

PATENT SPECIFICATION

(11) 1 561 505

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- (21) Application No. 32545/76 (22) Filed 4 Aug. 1976 (19)
- (31) Convention Application No. 50/098954 (32) Filed 14 Aug. 1975 in
- (33) Japan (JP)
- (44) Complete Specification Published 20 Feb. 1980
- (51) INT. CL. B63H 5/16
- (52) Index at Acceptance
B7V 102 121 AA



(54) SHIP WITH IMPROVED STERN WATER FLOW

(71) We, MITSUI ENGINEERING & SHIPBUILDING CO., LTD., a Japanese Company of 6-4, 5-chome, Tsukiji, Chuo-ku, Tokyo, Japan do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

In recent years, attempts have been made to lower the building costs of hulls by making them as full as possible for a required dead-weight in an effort to improve the ship's economy.

However, as a hull form becomes fuller, turbulence and nonuniformity of the wake field around its stern increased, with a consequent increase in hull resistance, decrease in propulsive efficiency, and increase in propeller cavitation, vibration and/or noise level, which factors offset any economy attained by lowering the building cost. Accordingly, it is desirable to overcome the lowering of a ship's performance which arises from a full hull form, to allow promotion of this approach to lowering initial building costs.

Among the devices which have been aimed at to improve hull performance are ducted propellers, or so-called nozzle propellers and stern fins.

A ducted propeller has a duct which surrounds the propeller as shown in Fig. 16, of the accompanying drawings and thrust is produced not only by the propeller but also by the duct as a result of hydrodynamic interaction between the propeller and the duct, thereby improving the propulsive efficiency.

A ducted propeller thus utilizes hydrodynamic interaction between the propeller and the duct, and therefore it is necessary to optimize the design of the ducted propeller as an integral propulsion unit comprising the propeller and duct. Propellers designed for use without a duct can not be used as their diameter and pitch differ from those appropriate for use with a duct.

From previous studies on ducted propellers it is known that the appropriate length of the duct is about 50% of the diameter of the propeller and that appropriate position of the propeller is about the mid-position of the duct length. It is also known that the narrower the clearance between the propeller tip and the duct inner surface, the higher will be the propulsive efficiency.

As described above, by adopting a ducted propeller, it is possible to increase the propulsive efficiency and decrease the required horsepower of a ship with a heavily loaded propeller. However, in order so to maximize the propulsive efficiency of the ducted propeller, the clearance between the inner surface of the duct and the propeller tip must be minimized, and under such conditions cavitation erosion is liable to occur on the inner surface of the duct, due to the cavitation generated near the tip portions of the propeller, resulting in damage to the duct.

Moreover, if a duct is located too close to a ship hull, an increase of resistance and a drop of propulsive efficiency will be caused due to the acceleration of the flow around the ship hull caused by the duct. Accordingly, it is necessary for the leading edge of a duct to be spaced a correct distance away from the stern frame.

As described above, a ducted propeller requires high tolerances in its construction and is also liable to be damaged by cavitation erosion. If, in order to avoid this, the propeller tip and the inner surface of the duct are designed so as to be further away from each other, the propulsive efficiency becomes lower than that of a conventional propeller.

In cases where a ducted propeller is intended to be used on an existing ship, if the existing propeller is utilized as it is, the speed of revolution of the propeller becomes too high or the main engine output corresponding to the rated revolution speed becomes

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too small, which inevitably necessitates replacement of the existing propeller by a new one, which again reduces any economy of the change.

5 Stern fins are, as shown in Fig. 17 of the accompanying drawings, appendages of a ship's hull mounted at the upper portion of the stern in front of the propeller. The fins reduce hull vibration and noise by suppressing the unstable flow around the stern, particularly in the area of a cruiser stern, but the power saving is small and so-called tip vortex is produced from the edge of fin, resulting in an increase of resistance in many cases.

10 Moreover, this tip vortex sometimes causes cavitation which flows down to the aftwardly located propeller, resulting in damage to the propeller and an increase of hull vibration. Further, stern fins are of cantilever construction and therefore a substantial reinforcement of the ship hull is necessary for supporting the fins. Because of these difficulties, stern fins can not be used very effectively.

