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(54) **PROPELLING EFFICIENCY ENHANCING DEVICE**

VORRICHTUNG ZUR STEIGERUNG DES ANTRIEBSWIRKUNGSGRADES

DISPOSITIF D'AMÉLIORATION DE L'EFFICACITÉ DE PROPULSION

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Description

Technical Field

[0001] The present invention relates to a propulsion efficiency enhancing apparatus.

Background Art

[0002] In order to enhance the propulsion efficiency of a vessel, pre-swirl stators are typically used. The pre-swirl stators make, when a propeller rotates to move the vessel forward, the flow of water around the stern bent in the opposite direction of the rotation direction of the propeller so that the water can flow to the propeller. At this time, swirling flow generated by the pre-swirl stators is absorbed by the propeller so that the propulsion efficiency of the propeller can be enhanced.

[0003] However, the pre-swirl stators act as resistance when the vessel sails, resulting in a deterioration of the resistance performance of the vessel.

[0004] Document JP 2010 179869 A shows a propulsion performance enhancement device comprising a fin and a current plate in which damage of the fin by rolling-in of a foreign matter shall be avoided. Two right and left fins are provided at a slight lower side in a width direction and at an obliquely upper side, and a radius of the fin in the obliquely upper side is made to 85-115% of the propeller radius. A radius of the slightly downward fin in the width direction is made to 35-55% of the propeller radius, and a wing end plate is provided on a distal end.

[0005] Document JP 2011 121569 A discusses a propulsion performance improving device of a ship, which prevents a propeller from being damaged by a vortex generated by reaction fins. It includes a plurality of reaction fins arranged on the front side of a propeller to generate a swirling flow in the inverse direction of the rotational direction of the propeller and radially extending with a rotary shaft of the propeller as the center. The reaction fins include a first reaction fin extending obliquely upward and two further reaction fins extending in the horizontal direction or obliquely downward. A first distance to the blade end of the reaction fin extending obliquely upward from the rotary shaft is larger than a propeller radius of the propeller. A second distance to the blade end of the further reaction fins from the rotary shaft is smaller than the propeller radius.

[0006] Document KR 2012 0126910 A shows a propeller duct structure for a ship with fins in rows. The structure flows parallel flow into a propeller by smoothly flowing fluid because the fins are asymmetrically installed inside a duct member.

[0007] In Document JP 2004 306839 A, propulsive resistance of a ship is reduced by suppressing the generation of tip vortexes in the neighborhood of a blade tip of a reaction fin of the ship. The trailing edge of a reaction fin projecting radially is composed of a blade root leading edge connected to the blade root of the reaction fin, and

a blade tip trailing edge connected to the blade tip of the reaction fin. An angle made by the blade tip trailing edge with the blade tip is larger than an angle made by the blade root trailing edge with the blade tip.

[0008] Document KR 2014 0085644 relates to a pre-swirl stator of a ship, which is provided to increase propulsion efficiency and to decrease erosion of the surface of a propeller. The pre-swirl stator discussed therein is fixed on a shaft of the propeller propelling the ship, and placed on the front side of the propeller. The pre-swirl stator comprises a stator body and a stator end plate formed on the end of the stator body, wherein the stator end plate is formed toward one side of the stator body and has a semi-elliptical shape.

Disclosure

Technical Problem

[0009] An aspect of the present disclosure is to provide a propulsion efficiency enhancing apparatus configured to reduce resistance applied onto pre-swirl stators.

[0010] Also, another aspect of the present disclosure is to provide a propulsion efficiency enhancing apparatus including pre-swirl stators capable of reducing cavitation influencing the propeller. More specifically, the propulsion efficiency enhancing apparatus is configured to reduce cavitation that is generated around the tip portions of the pre-swirl stators.

Technical Solution

[0011] In accordance with an aspect of the present disclosure, there is provided a propulsion efficiency enhancing apparatus including a plurality of pre-swirl stators disposed ahead of a propeller, and arranged radially with respect to a rotation axis of the propeller, wherein the pre-swirl stators are located in a region of a rotation surface of the propeller, where the propeller rotates upward, among the left and right regions of the rotation surface of the propeller, a span length of at least one pre-swirl stator of the pre-swirl stators is different from span lengths of the remaining pre-swirl stators, and a span length of a pre-swirl stator arbitrarily selected from among the pre-swirl stators is longer than or equal to a span length of another pre-swirl stator located just below the selected pre-swirl stator.

[0012] The span lengths of the pre-swirl stators may be reduced sequentially in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.

[0013] The number of the pre-swirl stators may be three, and an installation angle of a first pre-swirl stator located at the uppermost position among the pre-swirl stators may be in a range of 30 degrees to 50 degrees, an installation angle of a second pre-swirl stator located at the middle position may be in a range of 60 degrees to 80 degrees, and an installation angle of a third pre-

swirl stator located at the lowermost position may be in a range of 100 degrees to 120 degrees.

[0014] A span length of the first pre-swirl stator may be in a range of 0.9 times to 1.1 times of the radius of the propeller, a span length of the second pre-swirl stator may be in a range of 0.8 times to 1.0 times of the radius of the propeller, and a span length of the third pre-swirl stator may be in a range of 0.6 times to 0.8 times of the radius of the propeller, and the span lengths of the pre-swirl stators may be reduced sequentially in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.

[0015] The pre-swirl stators may be arranged toward the front direction sequentially in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.

[0016] Chord lengths of the pre-swirl stators may be reduced, at the same radius with respect to the rotation axis, in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.

[0017] The tip portions of the pre-swirl stators have smaller pitch angles than the remaining portions of the pre-swirl stators.

[0018] A winglet may be formed in the tip portion of each pre-swirl stator, and the winglet is bent toward a suction surface or a pressure surface.

[0019] The pitch angles of the tip portions may be reduced continuously toward the tips of the tip portions.

[0020] The tip portions may have lengths of 0.1 times to 0.3 times of the span lengths of the pre-swirl stators.

[0021] The corners of the tips of the tip portions may be rounded, as seen from the pressure surface.

[0022] An additional member may be formed in the tip portion of each pre-swirl stator, and the additional member may be in the shape of a plate extending toward a suction surface and a pressure surface.

Advantageous Effects

[0023] According to the embodiments of the present disclosure, since the span length of at least one of the pre-swirl stators arranged radially is different from those of the remaining pre-swirl stators, and the span length of a pre-swirl stator arbitrarily selected from among the pre-swirl stators is longer than or equal to that of another pre-swirl stator located just below the selected pre-swirl stator, it is possible to reduce resistance applied onto the pre-swirl stators in correspondence to the velocity of inflow, and to enhance the propulsion efficiency of the propeller.

[0024] Also, since the pitch angles of the tip portions of the pre-swirl stators are smaller than those of the remaining portions, an angle of attack with respect to inflow entering the tip portions can become relatively small so as to reduce cavitation generated around the tip portions, and to reduce influence of cavitation generated around the tip portions on the propeller, thereby effectively main-

taining the propulsion efficiency of the propeller.

[0025] Also, the winglets may be formed in the tip portions of the pre-swirl stators to reduce cavitation generated around the tip portions.

[0026] Also, the additional members may be formed in the tip portions of the pre-swirl stators to reduce cavitation generated around the tip portions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

FIG. 1 is a side view of a propulsion efficiency enhancing apparatus according to a first embodiment of the present disclosure.

FIG. 2 is a rear view of the propulsion efficiency enhancing apparatus 100 according to the first embodiment of the present disclosure.

FIG. 3 shows a flow distribution of wake entering the propeller, represented on the rotation surface of the propeller, in the bare hull having no pre-swirl stators, as seen in the front direction from the propeller.

FIG. 4 shows experimental data used in a test for deducing the propulsion efficiency enhancing apparatus according to the first embodiment of the present disclosure.

FIG. 5 shows a propulsion efficiency enhancing apparatus according to a second embodiment of the present disclosure.

FIG. 6A shows a comparative example for performance evaluation of the propulsion efficiency enhancing apparatuses according to the first and second embodiments of the present disclosure.

FIG. 6B shows an experimental example for performance evaluation of the propulsion efficiency enhancing apparatuses according to the first embodiment and the second embodiment,

FIG. 7 shows propulsion force reduction coefficients for the comparative example and the experimental example of FIG. 6.

FIG. 8 is a side view of a propulsion efficiency enhancing apparatus according to a third embodiment of the present disclosure,

FIG. 9 is a rear view of the propulsion efficiency enhancing apparatus according to the third embodiment of the present disclosure.

FIG. 10 is a view for describing the pre-swirl stators of the propulsion efficiency enhancing apparatus ac-

cording to the third embodiment of the present disclosure.

FIG. 11 is a view for comparing the chord lengths of the pre-swirl stators shown in FIG. 8 at the same radius with respect to the rotation axis of the propeller.

FIG. 12 shows a propulsion efficiency enhancing apparatus according to a fourth embodiment of the present disclosure.

FIG. 13 is a side view of a propulsion efficiency enhancing apparatus according to a fifth embodiment of the present disclosure, and

FIG. 14 is a rear view of the propulsion efficiency enhancing apparatus according to the fifth embodiment of the present disclosure.

FIG. 15 shows the cross-section of the tip portion of the pre-swirl stator according to the fifth embodiment of the present disclosure,

FIG. 16 shows the cross-section of the remaining portion of the pre-swirl stator according to the fifth embodiment of the present disclosure.

FIG. 17 is a view for describing the pre-swirl stators of the propulsion efficiency enhancing apparatus according to the fifth embodiment of the present disclosure.

FIG. 18 shows a propulsion efficiency enhancing apparatus according to a sixth embodiment of the present disclosure.

FIG. 19 is a side view of a propulsion efficiency enhancing apparatus according to a seventh embodiment of the present disclosure,

FIG. 20 is a rear view of the propulsion efficiency enhancing apparatus according to the seventh embodiment of the present disclosure.

FIG. 21 shows a propulsion efficiency enhancing apparatus according to an eighth embodiment of the present disclosure.

Best Mode

[0028] The present disclosure allows various variations and includes various embodiments, and specific embodiments of the present disclosure will be illustrated in the accompanying drawings and described in detail in the detailed description. However, the present disclosure is not limited to these specific embodiments, and it should be understood that all modifications, equivalents, and

substitutes can be made without departing from the technical idea and range of the present disclosure. In the following description, when it is determined that the detailed description of the related art well-known in the art may make the gist of the present disclosure obscure, the detailed description will be omitted.

[0029] Hereinafter, the embodiments of the present disclosure will be described in detail with reference to the appended drawings, and in the following description provided with reference to the appended drawings, the same or corresponding components will be represented by the same reference numerals, and the same description will be not repeated for avoiding redundant description.

[0030] FIG. 1 is a side view of a propulsion efficiency enhancing apparatus 100 according to a first embodiment of the present disclosure, and FIG. 2 is a rear view of the propulsion efficiency enhancing apparatus 100 according to the first embodiment of the present disclosure.

[0031] Referring to FIGS. 1 and 2, the propulsion efficiency enhancing apparatus 100 may include pre-swirl stators 110, 120, and 130. The pre-swirl stators 100, 120, and 130 are disposed ahead of propeller 20, and arranged radially with respect to the rotation axis X of the propeller 20.

[0032] The pre-swirl stators 110, 120, and 130 induce water entering the propeller 20 to flow in the opposite direction of the rotation direction of the propeller 20, thus generating swirling flow in the opposite direction of the rotation direction of the propeller 20. The swirling flow generated by the pre-swirl stators 110, 120, and 130 enters the propeller 20 to reduce swirling flow generated in the rotation direction of the propeller 20, thereby enhancing the propulsion efficiency of the propeller 20.

[0033] The pre-swirl stators 110, 120, and 130 may be installed at the stern boss 15 of the vessel body 10, although not limited to this.

[0034] According to the current embodiment, three pre-swirl stators 110, 120, and 130 may be provided. Hereinafter, for convenience of description, the pre-swirl stator 110 located at the uppermost position is referred to as a "first pre-swirl stator 110", the pre-swirl stator 120 located at the middle position is referred to as a "second pre-swirl stator 120", and the pre-swirl stator 130 located at the lowermost position is referred to as a "third pre-swirl stator 130".

[0035] Meanwhile, in the current embodiment, the number of the pre-swirl stators is, for convenience of description, three, however the number of the pre-swirl stators is not limited.

[0036] According to the current embodiment, the propeller 20 may rotate in a clockwise direction, when seen in a rear direction as shown in FIG. 2. In this case, all of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may be located in the left region of the rotation surface P of the propeller 20, where the propeller 20 rotates upward, among the left and right regions of the rotation surface P.

[0037] In regard of this, in the right region of the rotation

surface P of the propeller 20, the direction of inflow entering the propellers 20 may become the opposite direction of the rotation direction of the propeller 20 so that an angle of attack with respect to the sections of the blades of the propeller 20 increases, and a relatively great propulsion force is generated due to the increase of the angle of attack.

[0038] Meanwhile, in the left region of the rotation surface P of the propeller 20, the direction of inflow entering the propeller 20 may become the same direction as the rotation direction of the propeller 20 so that an angle of attack with respect to the sections of the blades of the propeller 20 decreases, and a relatively small propulsion force is generated due to the decrease of the angle of attack.

[0039] Accordingly, by locating the pre-swirl stators 110, 120, and 130 in the left region of the rotation surface P of the propeller 20 to generate flow in the opposite direction of the rotation direction of the propeller 20 in inflow entering the propeller 20, it is possible to increase an angle of attack with respect to the sections of the blades of the propeller 20, and to enhance the propulsion efficiency of the propeller 20.

[0040] Alternatively, the propeller 20 may rotate in a counterclockwise direction as seen in the rear direction, unlike FIG. 2. In this case, all of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may be located in the right region of the rotation surface P of the propeller 20, where the propeller 20 rotates upward, among the left and right regions of the rotation surface P.

[0041] According to the current embodiment, the span lengths of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may be reduced sequentially in the order from the first pre-swirl stator 110 located at the uppermost position to the third pre-swirl stator 130 located at the lowermost position.

[0042] In other words, the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may have different span lengths. Also, one arbitrarily selected from among the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 has a longer span length than another one located just below the selected one.

[0043] The span lengths of the pre-swirl stators 110, 120, and 130 may mean distances from the rotation axis X of the propeller 20 to the tips of the pre-swirl stators 110, 120, and 130.

[0044] FIG. 3 shows a flow distribution of wake entering the propeller, represented on the rotation surface of the propeller, in the barehull having no pre-swirl stators, as seen in the front direction from the propeller.

[0045] In the flow distribution of wake, the velocities of inflow respectively entering the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 sequentially arranged radially with respect to the rotation axis X may increase.

[0046] In correspondence to the increase in velocity of inflow, the span lengths of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may be reduced sequentially. In this case, the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 can prevent resistance from increasing according to the increase in velocity of inflow, in the order from the first pre-swirl stator 110 to the third pre-swirl stator 130.

[0047] In another aspect, referring to FIGS. 2 and 3, the flow velocity of wake on the rotation surface of the propeller (20 of FIG. 1) may intend to be higher at a greater angle in the clockwise or counterclockwise direction with respect to the upper section of a vertical line V, when the rotation axis X of the propeller (20 of FIG. 1) is the center, and the upper section of the vertical line V passing the rotation axis X is 0 degree. In the flow distribution of wake, the velocities of inflow respectively entering the third pre-swirl stator 130, the second pre-swirl stator 120, and the first pre-swirl stator 110 sequentially arranged radially with respect to the rotation axis X may decrease.

