

DESCRIPTION

Title of Invention: Thruster with Duct and Ship Including the Same

Technical Field

[0001] The present invention relates to a thruster with a duct included in a ship and a ship including the thruster.

Background Art

[0002] As a conventional marine thruster, there is a thruster with a duct configured such that the duct is provided around a propeller. This thruster with the duct is configured such that, for example, the output of a prime mover provided in a ship at a stern of a hull is transmitted from a vertical rotation shaft, projecting downward from the bottom of a ship and extending through the inside of a strut, through bevel gears, arranged in a gear case (pod) provided at a lower portion of the strut, to a horizontal rotation shaft, and the propeller is driven by this horizontal rotation shaft. In addition, by providing around the propeller a ring-shaped duct having an airfoil cross section, a ship, such as a tugboat, which requires high towing force, can generate high propulsive force.

[0003] Further, the thruster is configured such that the propeller thereof can make a 360-degree turn around a vertical axis so as to face in any direction by a turning prime mover provided at the hull. Thus, the thruster can adjust the direction of thrust force. As the propeller, a fixed pitch propeller or a variable pitch propeller is adopted depending on, for example, use conditions.

[0004] Fig. 8 is a side view of a general thruster 100 with a duct and shows a cross section of the duct. A propeller 102 is provided at a rear portion of a gear case 101, and a duct 103 formed in a ring shape and having an airfoil cross section is provided around the propeller 102. As shown in Fig. 9, the airfoil cross section of the duct 103 is

generally such that an outer surface thereof has a linear shape and an inner surface thereof has a bulging shape, and as described below, lift force is generated based on Bernoulli's theorem. The duct 103 is formed such that a front portion thereof spreads at a predetermined angle. In the duct 103 having the airfoil cross section, a frontmost end of the cross-sectional shape is referred to as a "leading edge 104", a rearmost end of the cross-sectional shape is referred to as a "trailing edge 105", a front end portion including the leading edge 104 is referred to as a "front end portion", and a rear end portion including the trailing edge 105 is referred to as a "rear end portion". In addition, a straight line connecting the leading edge 104 and the trailing edge 105 is referred to as a "nose-tail line 106 (chord line)", and a center line extending through the center in the thickness direction of the cross-sectional shape of the duct 103 is referred to as a "camber line 107 (camber line)". Further, an angle between a duct central axis X (propeller central axis) and the nose-tail line is referred to as a "duct spread angle α " (in Fig. 9, a line parallel to the duct central axis X is shown).

[0005] One example of the prior art related to this type of thruster with the duct is a marine propulsion device configured to improve propulsive efficiency by the improvement of the shape of the propeller in the duct (nozzle) and the arrangement of the propeller relative to the duct (see PTL 1, for example).

[0006] Another example of the prior art is a nozzle propeller configured to improve the thrust in a bollard state and the propulsive efficiency during traveling by forming the nozzle, provided around the propeller, such that the inner surface of the cross-sectional shape thereof largely bulges (see PTL 2, for example).

Citation List

Patent Literature

[0007] PTL 1: Japanese Laid-open Patent Application Publication No. 2009-1212

PTL 2: Japanese Laid-open Patent Application Publication No. 2006-306304

Summary of Invention

Technical Problem

[0008] One example of a general ship in which the above thruster with the duct is adopted is the tugboat. Examples of the tugboat are a harbor tug that mainly performs a low-speed operation, that is, pushes or pulls a large ship in, for example, a narrow harbor to cause the ship to dock at the harbor and an escort tug that leads, for example, a super tanker to secure the safety. The harbor tug is designed to be used for the low-speed operation of, for example, about 13 knots or lower, and the escort tug is designed to be used for high-speed traveling of, for example, 15 knots or higher.

[0009] These harbor tug and escort tug have existed as different tugboats respectively having appropriate performances. However, in recent years, there is a need for a tugboat that can be used as both the harbor tug and the escort tug.