15 According to the present invention there is provided a surface ship provided with a propeller and having a generally annular structure which is directly connected to and extends from the hull on both sides and is symmetrical about the central vertical longitudinal plane of the ship, the structure being mounted forward of the propeller and there being a gap between the propeller and the rearward end of the structure, the structure, as the ship is viewed in side elevation, at least partly overlapping a stern portion of the hull, and the inlet area of the structure at its forward end, that is the open area between the structure at its forward end, that is the open area between the structure and hull in the transverse plane at the forward end, being not greater than the outlet area at the rearward end of the structure.

20 The invention utilizes hydrodynamic characteristics of the flow field around the ship's stern and interaction between the hull and the propeller to improve performance.

The invention is directed towards the following considerations:

- 25 (1) suppressing disturbance of the wake field around the stern, and increasing uniformity of said field with depth;
- 30 (2) allowing effective use of the stern wake field by guiding the wake properly into the propeller disc;
- 35 (3) adding thrust,
- 40 (4) lack of a requirement for high tolerances in manufacture as required by ducted propellers, reduction of erosion as experienced with ducted propellers, lack of necessity for such additional constructions such as with stern fins, and reduction of drawbacks due to the tip vortex and cavitation caused thereby; and,
- 45 (5) easy applicability to existing ships.

The background to the above points will be explained. Concerning the factors affecting the required power of a ship:

When a ship is run at a speed of V_s against a ship resistance of R_s , the necessary delivered horsepower (DHP) from the main engine is expressed by the following;

$$\text{DHP} \propto R_s V_s / \eta$$

wherein η is the quasi-propulsive coefficient, which is expressed as follows:

$$\eta = \frac{1-t}{1-w} \cdot \eta_0 \cdot \eta_R$$

wherein $(1-t)/(1-w)$ is an element representing the interaction between the propeller and the hull, t is the thrust deduction factor, w is the Taylor wake fraction, η_0 is the open water efficiency of the propeller and η_R is called the relative rotative efficiency and represents a ratio of propeller efficiency in the so-called "behind condition" where the propeller operates in the disturbed flow behind a hull at a predetermined speed.

Accordingly, it is apparent from the foregoing discussion that in order to decrease the required horsepower for a predetermined speed, it is necessary to decrease the hull resistance and increase the propulsive efficiency.

Hull resistance can be generally subdivided into components of frictional resistance of an equivalent flat plate, form resistance and wave-making resistance using 3-dimensional analysis. Form resistance is made up of viscous pressure resistance and induced drag, which are largely affected by the hull form in the stern portion and the condition of the wake field resulting therefrom. As the hull form becomes more full, the flow around the stern is disturbed to a greater extent because of generation of the 3-dimensional separation vortices, et. and thereby the form resistance is increased. Accordingly, form resistance and therefore total hull resistance can be reduced by suppressing the disturbance of flow around the stern and making the non-uniformity to the wake field small.

In order to raise the propulsive efficiency, the following steps should be taken. The thrust deduction factor t represents the increase of hull resistance (in other words the increase of required thrust) due to operation of the propeller behind the ship, and for a ship at constant speed, the increase of the required thrust of the propeller is related to the decrease of the propulsive efficiency. Accordingly, if any means which can produce an additional thrust without increase of horsepower is provided besides the propeller (like the ducted propeller), the propulsive efficiency will be increased.

The Taylor wake fraction w is generally

expressed in the form of $1-w$, and this $(1-w)$ is defined by the ratio V_x/V_s , where V_x is the average water velocity flowing into the propeller and V_s is the ship velocity. Accordingly, $(1-w)$ is made small by concentrating as slow a flow as possible within the propeller disc (the circle having a diameter corresponding to that of the propeller), by ensuring a high value of wake fraction w so that the propulsive efficiency can be raised in the form of energy recovery at the propeller. Also in order to raise η_R , it is necessary to reduce the disturbance of flow into the propeller disc and to homogenize the flow field around the stern.

Non-uniformity of the wake field at the stern increases the variations in time and position with respect to the produced thrust and torque of the propeller operating in the flow field, and causes an increase in propeller cavitation and increases of hull vibration and noise caused by increase of the exciting forces, and therefore the equalization of the stern flow field is desirable to remove the causes of these performance obstructions.