[0048] In correspondence to the decrease in velocity of inflow, the span lengths of the third pre-swirl stator 130, the second pre-swirl stator 120, and the first pre-swirl stator 110 may increase sequentially.

[0049] In this case, the third pre-swirl stator 130, the second pre-swirl stator 120, and the first pre-swirl stator 110 may have a more improved function of generating swirling flow in the opposite direction of the rotation direction of the propeller (20 of FIG. 1), in the order from the third pre-swirl stator 130 to the first pre-swirl stator 110. The pre-swirl stators 110, 120, and 130 may have a more improved function of generating swirling flow in the opposite direction of the rotation direction of the propeller (20 of FIG. 1), at the lower velocity of inflow.

[0050] Referring to FIGS. 1 and 2, in the flow distribution of wake as shown in FIG. 3, an installation angle a of the first pre-swirl stator 110 may be in a range of 30 degrees to 50 degrees, an installation angle b of the second pre-swirl stator 120 may be in a range of 60 degrees to 80 degrees, and an installation angle c of the third pre-swirl stator 130 may be in a range of 100 degrees to 120 degrees.

[0051] Herein, the installation angles a, b, and c may be angles of the installation positions of the pre-swirl stators 110, 120, and 130 in the counterclockwise direction with respect to the upper section of the vertical line V, when the rotation axis X of the propeller 20 is the center, and the upper section of the vertical line V passing the rotation axis X is 0 degree.

[0052] If the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 are disposed respectively at the installation angles a, b, and c, resistance in the flow distribution of wake can be minimized.

[0053] FIG. 4 shows experimental data used in a test for deducing the propulsion efficiency enhancing apparatus 100 according to the first embodiment of the present

disclosure. In FIG. 4, the horizontal axis X represents the span lengths of the pre-swirl stators 110, 120, and 130 with respect to the radius R of the propeller 20, and the vertical axis Y represents resistance values calculated through computational fluid dynamics.

[0054] FIG. 4 shows resistance applied to each segment of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130, divided by 0.1 times of the radius R of the propeller 20, through computational fluid dynamics, when the installation angle of the first pre-swirl stator 110 (Stator 1) is in the range of 30 degrees to 50 degrees, the installation angle of the second pre-swirl stator 120 (Stator 2) is in the range of 60 degrees to 80 degrees, the installation angle of the third pre-swirl stator 130 (Stator 3) is in the range of 100 degrees to 120 degrees, and the span lengths of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 are 1.0 times of the radius R of the propeller 20, in the condition of wake as shown in FIG. 3.

[0055] Referring to FIG. 4, resistance applied to the first pre-swirl stator 110 changes to plus (+) at 0.9 times or more of the radius R of the propeller 20, resistance applied to the second pre-swirl stator 120 changes to plus (+) at 0.8 times or more of the radius R of the propeller 20, and resistance applied to the third pre-swirl stator 130 changes to plus (+) at 0.7 times or more of the radius R of the propeller 20.

[0056] Referring to FIG. 2, according to the experimental data, the span length of the first pre-swirl stator 110 may be decided to be in a range of 0.9 times to 1.1 times of the radius R of the propeller 20, the span length of the second pre-swirl stator 120 may be decided to be in a range of 0.8 times to 1.0 times of the radius R of the propeller 20, and the span length of the third pre-swirl stator 110 may be decided to be in a range of 0.6 times to 0.8 times of the radius R of the propeller 20.

[0057] In this case, resistance caused by inflow entering the pre-swirl stators 110, 120, and 130 can be effectively reduced.

[0058] Meanwhile, the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may have a swept back wing shape. The trailing edges of the pre-swirl stators 110, 120, and 130 may be located on a straight line that is vertical to the rotation axis X. In this case, the pre-swirl stators 110, 120, and 130 can be located closest to the propeller 20 so that swirling flow generated by the pre-swirl stators 110, 120, and 130 and flowing in the opposite direction of the rotation direction of the propeller 20 can directly enter the propeller 20, thereby enhancing the propulsion efficiency of the propeller 20.

[0059] Meanwhile, the chord lengths of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 at the same radius R with respect to the rotation axis X may be reduced sequentially. Herein, the chord lengths may mean the lengths from the leading edges to the trailing edges in the cross-sections

of the pre-swirl stators 110, 120, and 130.

[0060] The shorter chord lengths of the pre-swirl stators 110, 120, and 130 may mean smaller contact areas with inflow entering the pre-swirl stators 110, 120, and 130. In contrast, the longer chord lengths of the pre-swirl stators 110, 120, and 130 may mean larger contact areas with inflow entering the pre-swirl stators 110, 120, and 130.

[0061] Referring to FIGS. 2 and 3, the velocity of wake on the rotation surface P of the propeller (20 of FIG. 1) may be higher at a greater angle in the clockwise or counterclockwise direction with respect to the upper section of the vertical line V, when the rotation axis X of the propeller (20 of FIG. 1) is the center, and the upper section of the vertical line V passing the rotation axis X is 0 degree.

[0062] In the flow distribution of wake, the velocities of inflow respectively entering the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 sequentially arranged radially with respect to the rotation axis X may increase.

[0063] In correspondence of the increase in velocity of inflow, the chord lengths of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may be reduced sequentially. In this case, the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may prevent resistance from increasing according to the increase in velocity of inflow, in the order from the first pre-swirl stator 110 to the third pre-swirl stator 130.

[0064] Meanwhile, as described above, the installation angles a, b, and c of the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may have predetermined ranges. In the propulsion efficiency enhancing apparatus 100 according to the current embodiment, the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 may be respectively installed within the installation angle ranges.

[0065] According to a second embodiment, two or more first pre-swirl stators 110, two or more second pre-swirl stators 120, and two or more third pre-swirl stators 130 may be respectively installed within the installation angle ranges. In this case, the pre-swirl stators 110, 120, or 130 located within each installation angle range may have the same span length.

[0066] FIG. 5 shows a propulsion efficiency enhancing apparatus 200 according to a second embodiment of the present disclosure. Referring to FIG. 5, the propulsion efficiency enhancing apparatus 200 according to the current embodiment may include a first pre-swirl stator 210, a second pre-swirl stator 220, and a third pre-swirl stator 230.

[0067] The first pre-swirl stator 210, the second pre-swirl stator 220, and the third pre-swirl stator 230 according to the current embodiment may have the same features as the first pre-swirl stator 110, the second pre-swirl stator 120, and the third pre-swirl stator 130 according

to the previous embodiment, and accordingly, detailed descriptions thereof will be omitted.

[0068] The first pre-swirl stator 210, the second pre-swirl stator 220, and the third pre-swirl stator 230 may be arranged sequentially toward the front direction. That is, the third pre-swirl stator 230 may be located at the foremost position, the second pre-swirl stator 220 may be located at the middle position, and the first pre-swirl stator 210 may be located at the rearmost position.

[0069] As such, if the first pre-swirl stator 210, the second pre-swirl stator 220, and the third pre-swirl stator 230 are spaced predetermined distances in the longitudinal direction of the vessel body, resistance applied onto the vessel body can be reduced compared to when the pre-swirl stators 210, 220, and 230 are arranged on the same line in the longitudinal direction of the vessel body.

[0070] FIG. 6 shows a comparative example 100 and an experimental example 200 for performance evaluation of the propulsion efficiency enhancing apparatuses according to the first embodiment and the second embodiment, and FIG. 7 shows propulsion force reduction coefficients t for the comparative example 100 and the experimental example 200 of FIG. 6.

[0071] FIG. 6A shows the propulsion efficiency enhancing apparatus (hereinafter, referred to as a "comparative example 100") according to the first embodiment of the present disclosure in which stators are located on the same line in the longitudinal direction of the vessel body, and FIG. 6B shows the propulsion efficiency enhancing apparatus (hereinafter, referred to as an "experimental example 200") according to the second embodiment of the present disclosure in which stators are located sequentially toward the front direction.

[0072] By interpreting resistance and self-propulsion performance through computational fluid dynamics on the comparative example 100 and the experimental example 200 shown in FIG. 6, resistance for each example and resistance applied onto the vessel body upon self-propulsion for each example can be deduced, and the propulsion force reduction coefficients t as shown in FIG. 7 can be obtained through the deduced resistance.

[0073] Referring to FIG. 7, it can be seen that the propulsion force reduction coefficient t of the experimental example 200 is smaller than the propulsion force reduction coefficient t of the comparative example 100.

[0074] The results are obtained since the venturi effect generated between the pre-swirl stators 210, 220, and 230 is weakened when the first pre-swirl stator 210, the second pre-swirl stator 220, and the third pre-swirl stator 230 are spaced predetermined distances in the longitudinal direction of the vessel body, to reduce resistance applied onto the vessel body.

[0075] Referring to FIG. 5, a distance D1 between the first pre-swirl stator 210 and the second pre-swirl stator 220 in the longitudinal direction of the vessel body, and a distance D2 between the second pre-swirl stator 220 and the third pre-swirl stator 230 in the longitudinal direction of the vessel body may be in a range of 0.05 times

to 0.15 times of the diameter of the propeller 20.

[0076] If the distances D1 and D2 between the pre-swirl stators 210, 220, and 230 in the longitudinal direction of the vessel body exceed the range, the pre-swirl stators 210, 220, and 230 may become distant from the propeller 20 so that flow induced by the pre-swirl stators 210, 220, and 230 does not sufficiently enter the propeller 20, thereby deteriorating the propulsion efficiency of the propeller 20.

[0077] Also, if the distances D1 and D2 between the pre-swirl stators 210, 220, and 230 are smaller than the range, resistance applied onto the vessel body may increase by the venturi effect generated between the pre-swirl stators 210, 220, and 230.

[0078] Meanwhile, in the above-described embodiments, the number of the pre-swirl stators is, for convenience of description, three, however, the number of pre-swirl stators is not limited to three.

[0079] For example, the number of the pre-swirl stators may be two. Hereinafter, for convenience of description, the pre-swirl stator located at the upper position is referred to as a "first pre-swirl stator", and the pre-swirl stator located at the lower position is referred to as a "second pre-swirl stator".

[0080] In this case, an installation angle of the first pre-swirl stator may be in a range of 45 degrees to 75 degrees, and an installation angle of the second pre-swirl stator may be in a range of 90 degrees to 120 degrees. The ranges of the installation angles may be calculated by the same method as described above in the previous embodiment.

[0081] The span length of the first pre-swirl stator is longer than that of the second pre-swirl stator. In other words, the span length of the second pre-swirl stator located at the lower position may be shorter than that of the first pre-swirl stator located at the upper position.

[0082] Also, the span length of the first pre-swirl stator may be in a range of 0.8 times to 1.0 times of the radius of the propeller 20, and the span length of the second pre-swirl stator may be in a range of 0.6 times to 0.8 times of the radius of the propeller 20. The ranges of the span lengths may be calculated by the same method as described above in the previous embodiment.

[0083] Also, the first pre-swirl stator and the second pre-swirl stator may have a swept back wing shape.

[0084] Also, the chord length of the first pre-swirl stator may be longer than that of the second pre-swirl stator. In other words, the chord length of the second pre-swirl stator located at the lower position may be shorter than that of the first pre-swirl stator located at the upper position.

[0085] Also, the second pre-swirl stator may be positioned ahead of the first pre-swirl stator. In this case, the distance between the first pre-swirl stator and the second pre-swirl stator may be in a range of 0.05 times to 0.15 times of the diameter of the propeller.

[0086] As another example, the number of the pre-swirl stators may be three. Hereinafter, for convenience of de-

scription, the pre-swirl stator 110 located at the uppermost position is referred to as a "first pre-swirl stator", the pre-swirl stator 120 located at the middle position is referred to as a "second pre-swirl stator", and the pre-swirl stator 130 located at the lowermost position is referred to as a "third pre-swirl stator".

[0087] In this case, an installation angle of the first pre-swirl stator 110 may be in a range of 30 degrees to 50 degrees, an installation angle of the second pre-swirl stator 120 may be in a range of 60 degrees to 80 degrees, and an installation angle of the third pre-swirl stator 130 may be in a range of 100 degrees to 120 degrees. The ranges of the installation angles may be calculated by the same method as described above in the previous embodiments.

[0088] Also, the span length of the first pre-swirl stator 110 may be longer than that of the second pre-swirl stator 120, and the span length of the second pre-swirl stator 120 may be longer than that of the third pre-swirl stator 130. In other words, the span lengths of the pre-swirl stators 110 to 130 may be reduced sequentially in the order from the first pre-swirl stator 110 located at the uppermost position to the third pre-swirl stator 130 located at the lowermost position.

[0089] Also, the span length of the first pre-swirl stator 110 may be in a range of 0.9 times to 1.1 times of the radius R of the propeller 20, the span length of the second pre-swirl stator 120 may be in a range of 0.8 times to 1.0 times of the radius R of the propeller 20, and the span length of the third pre-swirl stator 130 may be in a range of 0.6 times to 0.8 times of the radius R of the propeller 20. The ranges of the span lengths may be calculated by the same method as described above in the previous embodiments. Also, in the overlapping areas of the ranges, the length of the pre-swirl stator located at the upper position may be decided to be longer than that of the pre-swirl stator located at the lower position.

[0090] FIG. 8 is a side view of a propulsion efficiency enhancing apparatus 300 according to a third embodiment of the present disclosure, and FIG. 9 is a rear view of the propulsion efficiency enhancing apparatus 300 according to the third embodiment of the present disclosure.

[0091] Referring to FIGS. 8 and 9, the propulsion efficiency enhancing apparatus 300 may include pre-swirl stators 310, 320, and 330.

[0092] The pre-swirl stators 310, 320, and 330 induce water entering the propeller 20 to flow in the opposite direction of the rotation direction of the propeller 20, thus generating swirling flow in the opposite direction of the rotation direction of the propeller 20. The swirling flow generated by the pre-swirl stators 310, 320, and 330 may enter the propeller 20 to reduce swirling flow generated in the rotation direction of the propeller 20, thereby enhancing the propulsion efficiency of the propeller 20.

[0093] The pre-swirl stators 310, 320, and 330 may be installed at the stern boss 15 of the vessel body 10, although not limited to this.

[0094] In the current embodiment, the number of the

pre-swirl stators 310, 320, and 330 is, for convenience of description, three, however, the number of pre-swirl stators 310, 320, and 330 is not limited to three. For example, the propulsion efficiency enhancing apparatus 300 may include a plurality of pre-swirl stators.

[0095] FIG. 10 is a view for describing the pre-swirl stators of the propulsion efficiency enhancing apparatus 300 according to the third embodiment of the present disclosure. In FIG. 10, the left direction represents the front direction of the pre-swirl stator 310, and the right direction represents the rear direction of the pre-swirl stator 310.

[0096] Referring to FIG. 10, the tip portions 311, 321, and 331 of the pre-swirl stators 310, 320, and 330 have smaller pitch angles than the remaining portions 312, 322, and 332 of the pre-swirl stators 310, 320, and 330. In this case, the remaining portions 312, 322, and 332 of the pre-swirl stators 310, 320, and 330 may have the same pitch angle or partially different pitch angles.

[0097] If the pitch angles of the tip portions 311, 321, and 331 are smaller than those of the remaining portions 312, 322, and 332, an angle of attack with respect to inflow entering the tip portions 311, 321, and 331 may be reduced so that cavitation generated around the tip portions 311, 321, and 331 can be reduced. In this case, cavitation generated by the tip portions 311, 321, and 331 of the pre-swirl stators 310, 320, and 330 may less influence the propeller 20, thereby effectively maintaining the propulsion efficiency of the propeller 20.

