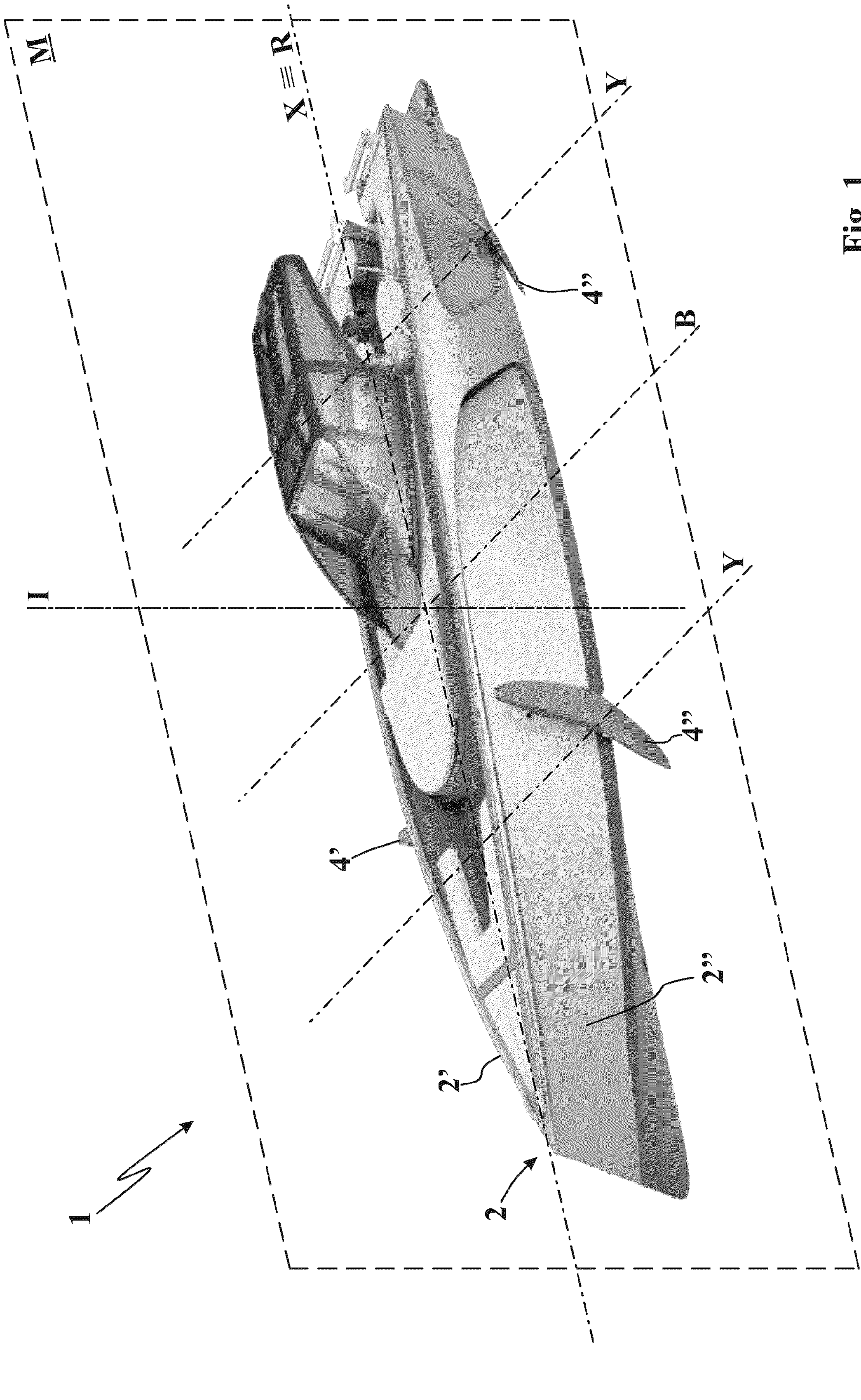

Fig. 1

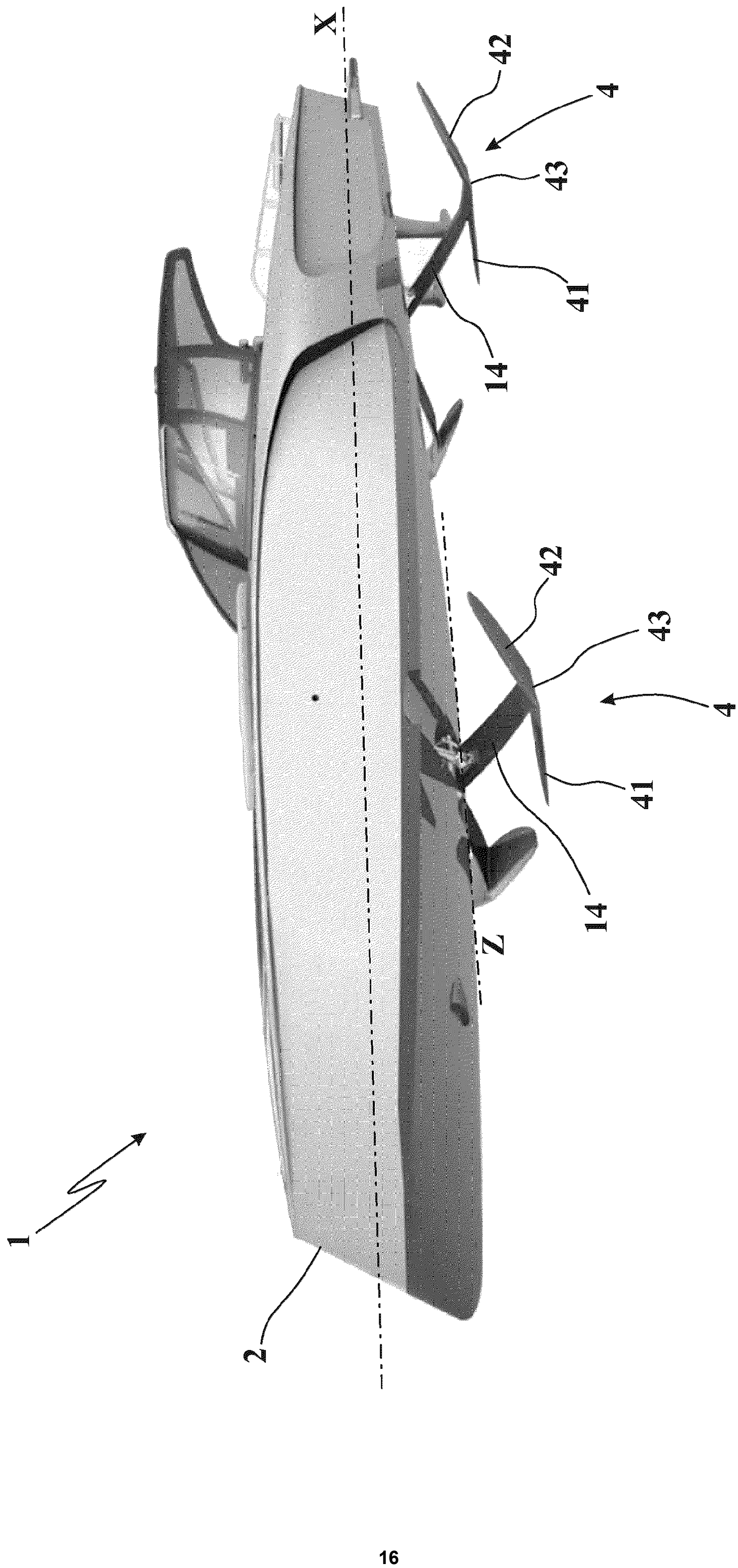

Fig. 2

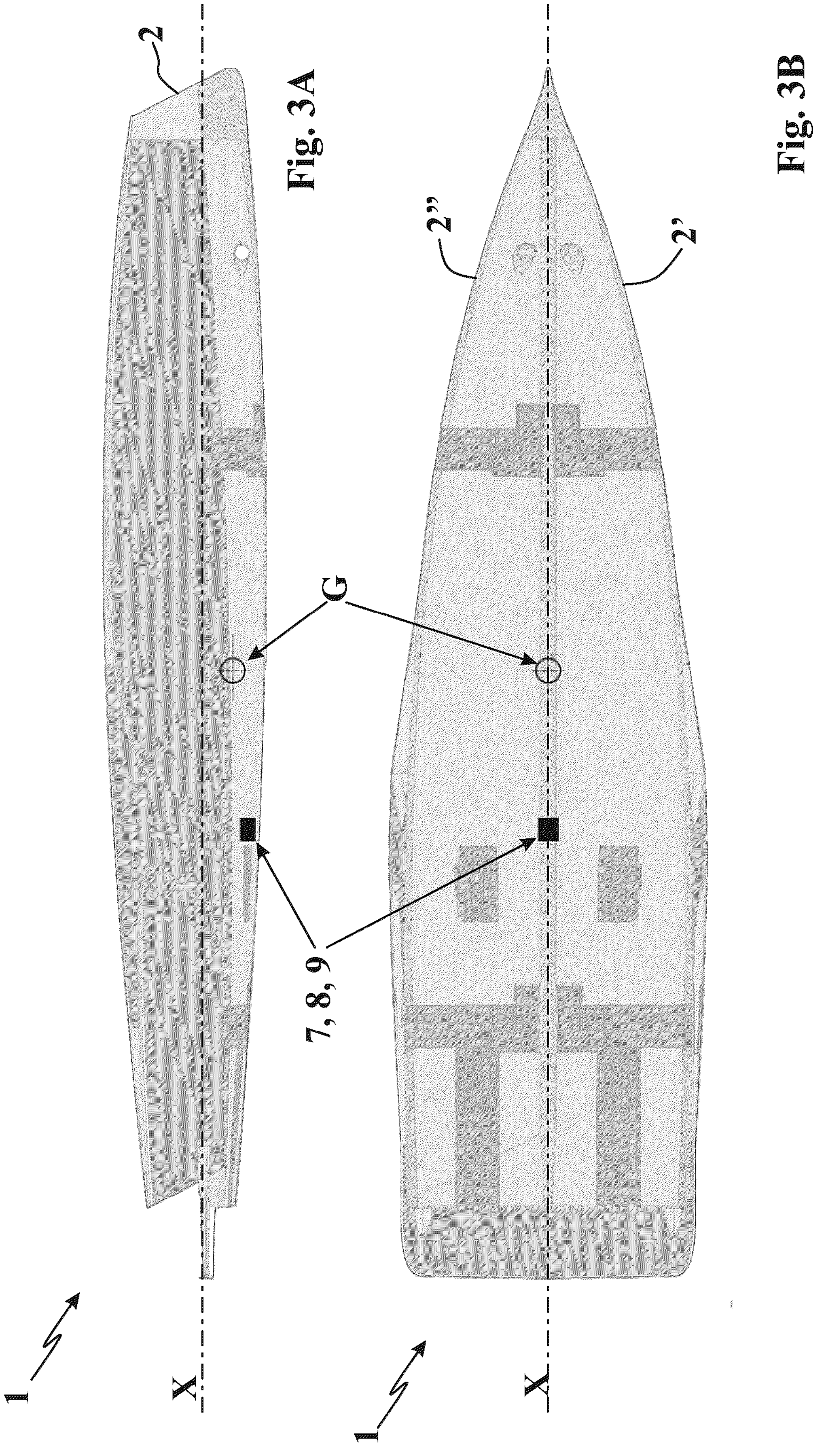