As stated above, the performance of a ship becomes gradually inferior as the hull form becomes fuller, and the disturbance of the wake field around the ship stern, to equalize the wake field as much as possible, to utilize the wake field of the ship stern effectively by guiding the wake, particularly the boundary layer flow, into the propeller disc as uniformly as possible all over the disc, and to provide an additional thrust.

In order that the invention may be more clearly understood, the following description is given, merely by way of example, with reference to the accompanying drawings, in which,

Figs. 1 to 4 show a first embodiment of the present invention, Fig. 1 being a side view of the stern portion of a ship, showing an annular structure mounted at the stern portion in section and Fig. 2 being a sectional view as seen in the direction of the arrow A-A of Fig. 1;

Fig. 3 is a sectional view taken on the line B-B of Fig. 2;

Fig. 4 is a sectional view taken on the line A'-A' of Fig. 1;

Fig. 5 is a part sectional side view of a second embodiment of the invention and shows a ship stern having, shown in section an annular structure which is of greater length over its upper portion and gradually shortens towards the bottom of the lower portion;

Fig. 6 is a part sectional side view of a third embodiment of the invention and shows a ship stern having an annular structure of which the inclination to a horizontal plane at various vertical cross sections is different;

Fig. 7 is a part sectional side view of a fourth embodiment in which an annular

structure is inclined upwardly and forwardly;

Fig. 8 and 9 are views of fifth and sixth embodiments respectively showing the right halves of ship sterns provided with annular structures which, in transverse section, are other than circular;

Fig. 10 and 11 are views respectively showing sectional shapes of annular structures according to the invention.

Fig. 12 is a side view showing an arrangement according to the invention in which the upper portion of an annular structure is directly attached to a ship and the lower portion thereof is attached to the ship by means of a support member;

Fig. 13 is a part sectional side view showing an embodiment where the present invention is applied to a ship having a ducted propeller;

Fig. 14A is a part sectional side view showing an embodiment where the present invention is applied to a ship having stern fins;

Fig. 14B is a side view of an embodiment wherein an annular structure has an upper portion extended toward the propeller;

Fig. 14C is a side view of an embodiment wherein an annular structure has an upper portion extended forward and backward along the flow direction;

Fig. 15 is a side view of an embodiment having two annular structures arranged in series;

Fig. 16 is a side view of a prior art ducted propeller;

Fig. 17 is a side view of prior art stern fin arrangement;

Figs. 18 and 19 are diagrammatic views respectively showing the condition of flow at the cruiser stern portion of a ship without and with an annular structure as provided by the invention;

Fig. 20 shows a distribution of values of the fraction w at the front of the propeller disc of the ship shown in Fig. 18;

Fig. 21 is similar to Fig. 20 in respect of the ship shown in Fig. 19;

Fig. 22 is a plan view illustrating the water flows round the sterns of ships with and without an annular structure of the invention;

Fig. 23 is a plan view showing the distributions of axial flow velocity at the horizontal level of the propeller shaft flowing into the propeller disc of ships with and without an annular structure according to the invention;

Fig. 24 is a view showing the distribution of the velocity components of the wake to the propeller disc;

Fig. 25 is a graph showing the difference in the required power for a ship of 100,000 DWT with and without an annular structure as shown in Figures 1 to 4; and

Fig. 26 shows traces of variations in the thrust variations on propellers in ships with, and without, the present invention.

The invention will first be described with reference to the embodiment shown in Fig-

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ures 1 to 4, and explanatory Figures 18 to 26 inclusive.

Figs 1 to 4 show a first and preferred embodiment of the present invention, in which there is provided an annular structure 2 attached to the hull, at the stern of a ship. This annular structure 2 partly overlaps the hull when the ship is viewed in side elevation, and is directly joined to the hull 1 by joint portions 2a, 2b, 2a' and 2b' as shown in Fig. 2. A part of the structure which does not so overlap the hull may be connected by means of a support member 5 if desired, as shown in Fig. 1. Aftward of the annular structure 2 is a propeller 3 of a diameter of D_p , and behind that is a rudder 4. As is evident from Fig. 1, the structure 2 is directly supported by the hull 1 and the propeller 3 is mounted at a position separated a little rearward from the rear end of the structure 2. The structure 2 may be a unitary annular member or composed, for instance, of separated, e.g. part ring-shaped parts according to its position and the design of the ship.