[0098] The tip portions 311, 321, and 331 may have lengths LT of 0.1 times to 0.3 times of the span lengths LX of the pre-swirl stators 310, 320, and 330. The span lengths LX of the pre-swirl stators 310, 320, and 330 may mean distances from the rotation axis X of the propeller 20 to the tips of the pre-swirl stators 310, 320, and 330.

[0099] The present applicant has performed a test on a general pre-swirl stator in which the pitch angles of the tip portions are not smaller than those of the remaining portions, and found that cavitation generated around the tips of the pre-swirl stators flows to a slipstream to hit the surfaces of the propeller hard.

[0100] Also, the present applicant has found that the general pre-swirl stator dominantly generates swirling flow in the opposite direction of the rotation direction of the propeller in a region of 0.7 times to 0.9 time of the span length of the pre-swirl stator.

[0101] Based on the test results, in order for the pre-swirl stators 310, 320, and 330 to smoothly generate swirling flow, while reducing cavitation generated around the tips, the lengths of the tip portions 311, 321, and 331 may be decided to be in a range of 0.1 times to 0.3 times of the span lengths of the pre-swirl stators 310, 320, and 330.

[0102] If the pitch angles of the tip portions 311, 322, and 331 having the lengths are smaller than those of the remaining portions 312, 322, and 332, cavitation generated around the tip portions 311, 321, and 331 can be effectively reduced.

[0103] The pitch angles of the tip portions 311, 321, and 331 may be reduced continuously toward the tips. In this case, additional cavitation that may be generated when the shapes of the tip portions 311, 321, and 331 are discontinuous can be effectively prevented.

[0104] The corners of the tips of the tip portions 311, 321, and 331 may be, as shown in FIG. 10, rounded, as seen from a pressure surface 301 (or a suction surface). In other words, the front and rear corners of the tip portions 311, 321, and 331 may be rounded, as seen from the lateral sides.

[0105] In this case, cavitation generated around the tip portions 311, 321, and 331 can be reduced, compared to the general pre-swirl stators in which the front and rear corners of the tip portions are squared as seen from the lateral sides.

[0106] The tip portions 311, 321, and 331 may be fabricated by casting. In this case, the tip portions 311, 321, and 331 can be easily fabricated so that the pre-swirl stators 310, 320, and 330 including the tip portions 311, 321, and 331 can also be easily fabricated. Alternatively, the tip portions 311, 321, and 331 may be fabricated by any other various methods, instead of casting.

[0107] The tip portions 311, 321, and 331 may be fabricated separately, and then coupled with the remaining portions 312, 322, and 332 of the pre-swirl stators 310, 320, and 330, although not limited to this.

[0108] The present applicant has discovered that the propulsion efficiency enhancing apparatus 300 configured as described above can reduce cavitation, through a cavitation tunnel test.

[0109] FIG. 11 is a view for comparing the chord lengths of the pre-swirl stators shown in FIG. 8 at the same radius with respect to the rotation axis of the propeller.

[0110] Referring to FIGS. 8 to 11, a pre-swirl stator arbitrarily selected from among the first pre-swirl stator 310, the second pre-swirl stator 320, and the third pre-swirl stator 330 at the same radius with respect to the rotation axis X of the propeller 20 may have a longer chord length than another pre-swirl stator located just below the selected pre-swirl stator.

[0111] In other words, the chord lengths of the first pre-swirl stator 310, the second pre-swirl stator 320, and the third pre-swirl stator 330 at the same radius R with respect to the rotation axis X of the propeller 20 may be reduced sequentially. Herein, the chord lengths of the pre-swirl stators 310, 320, and 330 may mean the lengths from the leading edges 302 to the trailing edges 303 in the cross-sections of the pre-swirl stators 310, 320, and 330.

[0112] The shorter chord lengths of stators may mean smaller contact areas with inflow entering the stators. In contrast, the longer chord lengths of stators may mean larger contact areas with inflow entering the stators.

[0113] Also, the velocity of wake on the rotation surface P of the propeller (20 of FIG. 8) may intend to be higher at a greater angle in the clockwise or counterclockwise

direction with respect to the upper section of a vertical line V, when the rotation axis X of the propeller (20 of FIG. 8) is the center, and the upper section of the vertical line V passing the rotation axis X is 0 degree.

[0114] In the flow distribution of wake, the velocities of inflow respectively entering the first pre-swirl stator 310, the second pre-swirl stator 320, and the third pre-swirl stator 330 sequentially arranged radially with respect to the rotation axis X may increase.

[0115] In correspondence of the increase in velocity of inflow, the chord lengths of the first pre-swirl stator 310, the second pre-swirl stator 320, and the third pre-swirl stator 330 may be reduced sequentially. In this case, the first pre-swirl stator 310, the second pre-swirl stator 320, and the third pre-swirl stator 330 may prevent resistance from increasing according to the increase in velocity of inflow, in the order from the first pre-swirl stator 310 to the third pre-swirl stator 330.

[0116] FIG. 12 shows a propulsion efficiency enhancing apparatus 400 according to a fourth embodiment of the present disclosure. Referring to FIG. 12, the propulsion efficiency enhancing apparatus 400 according to the current embodiment may include a first pre-swirl stator 410, a second pre-swirl stator 420, and a third pre-swirl stator 430.

[0117] The first pre-swirl stator 410, the second pre-swirl stator 420, and the third pre-swirl stator 430 according to the current embodiment may have the same features as the first pre-swirl stator 310, the second pre-swirl stator 320, and the third pre-swirl stator 330 according to the previous embodiment, and accordingly, detailed descriptions thereof will be omitted.

[0118] In the current embodiment, a pre-swirl stator arbitrarily selected from among the first pre-swirl stator 410, the second pre-swirl stator 420, and the third pre-swirl stator 430 may be located behind another pre-swirl stator located just below the selected pre-swirl stator.

[0119] In other words, the first pre-swirl stator 410, the second pre-swirl stator 420, and the third pre-swirl stator 430 may be arranged sequentially toward the front direction. That is, the first pre-swirl stator 410 may be located at the rearmost position, the second pre-swirl stator 420 may be located at the middle position, and the third pre-swirl stator 430 may be located at the foremost position.

[0120] As such, if the first pre-swirl stator 410, the second pre-swirl stator 420, and the third pre-swirl stator 430 are spaced predetermined distances in the longitudinal direction of the vessel body 10, resistance applied onto the vessel body 10 can be reduced compared to when the pre-swirl stators 410, 420, and 430 are arranged on the same line in the longitudinal direction of the vessel body 10.

[0121] FIG. 13 is a side view of a propulsion efficiency enhancing apparatus 500 according to a fifth embodiment of the present disclosure, and FIG. 14 is a rear view of the propulsion efficiency enhancing apparatus 500 according to the fifth embodiment of the present disclosure.

[0122] Referring to FIGS. 13 and 14, the propulsion

efficiency enhancing apparatus 500 may include pre-swirl stators 510, 520, and 530.

[0123] The pre-swirl stators 510, 520, and 530 induce water entering the propeller 20 to flow in the opposite direction of the rotation direction of the propeller 20, thus generating swirling flow in the opposite direction of the rotation direction of the propeller 20. The swirling flow generated by the pre-swirl stators 510, 520, and 530 may enter the propeller 20 to reduce swirling flow generated in the rotation direction of the propeller 20, thereby enhancing the propulsion efficiency of the propeller 20.

[0124] The pre-swirl stators 510, 520, and 530 may be installed at the stern boss 15 of the vessel body 10, although not limited to this.

[0125] In the current embodiment, the number of the pre-swirl stators 510, 520, and 530 is, for convenience of description, three, however, the number of pre-swirl stators 510, 520, and 530 is not limited to three. For example, the propulsion efficiency enhancing apparatus 500 may include a plurality of pre-swirl stators.

[0126] In the current embodiment, winglets 5111, 5211, and 5311 may be formed in the tip portions 511, 521, and 531 of the pre-swirl stators 510, 520, and 530.

[0127] The winglets 5111, 5211, and 5311 may be bent toward a suction surface 502 from the tips of the tip portions 511, 521, and 531. Alternatively, the winglets 5111, 5211, and 5311 may be bent toward a pressure surface 501 from the tips of the tip portions 511, 521, and 531.

[0128] The winglets 5111, 5211, and 5311 may be bent vertically from the tips of the tip portions 511, 521, and 531, although not limited to this.

[0129] The winglets 5111, 5211, and 5311 can reduce swirling flow generated around the tips of the tip portions 511, 521, and 531, thereby consequentially suppressing the generation of cavitation.

[0130] The tip portions 511, 521, and 531 may be fabricated by casting. In this case, the tip portions 511, 521, and 531 can be easily fabricated so that the pre-swirl stators 510, 520, and 530 including the tip portions 511, 521, and 531 can also be easily fabricated. Alternatively, the tip portions 511, 521, and 531 may be fabricated by any other various methods, instead of casting.

[0131] The winglets 5111, 5211, and 5311 may be integrated into the tip portions 511, 521, and 531, although not limited to this.

[0132] FIG. 15 shows the cross-section of the tip portion of the pre-swirl stator according to the fifth embodiment of the present disclosure, and FIG. 16 shows the cross-section of the remaining portion of the pre-swirl stator according to the fifth embodiment of the present disclosure.

[0133] Referring to FIGS. 14 to 16, the tip portions 511, 521, and 531 of the pre-swirl stators 510, 520, and 530 may have no cambers, and the remaining portions 512, 522, and 532 may have cambers.

[0134] Since the tip portions 511, 521, and 531 have no cambers, a difference in pressure between the pressure surface 501 and the suction surface 502 may be

reduced to reduce the generation of cavitation. However, unlike this, in the pre-swirl stators 510, 520, and 530 according to the current embodiment of the present disclosure, cambers may be formed in all of the tip portions 511, 521, and 531 and the remaining portions 512, 522, and 532. Also, it is possible that cambers are formed in the tip portions 511, 521, and 531 of the pre-swirl stators 510, 520, and 530, and no cambers are formed in the remaining portions 512, 522, and 532.

[0135] If the remaining portions 512, 522, and 532 have cambers, flow entering the propeller (20 of FIG. 13) can be more effectively induced in the opposite direction of the rotation direction of the propeller (20 of FIG. 13), compared to when the remaining portions 512, 522, and 532 have no cambers.

[0136] FIG. 17 is a view for describing the pre-swirl stators of the propulsion efficiency enhancing apparatus 500 according to the fifth embodiment of the present disclosure.

[0137] Referring to FIGS. 13 and 17, the tip portions 511, 521, and 531 may have lengths LT of 0.1 times to 0.3 times of the span lengths LX of the pre-swirl stators 510, 520, and 530. The span lengths LX of the pre-swirl stators 510, 520, and 530 may mean distances from the rotation axis X of the propeller 20 to the tips of the pre-swirl stators 510, 520, and 530.

[0138] The present applicant has performed a test on a pre-swirl stator in which a camber is formed in the entire area from the root portion to the tip portion, and found that cavitation generated around the tip of the pre-swirl stator flows to a slipstream to hit the surfaces of the propeller hard.

[0139] Also, the present applicant has discovered that the pre-swirl stator in which the camber is formed in the entire area dominantly generates swirling flow in the opposite direction of the rotation direction of the propeller 20 in a region of 0.7 times and 0.9 time of the span length of the pre-swirl stator.

[0140] Based on the test results, in order for the pre-swirl stators 510, 520, and 530 to smoothly generate swirling flow, while reducing cavitation generated around the tips, the lengths of the tip portions 511, 521, and 531 may be decided to be in a range of 0.1 times to 0.3 times of the span lengths of the pre-swirl stators 510, 520, and 530.

[0141] If the tip portions 511, 522, and 531 having the lengths are fabricated without forming any cambers, cavitation generated around the tip portions 511, 521, and 531 can be effectively reduced.

[0142] In the current embodiment, the corners of the tips of the tip portions 511, 521, and 531 may be, as shown in FIGS. 13 and 17, rounded, as seen from the pressure surface 501 (or the suction surface 502). The shapes of the tips of the tip portions 511, 521, and 531 can reduce the generation of cavitation.

[0143] The present applicant has discovered that the propulsion efficiency enhancing apparatus 500 configured as described above can reduce cavitation, through

a cavitation tunnel test.

[0144] Hereinafter, the propulsion efficiency enhancing apparatus 500 will be described with reference to FIGS. 13 and 14, under an assumption that the propulsion efficiency enhancing apparatus 500 has a plurality of pre-swirl stators.

[0145] Referring to FIGS. 13 and 14, the propulsion efficiency enhancing apparatus 500 according to the current embodiment may include three pre-swirl stators 510, 520, and 530. For convenience of description, the pre-swirl stator 510 located at the uppermost position is referred to as a "first pre-swirl stator 510", the pre-swirl stator 520 located at the middle position is referred to as a "second pre-swirl stator 520", and the pre-swirl stator 530 located at the lowermost position is referred to as a "third pre-swirl stator 530".

[0146] The first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 disposed ahead of the propeller 20, and spaced from each other. For example, the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 are arranged radially with respect to the rotation axis X of the propeller 20, as shown in FIG. 14.

[0147] In the current example, the propeller 20 may rotate in the clockwise direction, as shown in FIG. 14. In this case, all of the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may be located in the left region of the rotation surface P of the propeller 20, where the propeller 20 rotates upward, among the left and right regions of the rotation surface P.

[0148] In regard of this, in the right region of the rotation surface P of the propeller 20, the direction of inflow entering the propeller 20 may become the opposite direction of the rotation direction of the propeller 20 so that an angle of attack with respect to the sections of the blades of the propeller 20 increases, and a relatively great propulsion force is generated due to the increase of the angle of attack.

[0149] Meanwhile, in the left region of the rotation surface P of the propeller 20, the direction of inflow entering the propeller 20 may become the same direction as the rotation direction of the propeller 20 so that an angle of attack with respect to the sections of the blades of the propeller 20 decreases, and a relatively small propulsion force is generated due to the decrease of the angle of attack.

[0150] Accordingly, by locating the pre-swirl stators 510, 520, and 530 in the left region of the rotation surface P of the propeller 20 to generate flow in the opposite direction of the rotation direction of the propeller 20 in inflow entering the propeller 20, it is possible to increase an angle of attack with respect to the sections of the blades of the propeller 20, and to enhance the propulsion efficiency of the propeller 20.

[0151] Alternatively, the propeller 20 may rotate in the counterclockwise direction as seen in the rear direction. In this case, unlike FIG. 14, all of the first pre-swirl stator

510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may be located in the right region of the rotation surface P of the propeller 20, where the propeller 20 rotates upward, among the left and right regions of the rotation surface P.

[0152] The span lengths of the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may be reduced sequentially in the order from the first pre-swirl stator 510 located at the uppermost position to the third pre-swirl stator 530 located at the lowermost position. In other words, a pre-swirl stator arbitrarily selected from among the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may have a longer span length than another pre-swirl stator located just below the selected pre-swirl stator.

[0153] Referring to FIG. 13, the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may have a swept back wing shape. In this case, the trailing edges of the pre-swirl stators 510, 520, and 530 may be located on a straight line that is vertical to the rotation axis X.

[0154] In this case, the pre-swirl stators 510, 520, and 530 can be located closest to the propeller 20 so that swirling flow generated by the pre-swirl stators 510, 520, and 530 and flowing in the opposite direction of the rotation direction of the propeller 20 can directly enter the propeller 20, thereby enhancing the propulsion efficiency of the propeller 20.