[0010] As shown in Fig. 10, since the thruster 100 with the duct used when the harbor tug performs the low-speed operation generates the thrust force in a substantially stop state (bollard state), a water stream 111 flowing backward by the propeller 102 and a water stream 110 flowing from the outer surface of the duct 103 along the inner surface of the duct 103 are generated. The water stream 110 flows from a stagnation point SP through the leading edge 104 of the duct 103 to the inner surface of the duct 103. The stagnation point SP is located at a rear portion of the outer surface of the duct 103. Therefore, the thruster 100 with the duct configured to mainly perform the low-speed operation is configured such that by optimizing the camber line 107 (Fig. 9) of the duct 103 and setting the spread angle α of the duct 103 relative to the flow direction of the

water stream 111 to an optimal angle, negative pressure is generated at the front end portion of the inner surface of the duct 103 based on Bernoulli's theorem, and lift force L is generated by the duct 103.

[0011] Then, high towing force T (bollard thrust force) is obtained by a duct central axis X-direction component L_x of the lift force L and the thrust force of the propeller 102.

[0012] However, as shown in Fig. 11, in the case of the thruster 100 with the duct used when the escort tug travels at high speed, the stagnation point SP of the water stream 110 is located at the leading edge 104 of the duct 103, and a part of the water stream flows backward from the stagnation point SP along the outer surface of the duct 103.

[0013] In a case where the harbor tug designed to be used for the low-speed operation is used to travel at high-speed, as also shown in Fig. 8 described above, due to the duct 103 designed to have the airfoil cross section which generates the high towing force T, separation vortices 112 are generated by the turbulence of the water stream on the outer surface of the duct, and drag by the duct 103 increases. Thus, the propulsive efficiency deteriorates.

[0014] In the marine propulsion device described in PTL 1, the shape and arrangement of the propeller provided inside the duct are improved. Therefore, the marine propulsion device described in PTL 1 is not a device capable of obtaining the adequate propulsive efficiency in the ship which performs the low-speed operation and the high-speed traveling. In the propulsion device described in PTL 2, the thrust force is improved by forming the inner surface of the duct in a largely bulging shape. However, the propulsion device described in PTL 2 cannot suppress the separation vortices on the outer surface of the duct during the high-speed traveling, and the propulsive efficiency deteriorates.

Solution to Problem

[0015] Here, an object of the present invention is to provide a thruster with a duct capable of securing the stable towing force during the low-speed operation and the improvement of the propulsive efficiency by suppressing the separation vortices on the outer surface of the duct during the high-speed traveling, and a ship including the thruster with the duct.

[0016] To achieve the above object, a thruster with a duct according to the present invention includes the duct provided around a propeller and having an airfoil cross section, wherein: in a cross-sectional shape of the duct, a bulge portion bulging outward from a standard airfoil and having a circular-arc cross section is formed on an outer periphery of a front end portion of the duct so as to suppress pressure change on an outer surface of the front end portion of the duct during high-speed traveling; and the duct spreads at a spread angle in a leading edge direction so as to generate predetermined towing force during a low-speed operation. The term “standard airfoil” used in the present description and claims denotes “19A airfoil” generally adopted in a thruster with a duct.

[0017] With this, by the bulge portion formed on the outer periphery of the front end portion of the duct, sudden pressure change of the stream from the leading edge of the duct along the outer surface during the high-speed traveling can be suppressed. Therefore, the generation of the separation vortices at the front end portion of the outer surface of the duct can be suppressed, and the propulsive efficiency can be improved. In addition, by the spread angle at which the duct spreads in the leading edge direction, the towing force during the low-speed operation can be secured.

[0018] Moreover, it is preferable that the bulge portion be formed so as to bulge outward from a leading edge of the duct while making a smooth curve, further extend

from a most bulge portion and be connected to the outer surface of the duct while making a smooth curve, and further extend toward a trailing edge of the duct. With this, the water stream of smooth streamlines can flow from the bulge portion of the outer surface of the duct to the trailing edge of the duct.

[0019] Further, it is preferable that: the bulge portion be formed such that a ratio of an axial position of the most bulge portion to an entire length of the duct is in a range of more than 2.5% and not more than 30% from the leading edge of the duct, and a ratio of a radial position of the most bulge portion to the entire length of the duct is in a range of more than 2.8% and not more than 10% from the leading edge of the duct; and the spread angle of the duct be set such that an angle of a nose-tail line with respect to a duct central axis is in a range of more than 8° and not more than 12° , the nose-tail line connecting the leading edge of the duct and the trailing edge of the duct. With this, the further stable towing force can be obtained during the low-speed operation, and the propulsive efficiency can be further improved during the high-speed traveling.