As already explained, in order to reduce the hull resistance in a full ship, the form resistance may be reduced. The form resistance is largely affected by the condition of the wake field from the position of propeller to a position forward therefrom by about 10% of the length of ship. The condition of the wake field at the stern portion of a full hull form is as shown in Fig. 18, where there is, on one side, a flow S_1 welling upward from the hull bottom and this is accompanied by 3-dimensional separation vortices S_2 . A flow S_3 is along the side and changes in accordance with the hull shape near the stern. Thus in the vicinity of the stern portion, the water disturbance due to the hull becomes large due to complex inter-mixture of the flows S_1 and S_3 . Since the hull shape changes abruptly in the vicinity of a cruiser stern such as 1a at the upper portion of the propeller 3, a large separated flow S_4 is sometimes produced. As noted above, the flow at the stern is greatly disturbed, and energy lost by this disturbance is effective as a resistance (the form resistance). This disturbance of the stern wake field is, as shown in Fig. 18, greatest between the propeller 3 and a point forward therefrom at a distance of about 3 times the diameter D_p of the propeller 3.

If, as shown in Figure 19, an annular structure 2 according to the invention is mounted so that its leading edge lies within the range of said disturbance of the wake field, the flow S_1 accompanied by the 3-dimensional separation vortices S_2 directed upward forwardly of the ring-shaped construction 2 can be rectified and equalized into parallel flow. Moreover, the flow S_3 above the ring-shaped construction 2 is distinguished from the flow welling up from below, so that the disturbance due to interaction of these flows can be

suppressed. The structure 2 reduces the hull resistance and serves as a rectifying vane for the flow into the propeller disc so that the propeller 3 produces greater thrust.

The wake field around the ship's hull at the stern is divided into two parts, one part being a flow which is called the boundary layer and is on average, a slower flow than the ship speed, although on the hull surface the flow velocity becomes zero, (namely the wake fraction $w = 1$) and the other being not part of the boundary layer of the hull and having a velocity corresponding to the ship speed (i.e. the wake fraction $w = 0$). When the propeller is not rotating, the boundary layer flows rearwardly of the hull thereby resulting in an energy loss (i.e. resistance), but when the propeller is in operation, it results in an increase of the propulsive efficiency at the same ship speed. This is called the wake gain.

In order to make this wake gain more effective, it is necessary to guide the slower, boundary layer, flow into the propeller disc, and also, if possible, to slow the flow into the propeller disc further. Accordingly, the ring-shaped structure 2 attains a concentration of the wake and the effective utilization of the boundary layer flow into the propeller disc.

Fig. 20 shows an example of the wake pattern of a full ship, and it can be seen that a flow of $w = 1$ or a value close to this does not cover a large area within the propeller disc of diameter D_p .

Fig. 21 shows the wake pattern of the case in which an annular structure as shown in Fig. 1 or Fig. 19, is provided at the ship's stern, and this shows that the propeller disc receives a wake flow of $w = 0.8, 0.7$ or 0.6 . for the most part.

Fig. 22 shows in plan, the flow at the stern of a ship as shown in Figs. 18 and 19.

A ship as in Figure 18, with an annular structure has a flow W_1 . In a ship as in Figure 19, the flow is spread as at W_2 , so that a slow wake flow enters a greater proportion of the disc of the propeller 3, and results in the wake pattern shown in Fig. 21. The requirement that the open area between the structure and hull at the forward end is not greater than that at the rearward end arises from this.

Fig. 23 shows in plan distributions of the axial flow velocity at the shaft center level. The velocity V_1 without the annular structure 2 is larger than the velocity V_2 with it.

The annular structure is preferably not located too far forward of the propeller 3, in particular if the distance between the propeller and structure is more than 3 times the propeller diameter D_p , the boundary layer at that position is so thin that it will not effectively utilize the wake. On the other hand, if the leading edge of the annular structure is too close to the propeller, e.g. by being

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located aft of the stern frame, the wake will already have diffused ahead of the structure, so that the structure will be unable to guide the wake into the propeller disc.

If the length ℓ of the structure 2 (see Fig. 1) is too short, it will have reduced effect on the wake field at the stern. If it is too long, its resistance becomes too large. Taking these various facts into consideration, the preferred length ℓ of the structure 2 is effective from 20% to 100% of the propeller diameter.