[0155] Referring to FIG. 13, a pre-swirl stator arbitrarily selected from among the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 at the same radius with respect to the rotation axis X of the propeller 20 may have a longer chord length than another pre-swirl stator located just below the selected pre-swirl stator.

[0156] In other words, the chord lengths of the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 at the same radius R with respect to the rotation axis X of the propeller 20 may be reduced sequentially. Herein, the chord lengths of the pre-swirl stators 510, 520, and 530 may mean the lengths from the leading edges to the trailing edges in the cross-sections of the pre-swirl stators 510, 520, and 530.

[0157] The shorter chord lengths of stators may mean smaller contact areas with inflow entering the stators. In contrast, the longer chord lengths of stators may mean larger contact areas with inflow entering the stators.

[0158] Referring to FIG. 14, the velocity of wake on the rotation surface P of the propeller (20 of FIG. 13) may intend to be higher at a greater angle in the clockwise or counterclockwise direction with respect to the upper section of a vertical line V, when the rotation axis X of the propeller (20 of FIG. 13) is the center, and the upper section of the vertical line V passing the rotation axis X is 0 degree.

[0159] In the flow distribution of wake, the velocities of inflow respectively entering the first pre-swirl stator 510,

the second pre-swirl stator 520, and the third pre-swirl stator 530 sequentially arranged radially with respect to the rotation axis X may increase.

[0160] In correspondence of the increase in velocity of inflow, the chord lengths of the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may be reduced sequentially. In this case, the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 may prevent resistance from increasing according to the increase in velocity of inflow, in the order from the first pre-swirl stator 510 to the third pre-swirl stator 530.

[0161] FIG. 18 shows a propulsion efficiency enhancing apparatus 600 according to a sixth embodiment of the present disclosure. Referring to FIG. 18, the propulsion efficiency enhancing apparatus 600 according to the current embodiment may include a first pre-swirl stator 610, a second pre-swirl stator 620, and a third pre-swirl stator 630.

[0162] The first pre-swirl stator 610, the second pre-swirl stator 620, and the third pre-swirl stator 630 according to the current embodiment may have the same features as the first pre-swirl stator 510, the second pre-swirl stator 520, and the third pre-swirl stator 530 according to the previous embodiment, and accordingly, detailed descriptions thereof will be omitted.

[0163] In the current embodiment, a pre-swirl stator arbitrarily selected from among the first pre-swirl stator 610, the second pre-swirl stator 620, and the third pre-swirl stator 630 may be located behind another pre-swirl stator located just below the selected pre-swirl stator.

[0164] In other words, the first pre-swirl stator 610, the second pre-swirl stator 620, and the third pre-swirl stator 630 may be arranged sequentially toward the front direction. That is, the first pre-swirl stator 610 may be located at the rearmost position, the second pre-swirl stator 620 may be located at the middle position, and the third pre-swirl stator 630 may be located at the foremost position.

[0165] As such, if the first pre-swirl stator 610, the second pre-swirl stator 620, and the third pre-swirl stator 630 are spaced predetermined distances in the longitudinal direction of the vessel body 10, resistance applied onto the vessel body 10 can be reduced compared to when the pre-swirl stators 610, 620, and 630 are arranged on the same line in the longitudinal direction of the vessel body 10.

[0166] FIG. 19 is a side view of a propulsion efficiency enhancing apparatus 700 according to a seventh embodiment of the present disclosure, and FIG. 20 is a rear view of the propulsion efficiency enhancing apparatus 700 according to the seventh embodiment of the present disclosure.

[0167] Referring to FIGS. 19 and 20, the propulsion efficiency enhancing apparatus 700 may include pre-swirl stators 710, 720, and 730.

[0168] The pre-swirl stators 710, 720, and 730 induce water entering the propeller 20 to flow in the opposite direction of the rotation direction of the propeller 20, thus

generating swirling flow in the opposite direction of the rotation direction of the propeller 20. The swirling flow generated by the pre-swirl stators 710, 720, and 730 may enter the propeller 20 to reduce swirling flow generated in the rotation direction of the propeller 20, thereby enhancing the propulsion efficiency of the propeller 20.

[0169] The pre-swirl stators 710, 720, and 730 may be installed at the stern boss 15 of the vessel body 10, although not limited to this.

[0170] In the current embodiment, the number of the pre-swirl stators 710, 720, and 730 is, for convenience of description, three, however, the number of the pre-swirl stators 710, 720, and 730 is not limited to three. For example, the propulsion efficiency enhancing apparatus 700 may include a plurality of pre-swirl stators.

[0171] In the current embodiment, additional members 7111, 7211, and 7311 may be formed in the tip portions 711, 721, and 731 of the pre-swirl stators 710, 720, and 730.

[0172] The additional members 7111, 7211, and 7311 may be formed in the tips of the tip portions 711, 721, and 731. The additional members 7111, 7211, and 7311 can reduce swirling flow generated around the tips of the tip portions 711, 721, and 731, thereby consequentially suppressing the generation of cavitation. The additional members 7111, 7211, and 7311 may function as winglets.

[0173] The additional members 7111, 7211, and 7311 may be in the shape of a plate extending toward the suction surface and the pressure surface. The additional members 7111, 7211, and 7311 may be arranged vertically to the tip portions 711, 721, and 731, although not limited to this.

[0174] The additional members 7111, 7211, and 7311 may be fabricated separately, and then weld-bonded with the tip portions 711, 721, and 731. Alternatively, the additional members 7111, 7211, and 7311 may be integrated into the tip portions 711, 721, and 731 by casting.

[0175] The tip portions 711, 721, and 731 may be fabricated by casting, and then coupled with the remaining portions 712, 722, and 732 of the pre-swirl stators 710, 720, and 730, although not limited to this.

[0176] FIG. 21 shows a propulsion efficiency enhancing apparatus 800 according to an eighth embodiment of the present disclosure. Referring to FIG. 21, the propulsion efficiency enhancing apparatus 800 according to the current embodiment may include a first pre-swirl stator 810, a second pre-swirl stator 820, and a third pre-swirl stator 830.

[0177] The first pre-swirl stator 810, the second pre-swirl stator 820, and the third pre-swirl stator 830 according to the current embodiment may have the same features as the first pre-swirl stator 710, the second pre-swirl stator 720, and the third pre-swirl stator 730 according to the previous embodiment, and accordingly, detailed descriptions thereof will be omitted.

[0178] In the current embodiment, a pre-swirl stator arbitrarily selected from among the first pre-swirl stator

810, the second pre-swirl stator 820, and the third pre-swirl stator 830 may be located behind another pre-swirl stator located just below the selected pre-swirl stator.

[0179] In other words, the first pre-swirl stator 810, the second pre-swirl stator 820, and the third pre-swirl stator 830 may be arranged sequentially toward the front direction. That is, the first pre-swirl stator 810 may be located at the rearmost position, the second pre-swirl stator 820 may be located at the middle position, and the third pre-swirl stator 830 may be located at the foremost position.

[0180] As such, if the first pre-swirl stator 810, the second pre-swirl stator 820, and the third pre-swirl stator 830 are spaced predetermined distances in the longitudinal direction of the vessel body 10, resistance applied onto the vessel body 10 can be reduced compared to when the pre-swirl stators 810, 820, and 830 are arranged on the same line in the longitudinal direction of the vessel body 10.

[0181] It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention by adding, changing, or removing one or more components, without departing from the scope of the inventions. Thus, it is intended that the present invention covers the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

10: vessel body

15: stern boss

20: propeller

100, 200, 300, 400, 500, 600, 700, 800: propulsion efficiency enhancing apparatus

110, 210, 310, 410, 510, 610, 710, 810: first pre-swirl stator

120, 220, 320, 420, 520, 620, 720, 820: second pre-swirl stator

130, 230, 330, 430, 530, 630, 730, 830: third pre-swirl stator

Claims

1. A propulsion efficiency enhancing apparatus (300) for a vessel, comprising a plurality of pre-swirl stators and a propeller (20), the plurality of pre-swirl stators (310, 320, 330) disposed ahead of the propeller (20), and arranged radially with respect to a rotation axis of the propeller (20), wherein the pre-swirl stators (310, 320, 330) are located in a left region or a right region of a rotation surface of the propeller where the propeller (20) rotates upward, to generate flow in a direction opposite to a rotation direction of the propeller (20) in an inflow entering the propeller (20), to increase an angle of attack with respect to sections of blades of the propeller (20), and wherein

a span length of at least one pre-swirl stator of the pre-swirl stators (310, 320, 330) is different from span lengths of the remaining pre-swirl stators, and a span length of a pre-swirl stator arbitrarily selected from among the pre-swirl stators (310, 320, 330) is longer than or equal to a span length of another pre-swirl stator located just below the selected pre-swirl stator,

characterized in that

tip portions (311, 321, 331) of the pre-swirl stators (310, 320, 330) have smaller pitch angles than remaining portions (312, 322, 332) of the pre-swirl stators (310, 320, 330).

2. The propulsion efficiency enhancing apparatus (300) according to claim 1, wherein the span lengths of the pre-swirl stators (310, 320, 330) are reduced sequentially in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.
3. The propulsion efficiency enhancing apparatus (300) according to claim 1 or 2, wherein the number of the pre-swirl stators (310, 320, 330) is three, and wherein an installation angle of a first pre-swirl stator (310) located at the uppermost position among the pre-swirl stators (310, 320, 330) is in a range of 30 degrees to 50 degrees, an installation angle of a second pre-swirl stator (320) located at the middle position is in a range of 60 degrees to 80 degrees, and an installation angle of a third pre-swirl stator (330) located at the lowermost position is in a range of 100 degrees to 120 degrees, the installation angles of the pre-swirl stators (310, 320, 330) being angles of installation positions of the pre-swirl stators (310, 320, 330) with respect to an upper section of a vertical line (V) passing through the rotation axis of the propeller (20), the rotation axis of the propeller (20) being a center and the upper section of the vertical line (V) being 0 degrees.
4. The propulsion efficiency enhancing apparatus (300) according to claim 3, wherein a span length of the first pre-swirl stator (310) is in a range of 0.9 times to 1.1 times of the radius of the propeller (20), a span length of the second pre-swirl stator (320) is in a range of 0.8 times to 1.0 times of the radius of the propeller (20), and a span length of the third pre-swirl stator (330) is in a range of 0.6 times to 0.8 times of the radius of the propeller (20), and wherein the span lengths of the pre-swirl stators (310, 320, 330) are reduced sequentially in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.
5. The propulsion efficiency enhancing apparatus (300) according to claim 1 or 2, wherein the pre-swirl

stators (310, 320, 330) are arranged toward the front direction sequentially in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.

6. The propulsion efficiency enhancing apparatus (300) according to claim 1 or 2, wherein chord lengths of the pre-swirl stators (310, 320, 330) are reduced, at the same radius with respect to the rotation axis, in the order from the pre-swirl stator located at the uppermost position to the pre-swirl stator located at the lowermost position.
7. The propulsion efficiency enhancing apparatus (300) according to claim 1, wherein an additional member is formed in the tip portion (311, 321, 331) of each pre-swirl stator (310, 320, 330), and the additional member is in the shape of a plate extending toward a suction surface and a pressure surface.
8. The propulsion efficiency enhancing apparatus (300) according to claim 1 or 7, wherein the pitch angles of the tip portions (311, 321, 331) are reduced continuously toward the tips of the tip portions (311, 321, 331).
9. The propulsion efficiency enhancing apparatus (300) according to claim 1 or 7, wherein the tip portions (311, 321, 331) have lengths of 0.1 times to 0.3 times of the span lengths of the pre-swirl stators (310, 320, 330).
10. The propulsion efficiency enhancing apparatus (300) according to claim 1 or 7, wherein the corners of the tips of the tip portions (311, 321, 331) are rounded, as seen from the pressure surface.
11. The propulsion efficiency enhancing apparatus (300) according to claim 1, wherein a winglet is formed in the tip portion (311, 321, 331) of each pre-swirl stator (310, 320, 330), and the winglet is bent toward a suction surface or a pressure surface.

Patentansprüche

1. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) für ein Wasserfahrzeug, umfassend eine Vielzahl von Vorleitstatoren und einen Propeller (20),
wobei die Vielzahl von Vorleitstatoren (310, 320, 330) vor dem Propeller (20) angeordnet und, bezogen auf eine Rotationsachse des Propellers (20), radial angeordnet ist,
wobei die Vorleitstatoren (310, 320, 330) in einem linken Bereich oder einem rechten Bereich einer Rotationsfläche des Propellers (20), worin sich der Propeller (20) aufwärts dreht, angeordnet sind zum Er-

zeugen eines Flusses in einer einer Rotationsrichtung des Propellers (20) entgegengesetzten Richtung in einem in den Propeller (20) eintretenden Fluss zum Erhöhen eines auf Flügelabschnitte des Propellers bezogenen Anströmwinkels und wobei eine Spannweite mindestens eines Vorleitstators der Vorleitstatoren (310, 320, 330) sich von Spannweiten der übrigen Vorleitstatoren unterscheidet und eine Spannweite eines willkürlich aus der Vielzahl der Vorleitstatoren (310, 320, 330) ausgewählten Vorleitstators größer als eine Spannweite eines unmittelbar unterhalb des ausgewählten Vorleitstators angeordneten weiteren Vorleitstators oder gleich dieser ist,

gekennzeichnet dadurch, dass

Spitzenabschnitte (311, 321, 331) der Vorleitstatoren (310, 320, 330) kleinere Anstellwinkel als übrige Bereiche (312, 322, 332) der Vorleitstatoren (310, 320, 330) haben.

2. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1, wobei die Spannweiten der Vorleitstatoren (310, 320, 330) in der Reihenfolge von dem an der obersten Position angeordneten Vorleitstator zu dem an der untersten Position angeordneten Vorleitstator sequentiell abnehmen.
3. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1 oder 2, wobei die Anzahl der Vorleitstatoren (310, 320, 330) drei beträgt und
wobei ein Anbringwinkel eines an der obersten Position der Vorleitstatoren (310, 320, 330) angeordneten ersten Vorleitstators (310) in einem Bereich von 30 Grad bis 50 Grad liegt, ein Anbringwinkel eines an der mittleren Position angeordneten zweiten Vorleitstators (320) in einem Bereich von 60 Grad bis 80 Grad liegt und ein Anbringwinkel eines an der untersten Position angeordneten dritten Vorleitstators (330) in einem Bereich von 100 Grad bis 120 Grad liegt,
wobei die Anbringwinkel der Vorleitstatoren (310, 320, 330) Winkel von Anbringpositionen der Vorleitstatoren (310, 320, 330) bezogen auf einen oberen Bereich einer vertikalen Linie (V) sind, welche die Rotationsachse des Propellers (20) schneidet, wobei die Rotationsachse des Propellers (20) ein Zentrum ist und der obere Bereich der vertikalen Linie (V) 0 Grad ist.
4. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 3, wobei eine Spannweite des ersten Vorleitstators (310) in einem Bereich des 0,9-Fachen bis 1,1-Fachen des Radius des Propellers (20) liegt, eine Spannweite des zweiten Vorleitstators (320) in einem Bereich des 0,8-Fachen bis 1,0-Fachen des Radius des Propellers (20)

liegt und eine Spannweite des dritten Vorleitstators (330) in einem Bereich des 0,6-Fachen bis 0,8-Fachen des Radius des Propellers (20) liegt und wobei die Spannweiten der Vorleitstatoren (310, 320, 330) in der Reihenfolge von dem an der obersten Position angeordneten Vorleitstator zu dem an der untersten Position angeordneten Vorleitstator sequentiell abnehmen.

5. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1 oder 2, wobei die Vorleitstatoren (310, 320, 330) in der Reihenfolge von dem an der obersten Position angeordneten Vorleitstator zu dem an der untersten Position angeordneten Vorleitstator sequentiell weiter vorne angeordnet sind. 10
6. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1 oder 2, wobei Profilschneidlängen der Vorleitstatoren (310, 320, 330) in der Reihenfolge von dem an der obersten Position angeordneten Vorleitstator zu dem an der untersten Position angeordneten Vorleitstator an dem gleichen Radius bezogen auf die Rotationsachse abnehmen. 15
7. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1, wobei ein zusätzliches Teil an dem Spitzenabschnitt (311, 321, 331) jedes Vorleitstators (310, 320, 330) ausgebildet ist und das zusätzliche Teil die Form einer sich zu einer Sogfläche und einer Druckfläche hin erstreckenden Platte hat. 20
8. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1 oder 7, wobei die Anstellwinkel der Spitzenabschnitte (311, 321, 331) kontinuierlich zu den Spitzen der Spitzenabschnitte (311, 321, 331) hin abnehmen. 25
9. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1 oder 7, wobei die Spitzenabschnitte (311, 321, 331) Längen vom 0,1-Fachen bis zum 0,3-Fachen der Spannweiten der Vorleitstatoren (310, 320, 330) haben. 30
10. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1 oder 7, wobei die Ecken der Spitzen der Spitzenabschnitte (311, 321, 331) von der Druckfläche aus gesehen abgerundet sind. 35
11. Vorrichtung zur Steigerung des Antriebswirkungsgrades (300) nach Anspruch 1, wobei am Spitzenabschnitt (311, 321, 331) jedes Vorleitstators (310, 320, 330) ein Winglet ausgebildet ist und das Winglet zu einer Sogfläche oder einer Druckfläche hin gebogen ist. 40

Revendications

1. Appareil d'amélioration de l'efficacité de propulsion (300) pour un navire, comprenant une pluralité de stators de pré-déflexion et un organe de propulsion (20), les stators de la pluralité de stators de pré-déflexion (310, 320, 330) étant disposés à l'avant de l'organe de propulsion (20) et étant agencés radialement par rapport à un axe de rotation de l'organe de propulsion (20) ; dans lequel :

les stators de pré-déflexion (310, 320, 330) sont localisés dans une région gauche ou dans une région droite d'une surface de rotation de l'organe de propulsion au niveau de laquelle l'organe de propulsion (20) est entraîné en rotation vers le haut, de manière à ce qu'ils génèrent un écoulement dans une direction opposée à une direction de rotation de l'organe de propulsion (20) au niveau d'un écoulement entrant qui pénètre l'organe de propulsion (20), de manière à augmenter un angle d'attaque par rapport à des sections de pales de l'organe de propulsion (20) ; et dans lequel :

une longueur de portée d'au moins un stator de pré-déflexion (310, 320, 330) est différente de longueurs de portée des stators de pré-déflexion restants ; et

une longueur de portée d'un stator de pré-déflexion qui est sélectionné de façon arbitraire parmi les stators de pré-déflexion (310, 320, 330) est plus longue qu'une longueur de portée d'un autre stator de pré-déflexion qui est localisé juste au-dessous du stator de pré-déflexion sélectionné ou est égale à celle-ci ;

caractérisé en ce que :

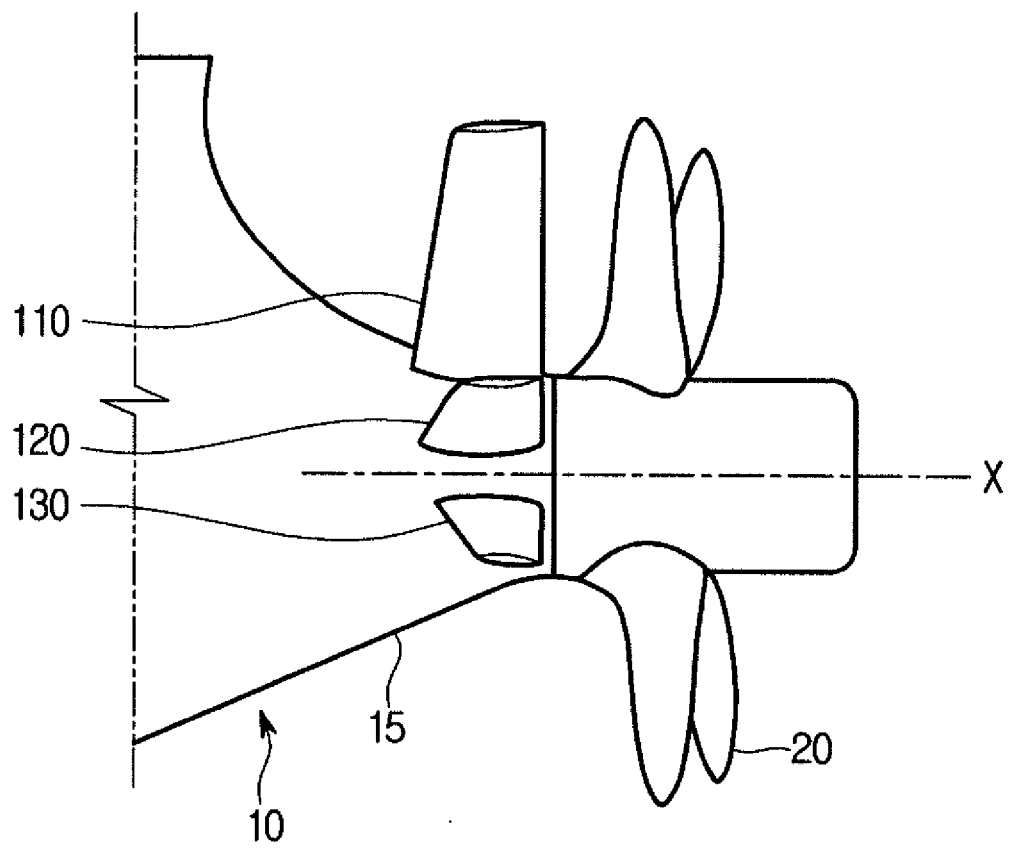
des parties d'extrémité (311, 321, 331) des stators de pré-déflexion (310, 320, 330) présentent des angles d'incidence plus petits que des parties restantes (312, 322, 332) des stators de pré-déflexion (310, 320, 330).

2. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1, dans lequel les longueurs de portée des stators de pré-déflexion (310, 320, 330) sont réduites de façon séquentielle selon l'ordre qui va depuis le stator de pré-déflexion qui est localisé au niveau de la position la plus haute jusqu'au stator de pré-déflexion qui est localisé au niveau de la position la plus basse.
3. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1 ou 2, dans lequel : le nombre des stators de pré-déflexion (310, 320, 330) est de trois ; et dans lequel :

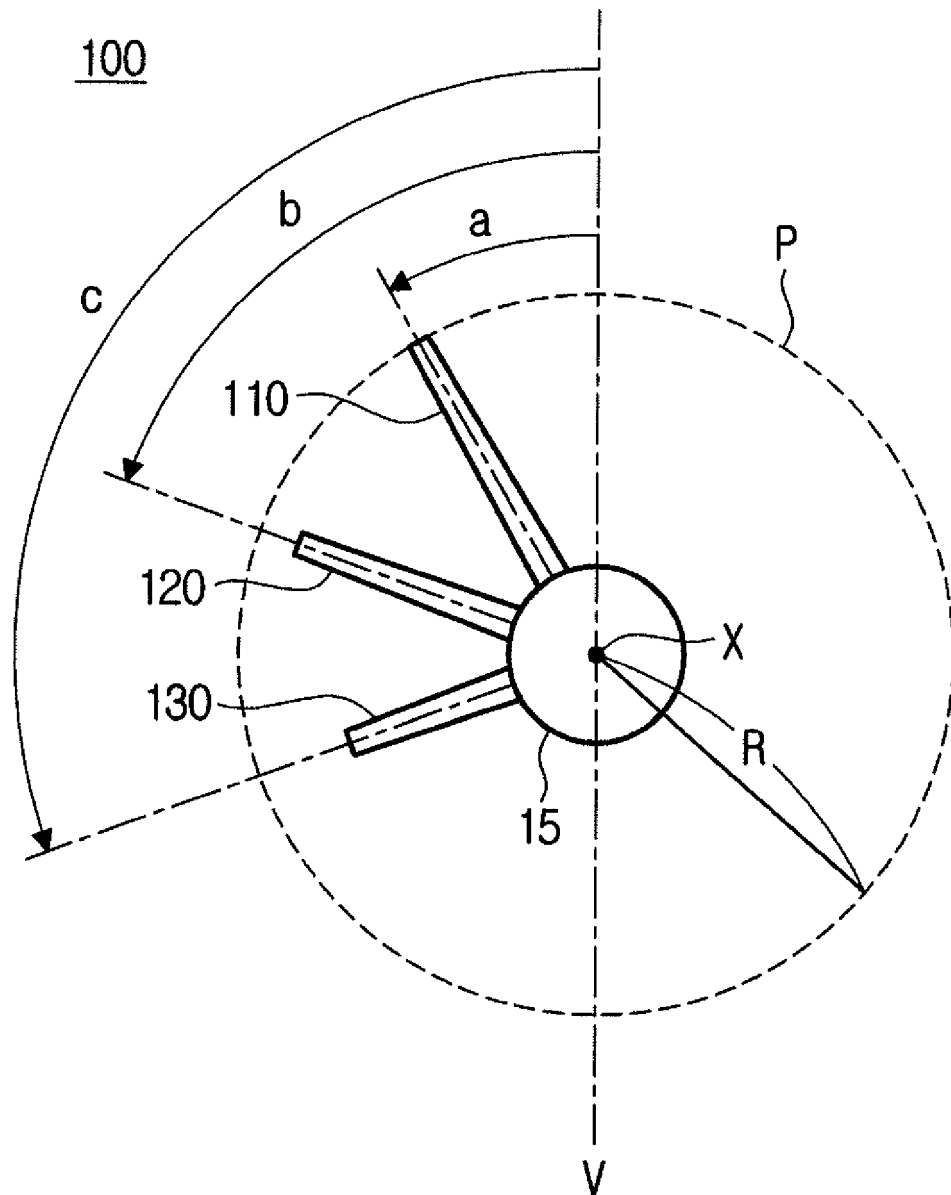
- un angle d'installation d'un premier stator de pré-déflexion (310) qui est localisé au niveau de la position la plus haute parmi les stators de pré-déflexion (310, 320, 330) s'inscrit à l'intérieur d'une plage qui va de 30 degrés à 50 degrés, un angle d'installation d'un deuxième stator de pré-déflexion (320) qui est localisé au niveau de la position intermédiaire s'inscrit à l'intérieur d'une plage qui va de 60 degrés à 80 degrés et un angle d'installation d'un troisième stator de pré-déflexion (330) qui est localisé au niveau de la position la plus basse s'inscrit à l'intérieur d'une plage qui va de 100 degrés à 120 degrés ; les angles d'installation des stators de pré-déflexion (310, 320, 330) étant des angles de positions d'installation des stators de pré-déflexion (310, 320, 330) par rapport à une section supérieure d'une ligne verticale (V) qui passe par l'axe de rotation de l'organe de propulsion (20), l'axe de rotation de l'organe de propulsion (20) étant un centre et la section supérieure de la ligne verticale (V) étant à 0 degré.
4. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 3, dans lequel :
une longueur de portée du premier stator de pré-déflexion (310) s'inscrit à l'intérieur d'une plage qui va de 0,9 fois à 1,1 fois le rayon de l'organe de propulsion (20), une longueur de portée du deuxième stator de pré-déflexion (320) s'inscrit à l'intérieur d'une plage qui va de 0,8 fois à 1,0 fois le rayon de l'organe de propulsion (20) et une longueur de portée du troisième stator de pré-déflexion (330) s'inscrit à l'intérieur d'une plage qui va de 0,6 fois à 0,8 fois le rayon de l'organe de propulsion (20) ; et dans lequel :
les longueurs de portée des stators de pré-déflexion (310, 320, 330) sont réduites de façon séquentielle selon l'ordre qui va depuis le stator de pré-déflexion qui est localisé au niveau de la position la plus haute jusqu'au stator de pré-déflexion qui est localisé au niveau de la position la plus basse.
5. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1 ou 2, dans lequel les stators de pré-déflexion (310, 320, 330) sont agencés en direction de la direction avant de façon séquentielle selon l'ordre qui va depuis le stator de pré-déflexion qui est localisé au niveau de la position la plus haute jusqu'au stator de pré-déflexion qui est localisé au niveau de la position la plus basse.
6. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1 ou 2, dans lequel des longueurs de corde ou tangentielles des stators de pré-déflexion (310, 320, 330) sont réduites, pour le même rayon par rapport à l'axe de rotation, selon l'ordre qui va depuis le stator de pré-déflexion qui est localisé au niveau de la position la plus haute jusqu'au stator de pré-déflexion qui est localisé au niveau de la position la plus basse.
7. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1, dans lequel un élément additionnel est formé dans la partie d'extrémité (311, 321, 331) de chaque stator de pré-déflexion (310, 320, 330), et l'élément additionnel se présente sous la forme d'une plaque qui s'étend en direction d'une surface d'aspiration et d'une surface de pression.
8. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1 ou 7, dans lequel les angles d'incidence des parties d'extrémité (311, 321, 331) sont réduits en continu en direction des extrémités des parties d'extrémité (311, 321, 331).
9. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1 ou 7, dans lequel les parties d'extrémité (311, 321, 331) présentent des longueurs qui sont égales à 0,1 fois à 0,3 fois les longueurs de portée des stators de pré-déflexion (310, 320, 330).
10. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1 ou 7, dans lequel les angles des extrémités des parties d'extrémité (311, 321, 331) sont arrondis, tel que vu depuis la surface de pression.
11. Appareil d'amélioration de l'efficacité de propulsion (300) selon la revendication 1, dans lequel une ailette est formée dans la partie d'extrémité (311, 321, 331) de chaque stator de pré-déflexion (310, 320, 330), et l'ailette est fléchée en direction d'une surface d'aspiration ou d'une surface de pression.