[0020] Moreover, it is further preferable that: the bulge portion be formed such that the ratio of the axial position of the most bulge portion to the entire length of the duct is in a range of 10% and more and not more than 25% from the leading edge of the duct, and the ratio of the radial position of the most bulge portion to the entire length of the duct is in a range of 4% and more and not more than 8% from the leading edge of the duct; and the spread angle of the duct be set such that the angle of the nose-tail line with respect to the duct central axis is in a range of more than 8° and not more than 10° . With this, both the further stable towing force and the further stable propulsive efficiency improvement can be obtained, and the thruster with the duct can be configured while suppressing the increase in weight.

[0021] A ship according to the present invention includes any one of the above thrusters

with the ducts, wherein the thruster with the duct is provided at a rear portion of a hull of the ship. With this, a ship can be configured, which can generate the stable towing force during the low-speed operation and has good propulsive efficiency by suppressing the generation of the separation vortices on the outer surface of the duct during the high-speed traveling.

Advantageous Effects of Invention

[0022] According to the present invention, the thruster with the duct can stably generate the towing force during the low-speed operation and achieve high propulsive efficiency during the high-speed traveling. Therefore, the present invention can provide the thruster with the duct which can be used for both the low-speed operation and the high-speed traveling.

Brief Description of Drawings

[0023] [Fig. 1] Fig. 1 is a diagram showing a thruster with a duct according to one embodiment of the present invention and is a side view showing a cross section of the duct.

[Fig. 2] Fig. 2 is a diagram showing a change tendency of a drag coefficient C_d when the position of an outer bulge portion of the cross section of the duct is parametrically changed in an axial direction and a radial direction in the thruster with the duct according to the present invention.

[Fig. 3] Fig. 3 is a side view showing water streams when a ship provided with the thruster with the duct shown in Fig. 1 travels at high speed.

[Fig. 4] Fig. 4 is a diagram showing the distribution of streamlines during the high-speed traveling by a two-dimensional CFD calculation in Comparative Example.

[Fig. 5] Fig. 5 is a diagram showing the distribution of streamlines during the high-speed traveling by the two-dimensional CFD calculation in Example.

[Fig. 6] Fig. 6 is a diagram showing characteristic curves of propulsive performances of the thruster with the duct shown in Fig. 1 and a conventional thruster with the duct for the purpose of comparing and analyzing the performances of the thruster with the duct shown in Fig. 1 and the conventional thruster with the duct, the characteristic curves being obtained by tank tests.

[Fig. 7] Fig. 7 is a diagram showing a relation between ship speed and required power for the purpose of comparing and analyzing the performances of the thruster with the duct shown in Fig. 1 and the conventional thruster with the duct.

[Fig. 8] Fig. 8 is a side view showing the water streams when a ship provided with the conventional thruster with the duct travels at high speed.

[Fig. 9] Fig. 9 is a cross-sectional view of the duct of the thruster with the duct shown in Fig. 8.

[Fig. 10] Fig. 10 is an explanatory diagram of the water streams acting on the duct when the thruster with the duct performs the low-speed operation.

[Fig. 11] Fig. 11 is an explanatory diagram of the water streams acting on the duct when a ship provided with the thruster with the duct travels at high speed.

Description of Embodiments

[0024] Hereinafter, one embodiment of the present invention will be explained based on the drawings. The term “standard airfoil” in the embodiment below denotes “19A airfoil” generally adopted in this type of duct since the “19A airfoil” excels in fabrication.

[0025] As shown in Fig. 1, a thruster 1 with a duct is configured such that a propeller 4

is provided on a horizontal rotation shaft 3 projecting from a gear case 2 and a ring-shaped duct 5 is provided around the propeller 4. The duct 5 is formed to have an airfoil cross section (Fig. 1 shows a cross section, and hatching is not shown.) and has the same cross-sectional shape around a duct central axis X (central axis of the propeller 4).

[0026] A bulge portion 6 bulging outward from the standard airfoil to have a circular-arc cross section is formed on an outer periphery of a front end portion of the duct 5. The bulge portion 6 is formed so as to bulge outward from a leading edge 7 of the duct 5 while making a smooth curve, further extend from a most bulge portion 8 and be connected to an outer surface 9 of the duct while making a smooth curve, and further extend toward a trailing edge 10 of the duct.