Where the upper end face of the structure 2 is directly joined to the hull, the distance from the rearmost joining point (in Fig. 1, the intersecting point P of the upper end face of the ring-shaped structure 2 with the stern frame) to the foremost end of the ring-shaped structure 2, namely the length ℓ , of the portion over which it is directly joined to the hull, is preferably more than 20% of the length ℓ of the ring-shaped structure 2 in order to attain suppression and equalization of the disturbance and an effective utilization of the wake as described above.

There is a preferred relation between the inner diameter of the annular structure 2 and the propeller diameter D_p . Namely, as shown in Fig. 4, the inner face of the trailing edge of the ring-shaped structure 2 at the horizontal level of the propeller shaft, preferably has a diameter D_1 which is about 60% to about 150% of that of the propeller diameter D_p . If D_1 is too large, the wake guided into the propeller disc by the ring-shaped structure 2 is not effective. However, if D_1 is too small, the relatively fast flow outside the structure flows into the propeller disc thereby reducing the propulsive efficiency. Accordingly, it is preferable to determine the diameter D_1 of the annular structure in consideration of the experimental comparison represented and described in connection with Figs. 20 and 21.

So far as the cross sectional shape of the ring-shaped structure 2 is concerned, these should be preferably of hydrofoil section. However, governing this shape is the requirement for the inlet area of the structure to be not greater than the outlet area.

Thus, in the embodiment of Figures 1 and 3, the inner face 2i of the structure is convex and outer peripheral face 2k is flat.

Also, if the angle α enclosed between the flat face 2k of the structure 2 and the center line of the hull is too large, the structure 2 is less effective in spreading the wake near the stern outward as shown in Fig. 22. If there is too large an angle made with the flow welling up from the bottom of hull, the resistance is increased. Otherwise if angle α is large and inclined inwardly with respect to the hull center-line, the resistance is increased. The suitable angle α is found to range approximately from 10 degrees inwardly to 30 degrees outwardly.

The flow around the stern has both radial

and circumferential components as indicated in Fig. 24, and therefore, the annular structure placed in this flow exerts thrust due to its aerofoil type cross-section, resulting in increase of the propulsive efficiency.

An important point of the present invention is that the annular structure is directly attached to the ship stern, so as to spread the wake flow entering the propeller disc. The benefits obtained by the present invention may be as follows:

(1) The annular structure reduces hull resistance and increases propulsive efficiency, since it acts as a kind of flow regulator thereby suppressing the turbulence of the stern flow, homogenizing the flow and making it possible to utilize effectively the stern flow for energy recovery at the propeller by guiding a wake of high w values into the propeller disc. Thus, the annular structure reduces the required engine power for a given speed.

(2) Non-uniformity in the stern wake field usually increases the thrust and torque variations in both time and position of a propeller operating in the wake field, and also causes increase in propeller cavitation and of the exciting forces acting on the hull, (which are accompanied by increase of hull vibration and noise in the ship) with the invention, the equalization of the wake field around the stern due to the annular structure reduces these problems.

(3) The annular structure is mounted forward of the propeller, so that damage to the inside face annular structure due to the propeller cavitation is reduced.

(4) The annular structure is directly fixed to the main hull, so that it can be of a lighter construction than if fixed to the hull by way of a support member. Also since it is of annular shape, it does not require so great a hull reinforcement as is the case of the cantilever construction in stern fin arrangements.

(5) The annular structure can be easily attached to an existing ship as well as a ship under construction, and even when applied to an existing ship, it provides an economical means of improving the ship's performance, and may in some cases be able to do so without a new design of propeller being required.

Further, it may be that the fitting of an annular structure to an existing, old ship, may allow higher propeller revolutions to be obtained than would otherwise be prudent.

(6) According to the present invention, the propulsive performance rises. Thus, when propulsion tests in a towing tank were carried out with an annular structure as shown in Fig. 1 - 3 attached to the stern of a 100,000 DWT ship, the advantageous effects of the present invention were confirmed, as shown in Figure 25 which shows speed-power curves obtained with model tests. In this example, a power saving of about 10%

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was obtained. Fig. 26 is an example of the records of the thrust variation in self-propulsion tests, wherein the upper curve A shows the condition of thrust variation on a propeller of a conventional ship, and the lower curve B shows the thrust variation of a ship according to the present invention. It is evident that in the case of curve B, the amplitude of thrust variation is notably small compared with that of curve A.