[Fig. 1]

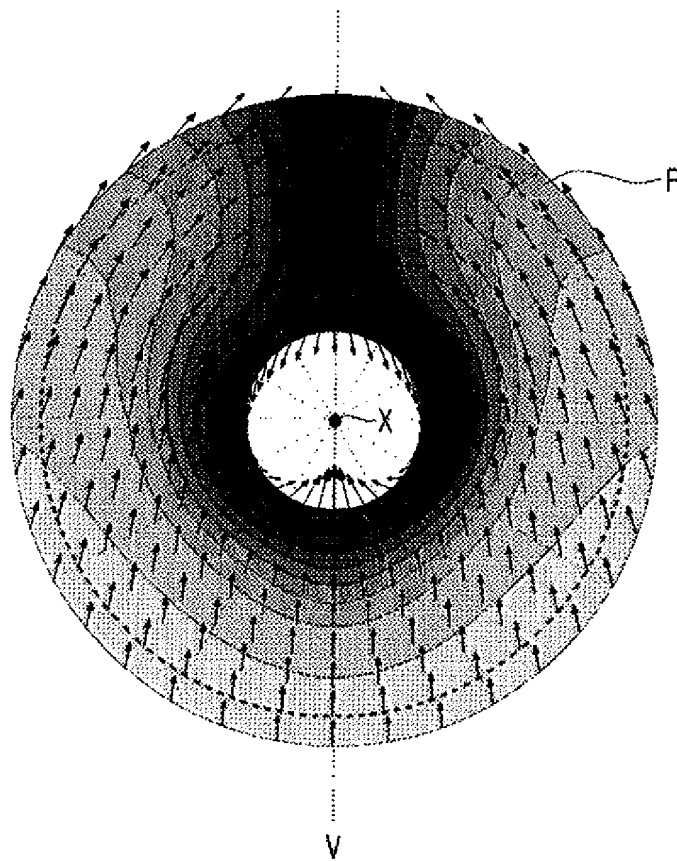
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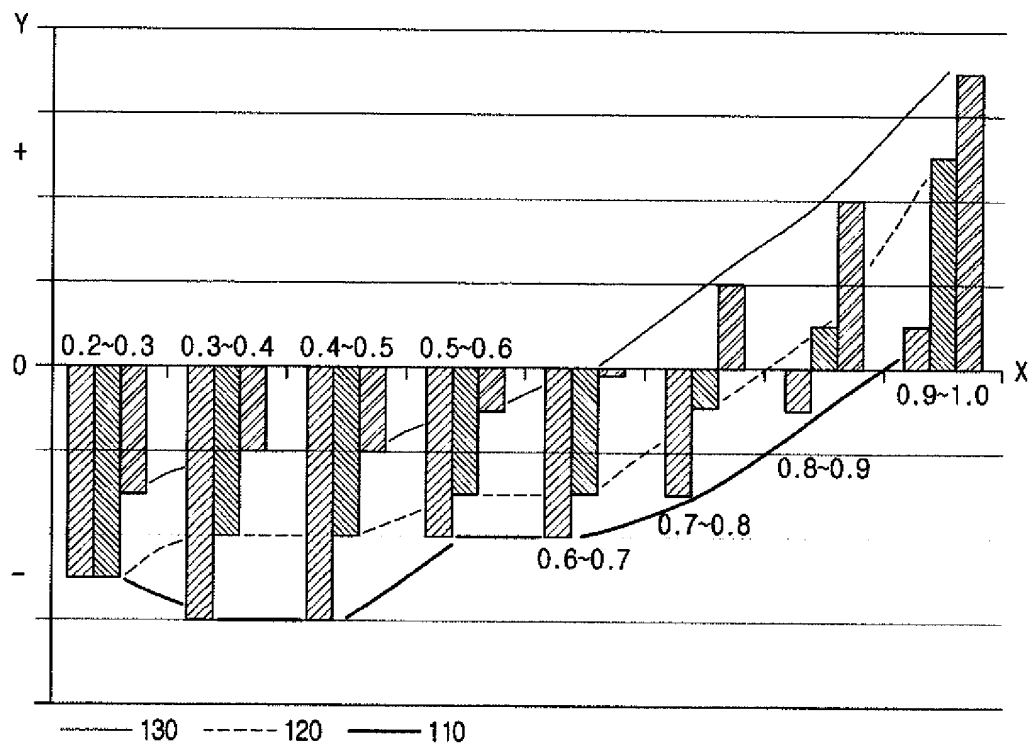
[Fig. 2]



[Fig. 3]

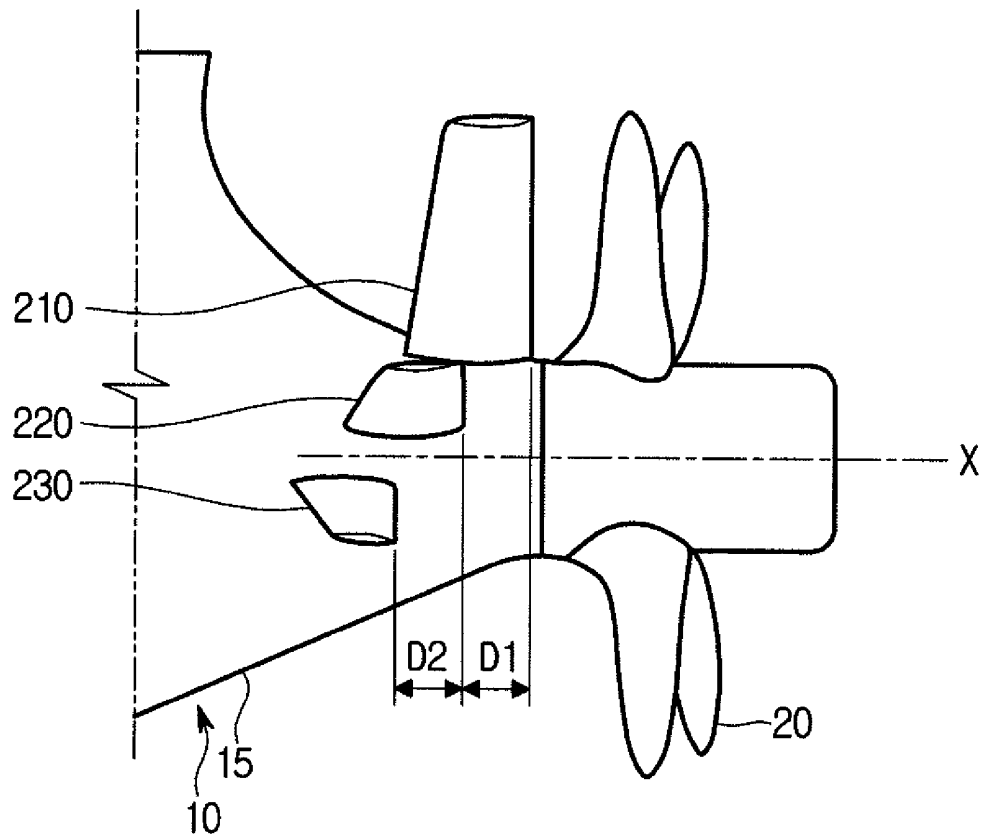


[Fig. 4]

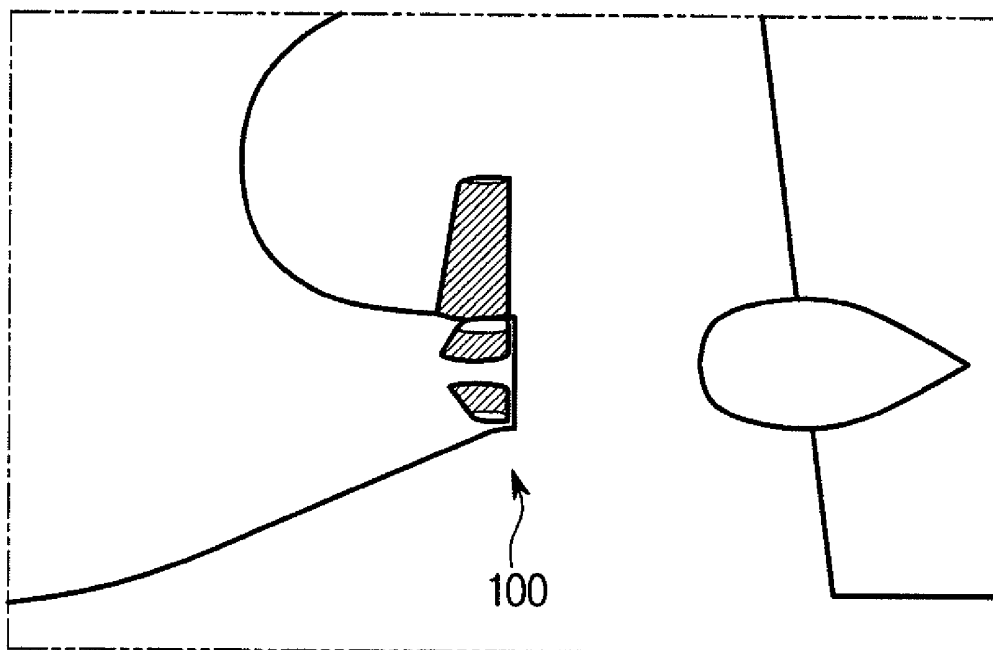


[Fig. 5]

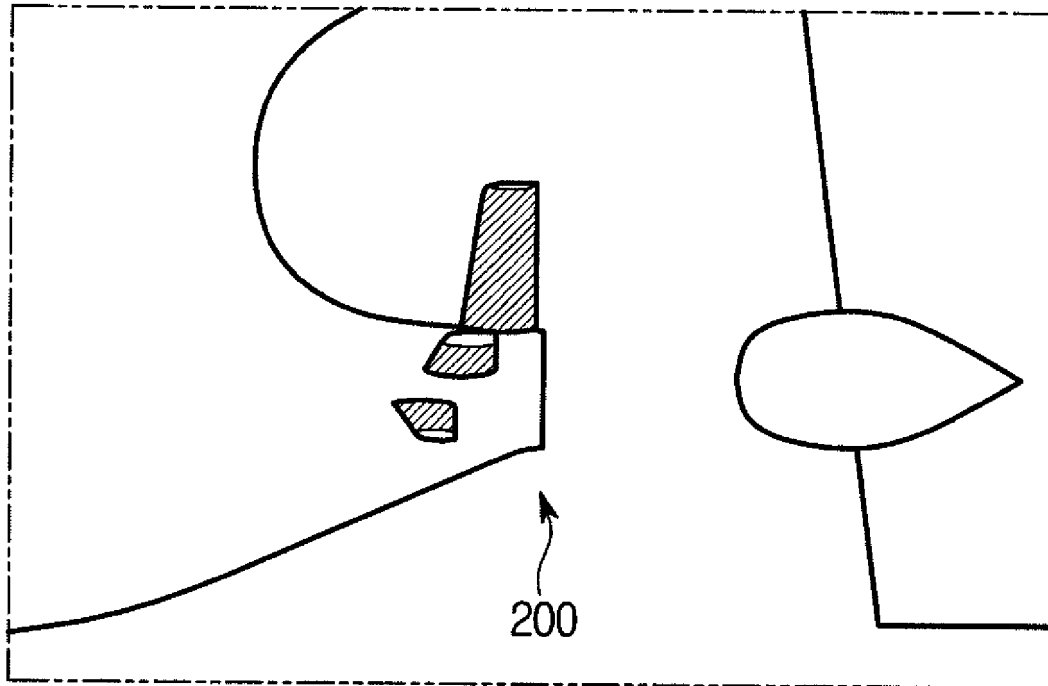
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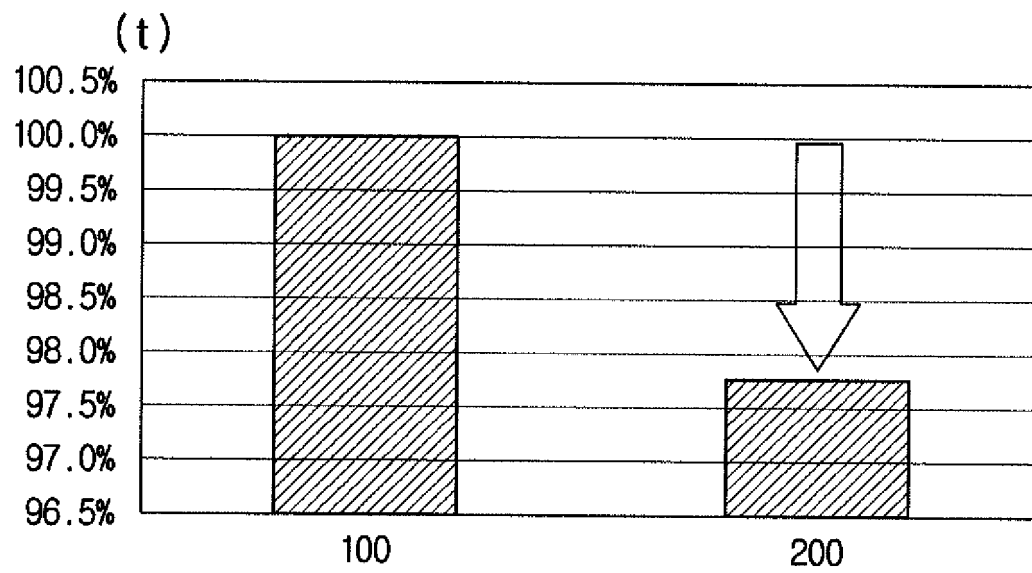
[Fig. 6a]



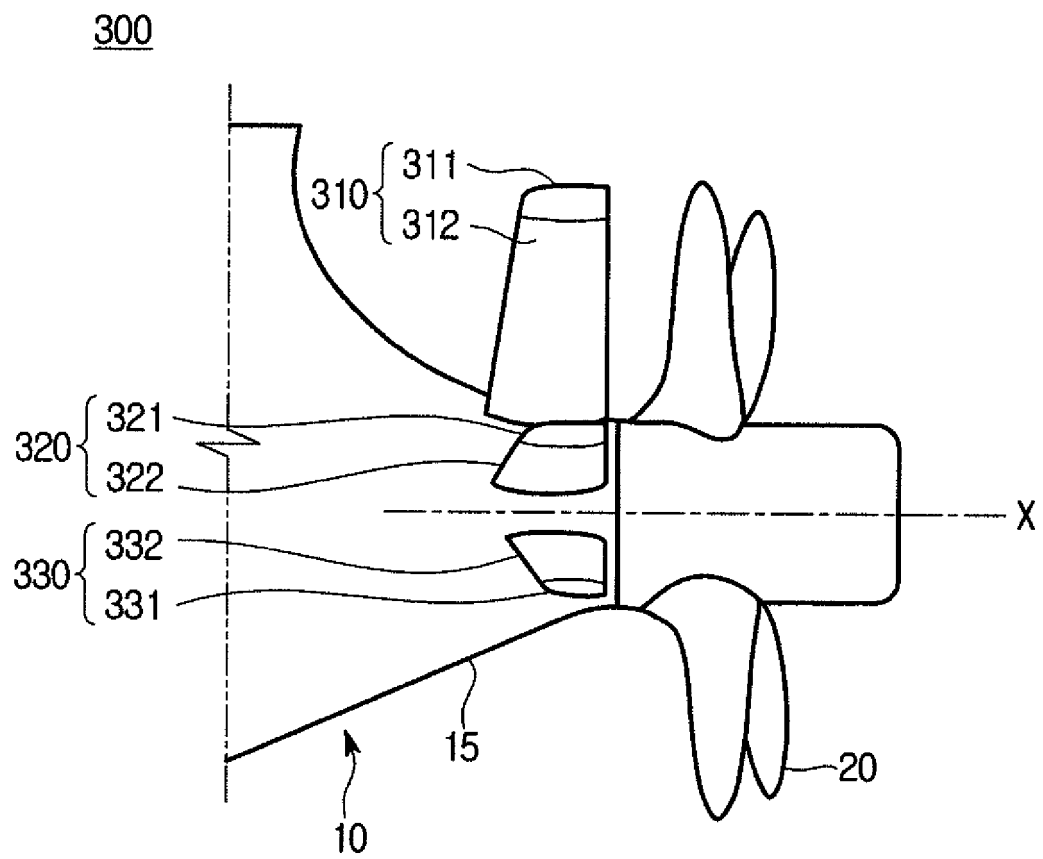
[Fig. 6b]