[0027] The bulge portion 6 is formed such that: the ratio of an axial position A of the most bulge portion 8 to an entire length Ld of the duct 5 is in a range of more than 2.5% and not more than 30% in a rear direction from the duct leading edge 7; and the ratio of a radial position B of the most bulge portion 8 to the entire length Ld of the duct 5 is in a range of more than 2.8% and not more than 10% in an outer radial direction from the duct leading edge 7.

[0028] If the ratio of the axial position A of the most bulge portion 8 to the entire length Ld of the duct is not more than 2.5% in the rear direction from the leading edge 7, the leading edge portion of the outer surface of the duct becomes a sharp shape toward the outer surface, and the water stream from the front side causes flow separation from the most bulge portion 8. Thus, separation vortices are generated, and these become drag. If the ratio of the axial position A to the duct entire length Ld is more than 30%, the inclination of the outer surface of the duct from the most bulge portion 8 to the trailing edge portion becomes steep. Thus, the separation vortices are generated, and these become the drag. In addition, the increase in the weight of the duct may be caused.

[0029] If the ratio of the radial position B of the most bulge portion 8 to the entire length L_d of the duct is not more than 2.8% in the outer radial direction from the leading edge 7, the leading edge portion of the duct and its vicinity become a sharp shape, and the pressure distribution in the vicinity of the leading edge portion suddenly changes toward the outer surface. Thus, the flow separation occurs, and this becomes the drag. If the ratio of the radial position B to the entire length L_d of the duct is more than 10%, the amount of protrusion of the outer surface of the duct increases, and the outer surface of the duct steeply inclines toward the trailing edge of the duct. Therefore, the water stream from the front side causes the flow separation from the most bulge portion 8. Thus, the separation vortices are generated, and these become the drag.

[0030] Further, it is more preferable that the most bulge portion 8 be formed such that the ratio of the axial position A to the entire length L_d is in a range from 10% to 25% in the rear direction from the duct leading edge 7 and the ratio of the radial position B to the entire length L_d is in a range from 4% to 8% in the outer radial direction from the leading edge 7 of the duct. By setting the ratios in the above ranges, the drag coefficient C_d is further reduced. In addition, the increase in the weight of the thruster 1 with the duct is suppressed, and the significant increase in cost by, for example, the increase in the size of the prime mover or the change of the hull can be suppressed.

[0031] The reason why the axial position A and radial position B of the most bulge portion 8 of the bulge portion 6 are respectively set in the above ranges is because as shown in Fig. 2, the drag coefficient C_d of the duct tends to become minimum in the above position ranges. Fig. 2 shows that estimated calculation of the drag coefficient C_d with respect to a two-dimensional airfoil similar to the duct cross-sectional shape of Fig. 1 is performed by using a two-dimensional boundary layer theory calculation program and shows the change in the drag coefficient C_d when a flow attack angle is

constant and the axial position A and radial position B of the most bulge portion 8 of the bulge portion 6 are parametrically changed. In Fig. 2, a broken line shows an envelope curve of respective drag coefficient C_d curves when the radial position B is fixed to a certain position. In this example, in a case where the ratio of the radial position B of the most bulge portion 8 to the entire length L_d of the duct is set to 5% in the outer direction from the leading edge 7, the drag coefficient C_d can be minimized by setting the ratio of the axial position A to the entire length L_d of the duct to 15% in the rear direction from the leading edge 7. The tendency of the range of the optimal combination of the axial position A and radial position B of the most bulge portion 8 is apparent from Fig. 2.

[0032] In a case where the outer peripheral surface of the duct 5 is caused to bulge by forming the bulge portion 6 on the outer surface of the front end portion of the duct 5, the camber line 11 of the cross section of the duct changes, and the camber decreases by the decrease in a maximum camber ratio. Thus, the lift force by the inner surface of the duct decreases. Here, by increasing an attack angle of a nose-tail line 12 with respect to the duct central axis X, that is, the spread angle α of the duct 5, the lift force is increased to compensate for the decrease of the camber. The nose-tail line 12 is a line connecting the leading edge 7 of the duct and the trailing edge 10 of the duct. To be specific, by increasing the spread angle α to compensate for the decrease of the camber, the towing force is increased to compensate for the decrease of the towing force decreased by the decrease of the maximum camber ratio.