This shows that present invention reduces hull vibration and the noise inside the hull (7). The flow field around a ship stern becomes stabilized compared with prior art ships, so that manoeuvrability is improved.

Other embodiments of the present invention will now be described.

Fig. 5 shows an annular structure 2, whose length varies around its periphery, the length ℓ_1 of the upper portion gradually reducing, as shown in the Figure 5 example to a length ℓ_2 at a lower portion.

The rate of change of length is determined in accordance with the condition of the wake field at the ship stern, and is thus designed individually according to the particular design shape and size of the hull. In most cases where this configuration is adopted, the condition $\ell_1 > \ell_2$ is applied, however $\ell_1 \neq \ell_2$ may also be possible depending on hull shape.

Fig. 6 shows an annular structure 2 having an outer peripheral face 2C which, when viewed in sectional side elevations has varying inclinations to horizontal planes at the height of the section. This inclination is optimized in accordance with bilge vortices and direction of the flow for a particular hull and in the illustrated embodiment, the wing section 2C' at the lower part of the structure 2 is directed downwardly and forwardly.

Fig. 7 shows an annular structure 2 which is similar to that shown in Figs. 1 - 3, but is mounted on the hull in an inclined manner, with its axis extending downwardly and forwardly in consideration of the direction of the flow welling up from the hull bottom, as referred to previously in connection with Fig. 18.

The annular structure of the present invention is preferably circular as shown in Fig. 2. However, it may be of other shapes according to hull form and wake flow. Thus Fig. 8 shows one that has an upward bulge, its radius of curvature becoming smaller towards its upper part. This shape is suitable when the hull bottom is relatively pointed.

An annular structure of circular or other curved e.g. elliptical shape is generally more difficult to build than one formed of straight segments as shown in Fig. 9. Structures including both straight and curved segments may be adopted.

In cross-section, the ring-shaped structure is preferably of hydrofoil shape, as shown in

Figs. 1, 5 and 6, but sections approximating this can be used, for instance if the section involves some, or only, straight lines production is easier. Fig. 10 shows an annular structure 2 of generally hydrofoil section which for easy production, and which for the most part thereof is formed by straight lines.

Considering for instance the relative arrangement of the annular structure, the ship stern and the propeller and the diameter of propeller and so on, there are instances where the shape of the hydrofoil section shown in Fig. 1 is not necessarily optimum. Fig. 11 shows an alternative section of an annular structure designed particularly to increase the propulsive efficiency by spreading the slow boundary layer flow over the propeller disc, and this has a diffuser angle γ at the rear end portion 2e' of the section 2e, which is from 0° to 10° , preferably $3^\circ - 5^\circ$.

Fig. 12 shows an embodiment of the invention wherein an annular structure 2 is mounted at the stern portion of a hull 1 having no sole-piece. In this embodiment, the lower end of the ring-shaped structure 2 is connected to the hull 1 by means of a support 6.

The invention can be employed in combination with other means of increasing propulsive efficiency.

Thus, Fig. 13 shows an embodiment wherein an annular structure 2 is mounted in front of a duct 7 attached to the stern of the hull 1 by means of support members 8.

In this case, the effects of the structure 2 and the ducted propeller are combined, resulting in an increase of propulsive efficiency, and in addition, another effect can also be attained in that the flow homogenized by the annular structure 2 moderates the erosion of the inside face of the duct.

Fig. 14A shows a case wherein the present invention is applied to a ship having stern fins 9. In this case, the flow at the upper portion of the stern is controlled by means of the stern fins 9, and the propulsive efficiency can be increased by guiding the wake flowing along the hull 1 into the propeller disc.

Fig. 14B and Fig. 14C show other embodiments of the present invention wherein stern fins 9 are integrally connected so as to extend backward or both forward and backward (alternatively they may extend only forward) in the vicinity of the upper half portion of the annular structure 2. In the case of a hull form causing violent disturbance of the wake field, it is possible to suppress the disturbance by overall lengthening of the annular structure 2, however by the combination of the structure 2 and the stern fins 9 such as in this embodiment, it is possible to obtain effects of equalization of the wake field and concentration of the wake, etc. by the structure 2 and in addition thereto an effect to suppress the disturbance without lengthening the struc-

ture, thereby increasing the propulsive efficiency. Moreover, the stern fin 9 is connected with the structure 2, and accordingly the stern fins 9 can be made of lighter construction.