Fig. 3A

Fig. 3B

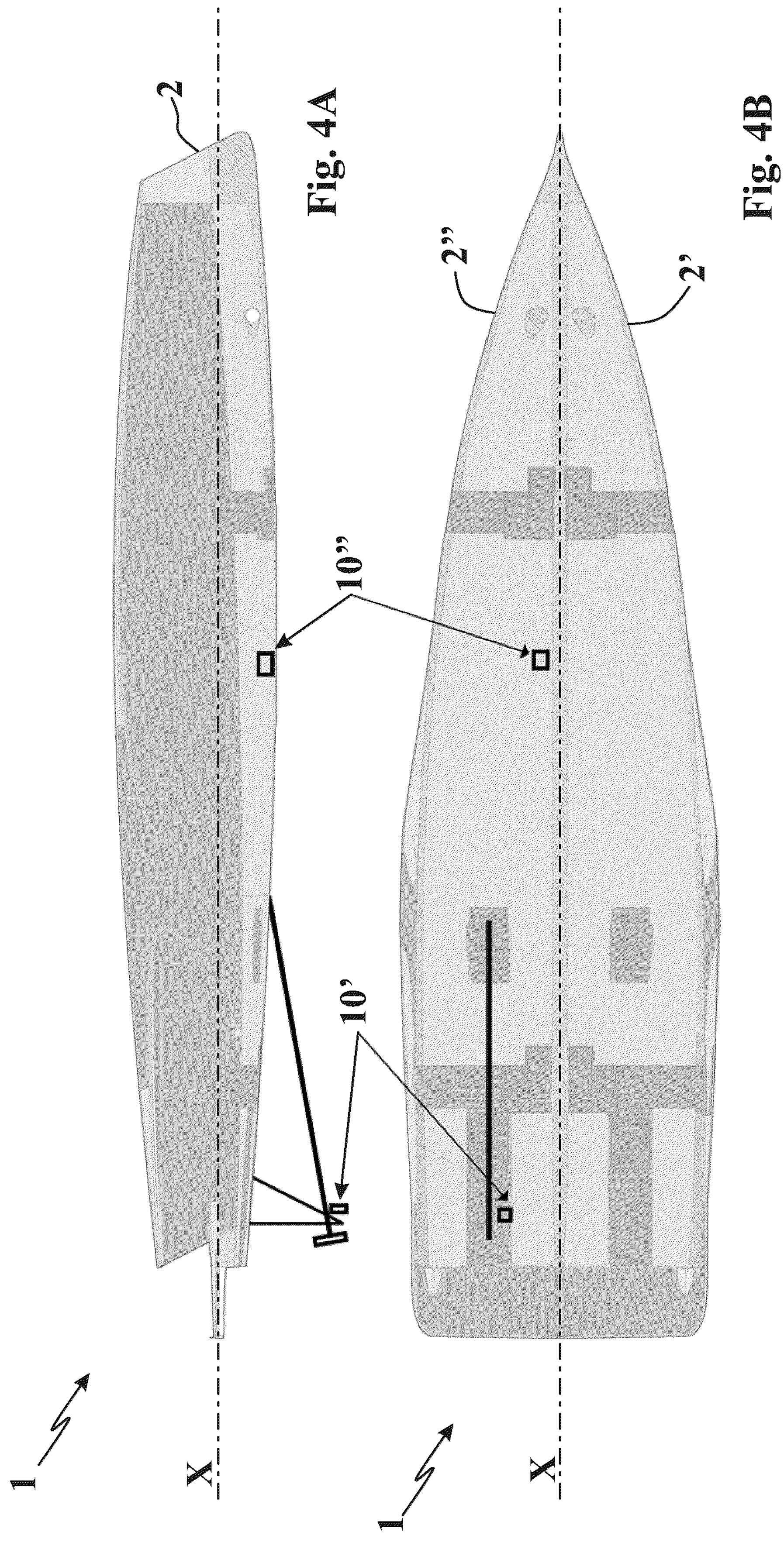

Fig. 4A

Fig. 4B

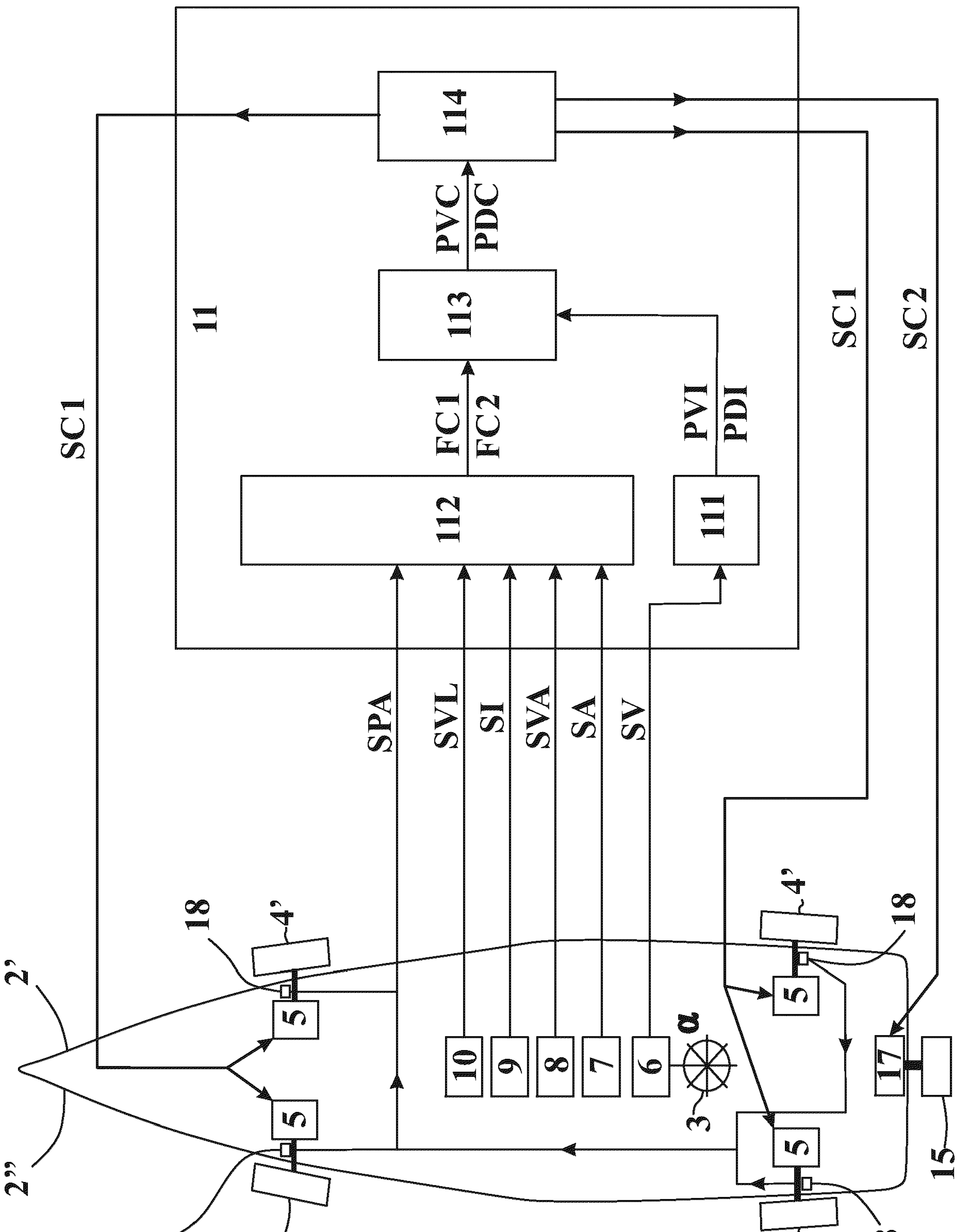
114
113
112
111
11
PVC
PDC
FC1
FC2
PVI
PDI
SC1
SC1
SC2
SPA
SVL
SI
SVA
SA
SV
10
9
8
7
6
α
3
5
17
15
18
4'
4''
2'
2''

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 21 16 3730

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Place of search	Date of completion of the search	Examiner
The Hague	8 September 2021	Barré, Vincent

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