[0033] The spread angle α of the duct 5 is set such that the angle of the nose-tail line 12 with respect to the duct central axis X is in a range of more than 8° and not more than 12° . If the spread angle α of the duct 5 is not more than 8° , the high towing force cannot be obtained at low speed. In contrast, if the spread angle α is more than 12° , the duct 5 causes a stall phenomenon during the high-speed traveling, and this becomes the

high drag. As above, the spread angle α of the duct 5 is set to such an angle that can realize both the suppressing of the pressure and flow velocity change on the outer surface of the leading edge portion of the duct 5 by the bulge portion 6 during the high-speed traveling and the generation of the towing force by the duct 5 during the low-speed operation.

[0034] Then, by forming the bulge portion 6 on the outer periphery of the duct 5 and setting the spread angle α of the duct 5 as above, the towing force can be stably generated during the low-speed operation while improving the propulsive efficiency by the reduction in the drag of the duct 5, the drag being reduced by suppressing the generation of the separation vortices in the vicinity of the outer surface of the front end portion of the duct 5 during the high-speed traveling, as shown in Fig. 3.

[0035] Therefore, the thruster 1 with the duct can realize both the securement of the towing force during the low-speed operation and the improvement of the propulsive efficiency during the high-speed traveling. Therefore, for example, the thruster 1 with the duct can be utilized as a thruster of a ship which can be used as the harbor tug and the escort tug.

[0036] Moreover, the position and size (amount of protrusion) of the bulge portion 6 and the spread angle α of the duct 5 may be determined in consideration of the increase in turn drag, the increase in turn power by the increase in weight, the manufacturing cost, and the like and may be determined such that, for example, the increase in production cost is suppressed.

[0037] Further, according to the thruster 1 with the duct, for example, as compared to the conventional thruster with the duct having the standard airfoil cross section, the propulsive efficiency can be increased by about 4% as described below.

Example

[0038] As Example, results of the comparison and analysis of influences by the differences between the cross-sectional shapes of the ducts 5 and 103 by CFD (Computational Fluid Dynamics) calculations are shown below. As the calculation conditions, two-dimensional calculation was used, and an actual ship state during the high-speed traveling was simulated. Fig. 4 shows the distribution of streamlines of the duct 103, and Fig. 5 shows the distribution of streamlines of the duct 5. In Figs. 4 and 5, the stream moves from right to left. In Fig. 4, the streamlines excessively concentrate in the vicinity of the outer surface of the leading edge portion of the duct, and this indicates a possibility that the flow separation may occur. In contrast, in Fig. 5, the concentration of the streamlines is eased at the same portion as above, and the stream is smooth. This indicates that the flow separation is unlikely to occur.

[0039] Next, Fig. 6 shows results of open-water tank tests of the thruster with the duct as Performance Verification Example. In the tank tests, an experimental tank having 200 m in length, 13 m in width, and 6.5 m in depth was used, and models each having a size of about 1/8.5 of the actual thruster with the duct were produced such that one model includes the duct 5 and the other includes the duct 103, and the propeller, the strut, and the like are common therebetween. Items to be measured in the tank tests were advance speed of propeller V_a , thrust T_t of the entire thruster, propeller torque Q , propeller revolution n .

[0040] In Fig. 6, solid lines correspond to the duct 5, broken lines correspond to the duct 103. In Fig. 6, a horizontal axis J denotes a propeller advance ratio ($= V_a/(nD)$), K_{tt} of a vertical axis denotes an entire thrust coefficient ($T_t/(\rho n^2 D^4)$), K_q of the vertical axis denotes a propeller torque coefficient ($= Q/(\rho n^2 D^5)$), and η_o of the vertical axis denotes an open-water efficiency ($= K_{tt}J/(2\pi K_q)$) of the entire thruster. Here, ρ denotes fresh water density, and D denotes a propeller diameter.

[0041] According to Fig. 6, when the propeller advance ratio J is about 0.5 or less, the characteristics of the ducts 5 and 103 are substantially the same as each other. However, when the propeller advance ratio J is more than about 0.5, which corresponds to the high-speed traveling, the entire thrust coefficient K_{tt} of the thruster including the duct 5 exceeds that of the thruster including the duct 103. To be specific, it is clear that as a result of the decrease in the drag of the duct, the open-water efficiency η_o of the thruster including the duct 5 exceeds that of the thruster including the duct 103. That is, it is clear that the thruster including the duct 5 has the higher propulsive efficiency when a ship travels at high speed.