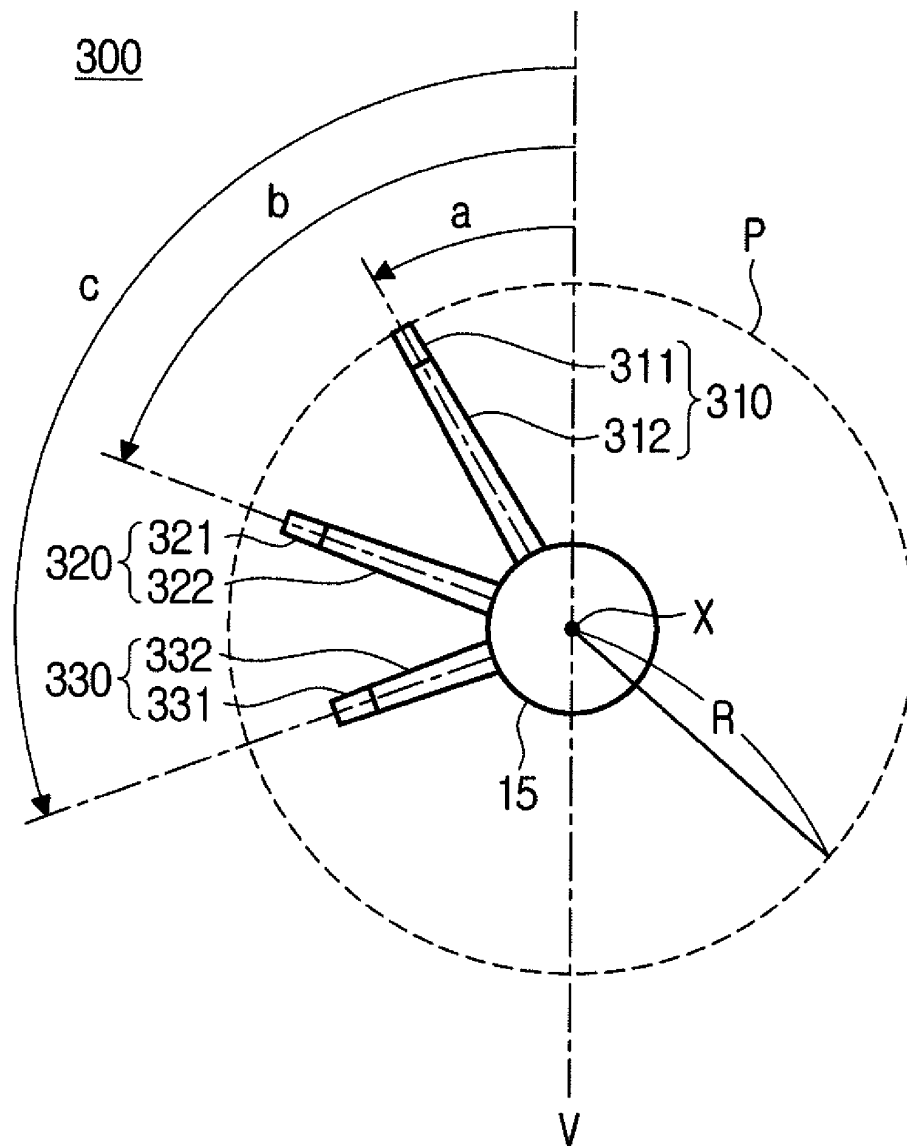
[Fig. 7]



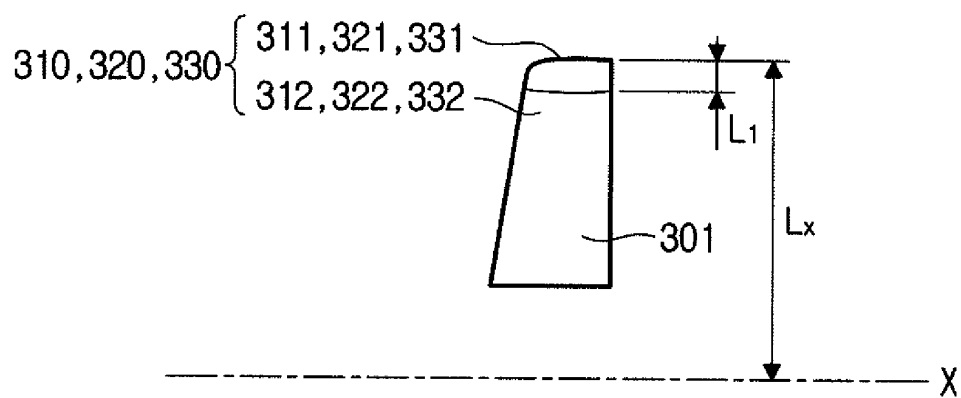
[Fig. 8]



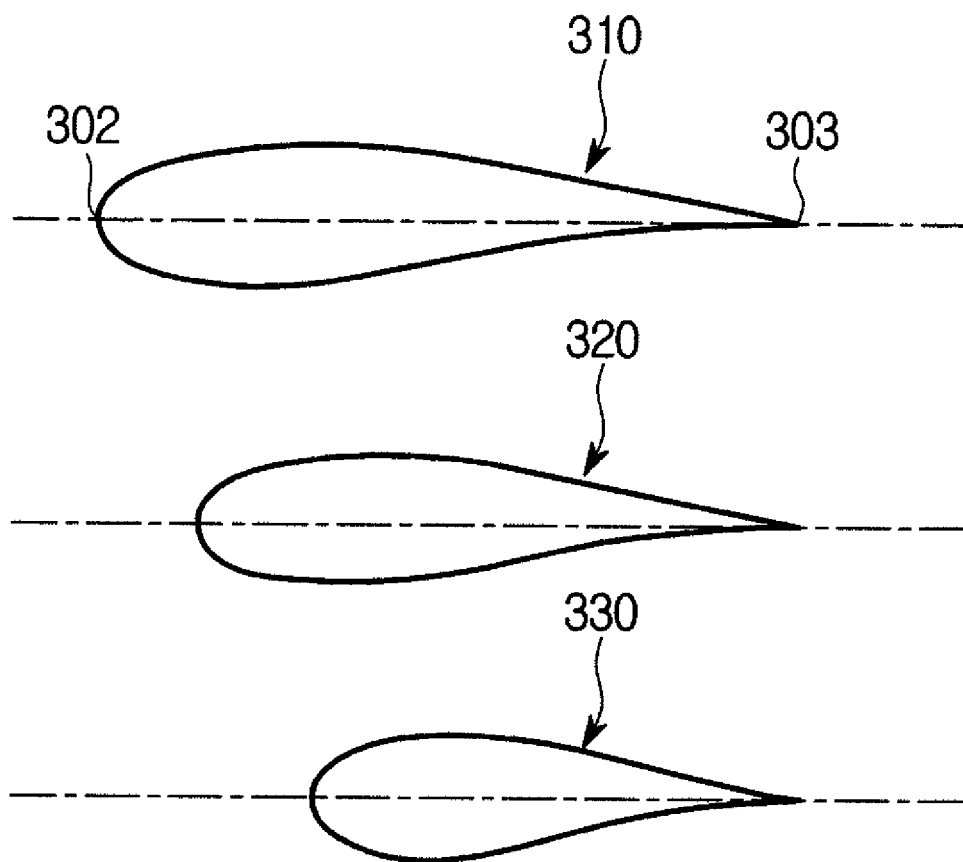
[Fig. 9]



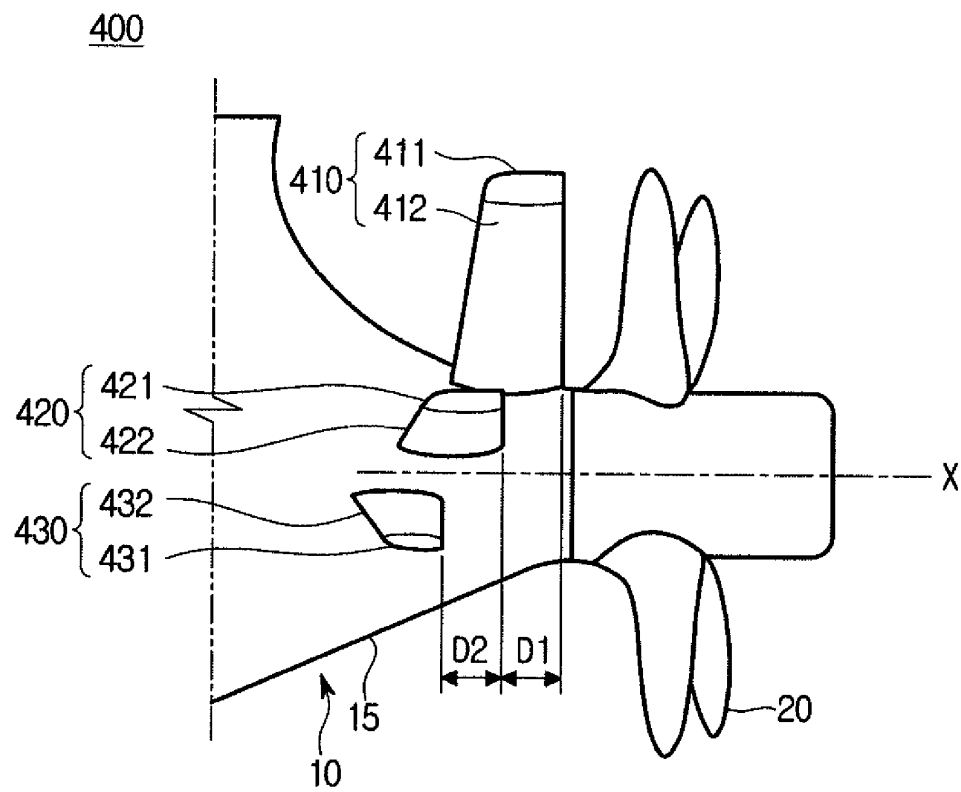
[Fig. 10]



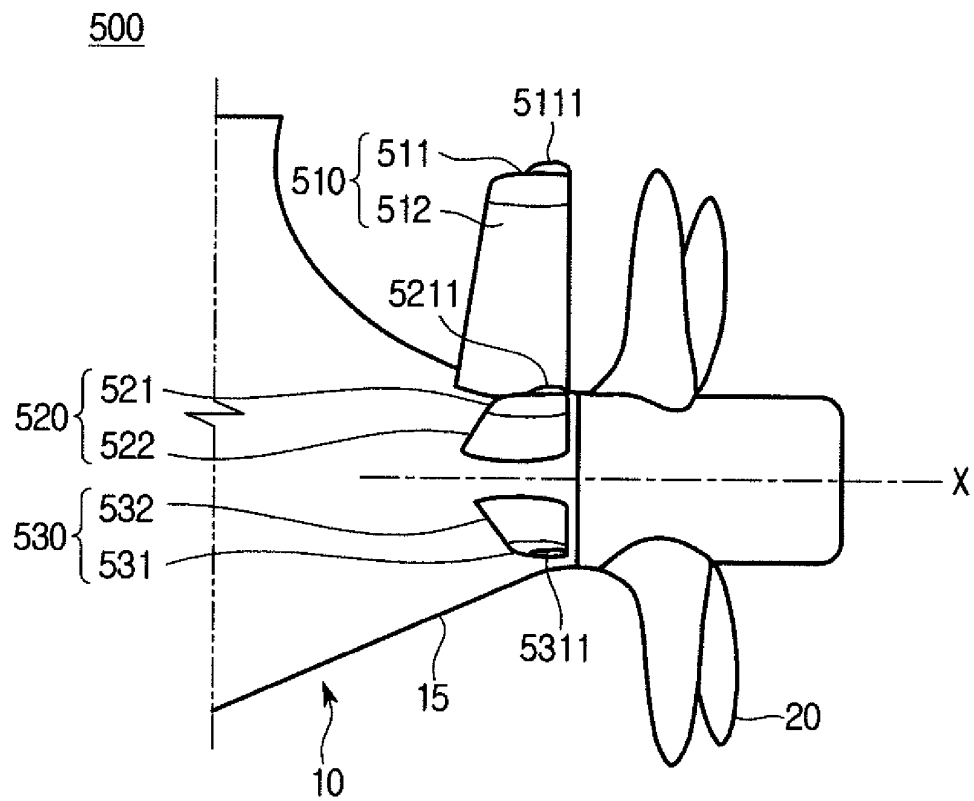
[Fig. 11]



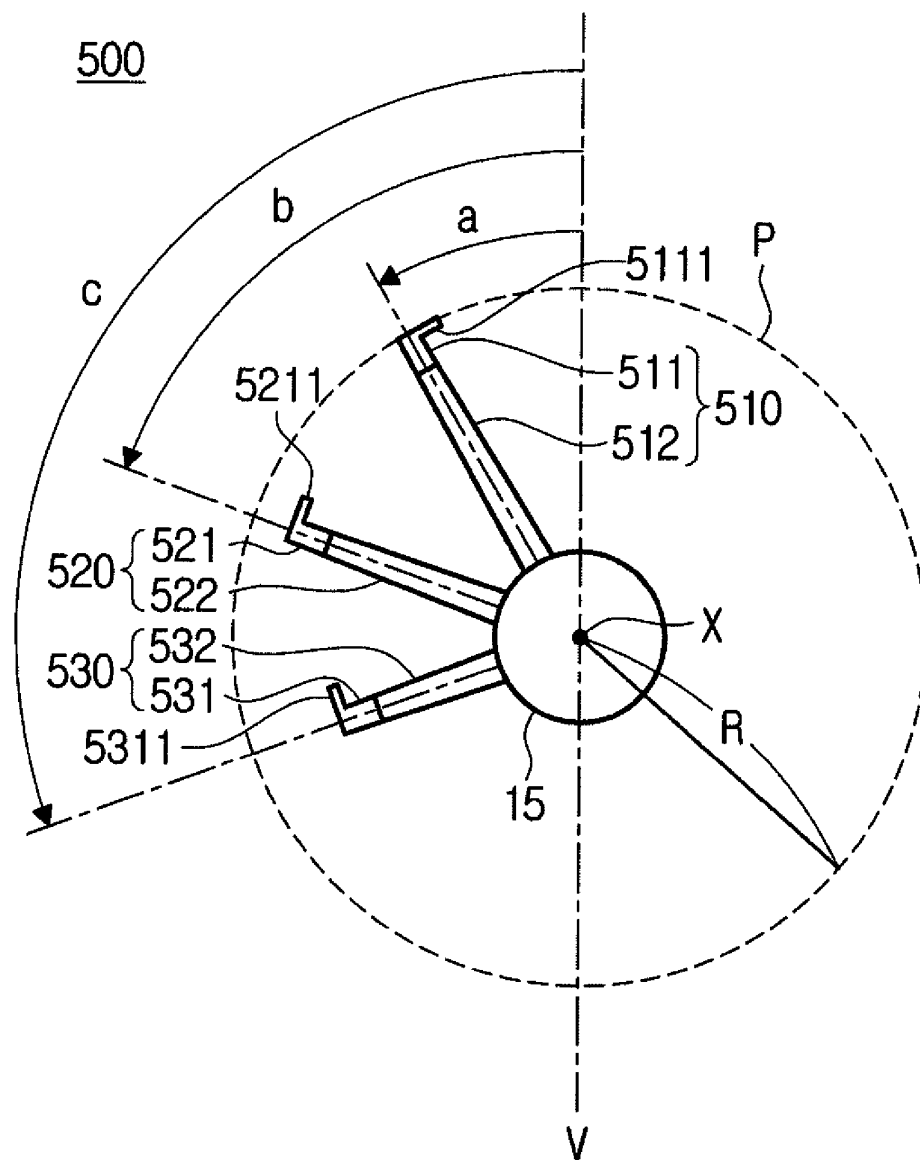
[Fig. 12]