[0042] Next, Fig. 7 shows results of the comparison and analysis of the estimations of thrust required power of the actual ship by using the propulsive performance characteristic curves of Fig. 6 and the same hull under the same traveling conditions. A horizontal axis denotes ship speed V_s , and a vertical axis denotes required power P_d . A solid line corresponds to the thruster including the duct 5 of Example of the present invention, and a broken line corresponds to the thruster including the conventional common duct 103 by way of comparison.

[0043] As shown in Fig. 7, the required power of the thruster including the duct 5 is lower by about 4 to 5% than that of the thruster including the duct 103 when the ship travels at the same ship speed. This means that the propulsive efficiency is improved by about 4 to 5%.

[0044] According to the above results, by forming the bulge portion 6 on the outer periphery of the front end portion of the duct, the propulsive efficiency during the high-speed traveling can be improved. In addition, by setting the spread angle α of the duct 5 to compensate for the decrease of the camber due to the formation of the bulge portion 6, the towing force during the low-speed operation can be stably secured.

[0045] The standard airfoil in the above embodiment is just one example. The same operational advantages as above can be obtained by a general airfoil cross section. The airfoil cross section is not limited to the above embodiment.

[0046] Moreover, the above embodiment is just one example. Various modifications may be made within the spirit of the present invention, and the present invention is not limited to the above embodiment.

Industrial Applicability

[0047] The thruster with the duct according to the present invention can be utilized in a ship which is used as both, for example, a harbor tug which requires stable towing force during the low-speed operation and an escort tug which requires the improvement of the propulsive efficiency during the high-speed traveling.

Reference Signs List

- [0048]
- | | |
|--------|-----------------------|
| 1 | thruster with duct |
| 4 | propeller |
| 5 | duct |
| 6 | bulge portion |
| 7 | leading edge |
| 8 | most bulge portion |
| 9 | outer surface of duct |
| 10 | trailing edge |
| 11 | camber line |
| 12 | nose-tail line |
| 15, 16 | water stream |

X duct central axis

α spread angle

A axial position

B radial position

CLAIMS

[1] A thruster with a duct comprising

the duct provided around a propeller and having an airfoil cross section, wherein:

in a cross-sectional shape of the duct, a bulge portion bulging outward from a standard airfoil and having a circular-arc cross section is formed on an outer periphery of a front end portion of the duct so as to suppress pressure change on an outer surface of the front end portion of the duct during high-speed traveling; and

the duct spreads at a spread angle in a leading edge direction so as to generate predetermined towing force during a low-speed operation.

[2] The thruster with the duct according to claim 1, wherein the bulge portion is formed so as to bulge outward from a leading edge of the duct while making a smooth curve, further extend from a most bulge portion and be connected to the outer surface of the duct while making a smooth curve, and further extend toward a trailing edge of the duct.

[3] The thruster with the duct according to claim 1 or 2, wherein:

the bulge portion is formed such that a ratio of an axial position of the most bulge portion to an entire length of the duct is in a range of more than 2.5% and not more than 30% from the leading edge of the duct, and a ratio of a radial position of the most bulge portion to the entire length of the duct is in a range of more than 2.8% and not more than 10% from the leading edge of the duct; and

the spread angle of the duct is set such that an angle of a nose-tail line with respect to a duct central axis is in a range of more than 8° and not more than 12°, the

nose-tail line connecting the leading edge of the duct and the trailing edge of the duct.

[4] The thruster with the duct according to claim 3, wherein:

the bulge portion is formed such that the ratio of the axial position of the most bulge portion to the entire length of the duct is in a range of 10% and more and not more than 25% from the leading edge of the duct, and the ratio of the radial position of the most bulge portion to the entire length of the duct is in a range of 4% and more and not more than 8% from the leading edge of the duct; and

the spread angle of the duct is set such that the angle of the nose-tail line with respect to the duct central axis is in a range of more than 8° and not more than 10° .

[5] A ship comprising

the thruster with the duct according to any one of claims 1 to 4, wherein

the thruster with the duct is provided at a stern of the ship.