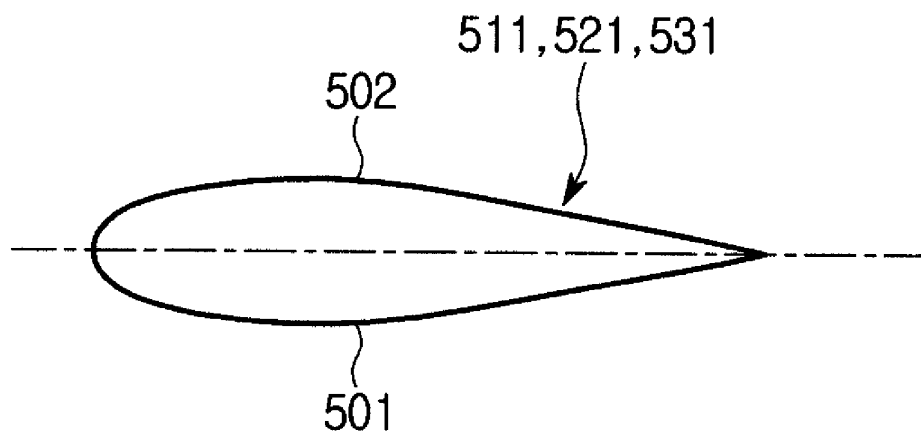
[Fig. 13]



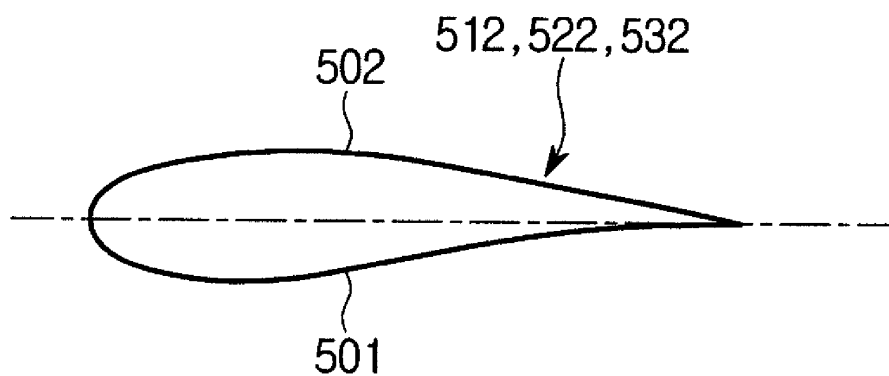
[Fig. 14]



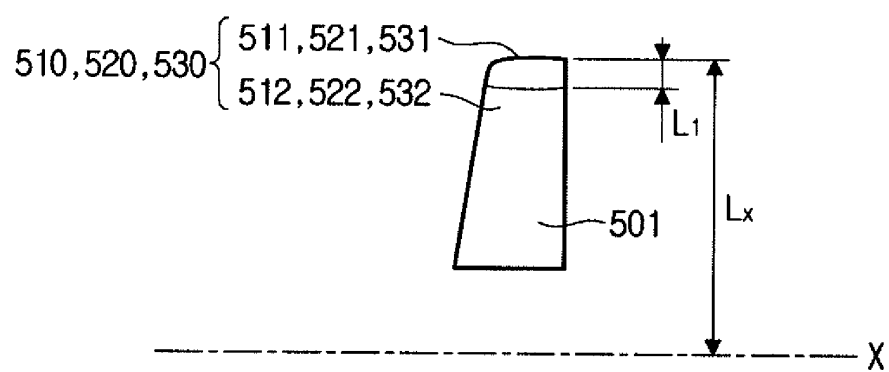
[Fig. 15]



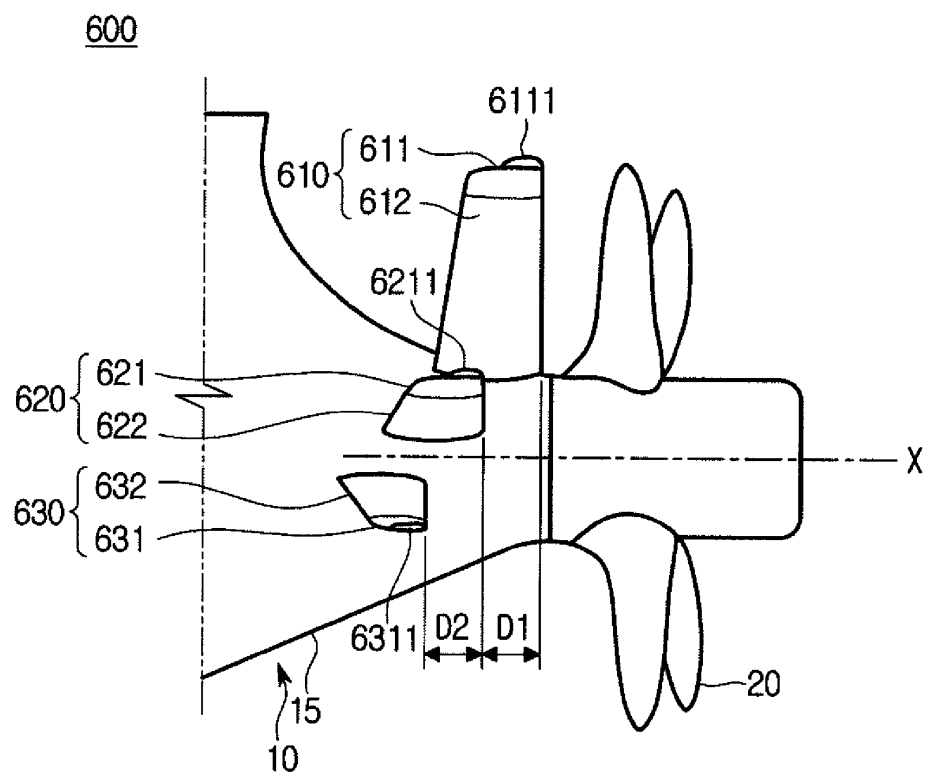
[Fig. 16]



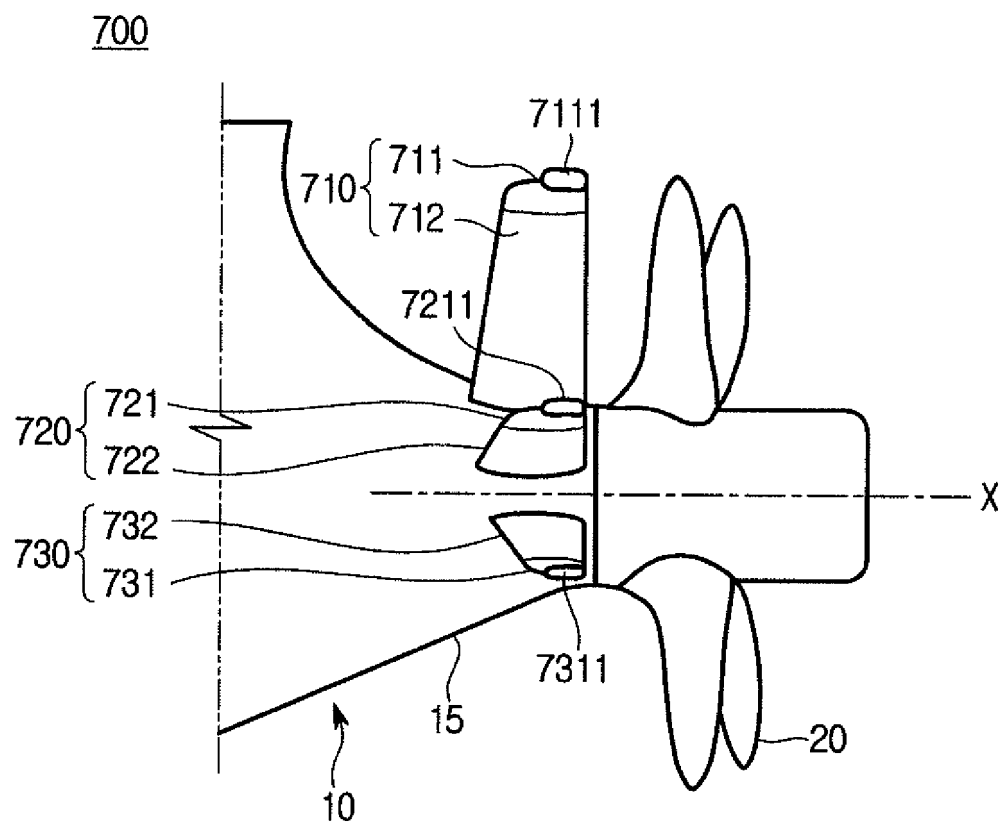
[Fig. 17]



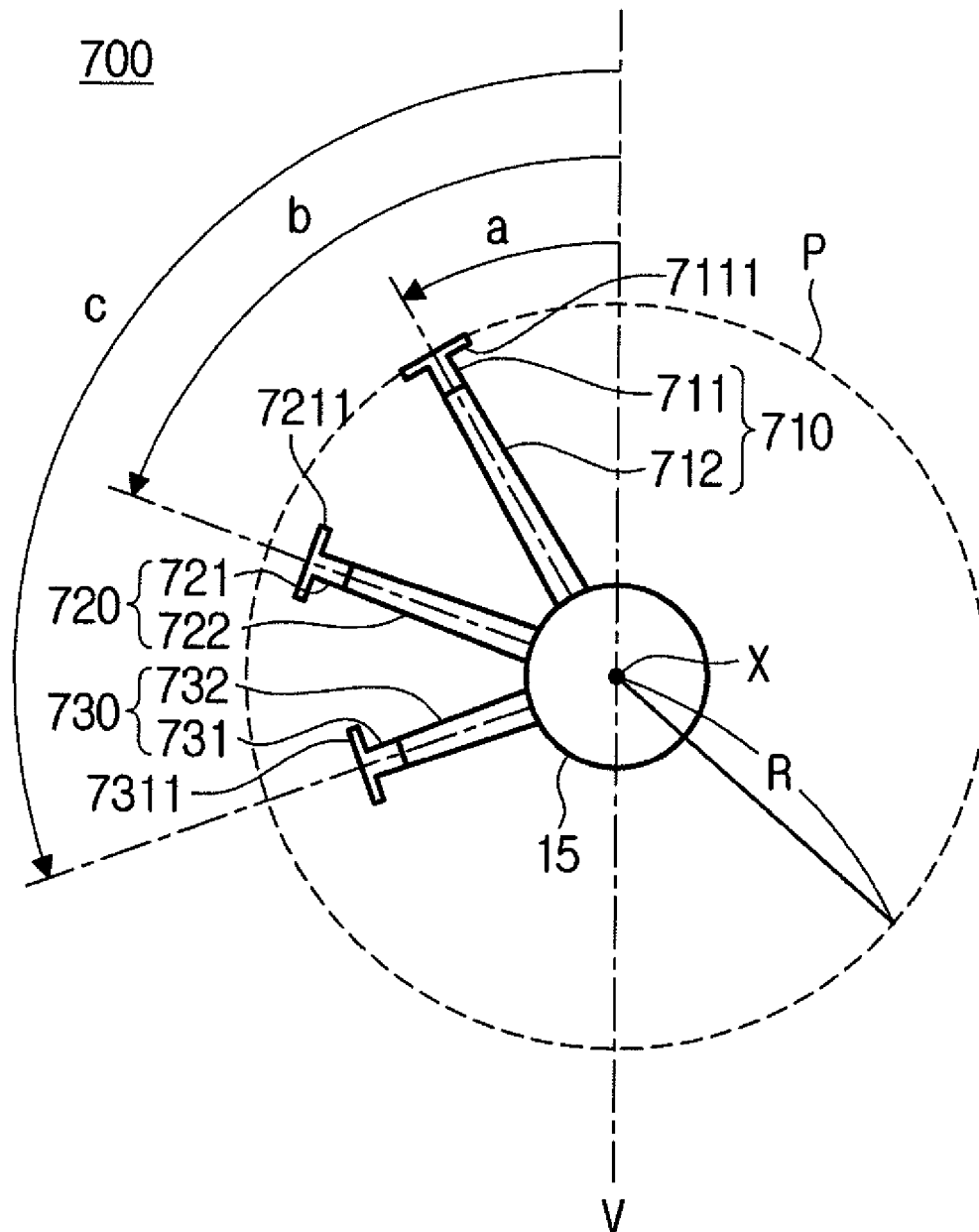
[Fig. 18]



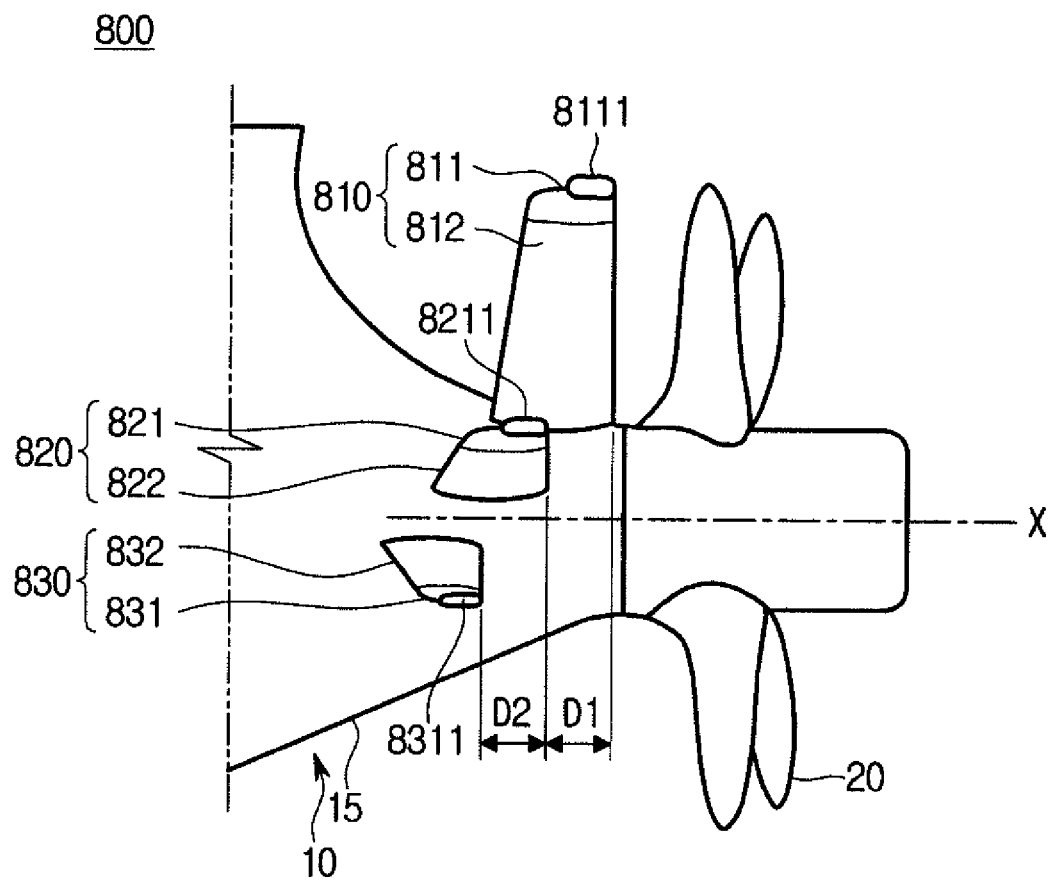
[Fig. 19]



[Fig. 20]



[Fig. 21]



REFERENCES CITED IN THE DESCRIPTION

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