The embodiment of Fig. 14B is effective for a hull form causing particular violent disturbance of the wake field at the upper portion of the stern, and the embodiment of Fig. 14C is particularly effective for a hull form causing not only violent disturbance of the wake at the upper portion of the stern but also violent disturbance of the wake field at the forward upper portion of the structure and the flow welling up from the hull bottom.

Fig. 15 shows an embodiment wherein an annular structure 2 is mounted immediately in front of the propeller 3 and another small annular structure 10 is mounted forwardly thereof. There may, in fact, be more than one additional annular structure.

According to this embodiment, the flow at the stern is controlled in two stages by means of the two annular structures 10 and 2, resulting in further improvement.

In our copending application No. 7687/79 (Serial No. 1561506) we describe certain of the above embodiments and claim certain aspects of the above described invention.

WHAT WE CLAIM IS:-

1. A surface ship provided with a propeller and having a generally annular structure which is directly connected to and extends from the hull on both sides and is symmetrical about the central vertical longitudinal plane of the ship, the structure being mounted forward of the propeller and there being a gap between the propeller and the rearward end of the structure, the structure, as the ship is viewed in side elevation, at least partly overlapping a stern portion of the hull, and the inlet area of the structure at its forward end, that is the open area between the structure and hull in the transverse plane at the forward end, being not greater than the outlet area at the rearward end of the structure.

2. A ship according to claim 1 wherein at, at least one position where the structure is connected to the hull, at least 20% of the minimum length of the structure as viewed in side elevation overlaps the hull.

3. A ship according to claim 1 or 2 wherein, the axial length (ℓ) of the structure is within the range of

$$\ell = (0.2 - 1.0) D_p$$

where D_p is the diameter of the propeller.

4. A ship as claimed in claim 1, 2 or 3 wherein the structure in transverse cross-section, is of circular or other curved shape such as elliptical.

5. A ship according to claim 1, 2 or 3, wherein the structure, in transverse cross-section, comprises a plurality of mutually inclined segments of which some are straight.

6. A ship as claimed in claim 1, 2, 3, 4 or 5 wherein the structure, when viewed in sectional side elevation, is longer at the upper portion thereof than at the lower portion, the length gradually reducing from the upper portion to the lower portion.

7. A ship as claimed in any preceding claim wherein the structure has an outer peripheral surface which, when viewed in plan at any horizontal plane therethrough, is inclined to the centre line of the hull at an angle from 10° forwardly and inwardly to 30° forwardly and outwardly.

8. A ship as claimed in any preceding claim, wherein the inner diameter D_1 of the annular structure has a range of

$$D_1 = (0.6 \sim 1.5) D_p$$

where D_p is the diameter of the propeller.

9. A ship according to any preceding claim wherein the outer face of the annular structure, when viewed in sectional side elevations, has varying inclinations to horizontal planes at the height of the sections.

10. A ship according to claim 9 wherein the outer surface is directed downwardly and forwardly at the lower part of the structure.

11. A ship according to any one of claims 1 to 8 wherein the axis of the annular structure is inclined downwardly and forwardly relative to that of the ship.

12. A ship according to any preceding claim wherein the annular structure is directly fixed to the hull at its upper portion, and is connected to the hull via a support member at its lower portion.

13. A ship according to any preceding claim wherein the annular structure has a convex inner face and straight outer face when viewed in section.

14. A ship according to any preceding claim, wherein, in section the annular member has a hydrofoil section.

15. A ship according to claim 13 or 14 wherein the inner face of the structure, in section, is defined by straight lines.

16. A ship according to claim 13, 14 or 15 wherein the interior of the structure diverges outwardly and rearwardly at the aft end of the structure.

17. A ship according to any preceding claim and including a plurality of said annular structures arranged along the length of the hull.

18. A ship according to any preceding claim wherein the propeller is mounted within a duct.

19. A ship according to any one of claims 1 to 17 wherein stern fins are provided above the annular structure.

20. A ship according to claim 19 wherein the stern fins are integrally connected to the upper part of the annular structure to extend backward or forward therefrom.

21. A ship according to claim 19 wherein the stern fins are integrally connected to the



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ture, thereby increasing the propulsive efficiency. Moreover, the stern fin 9 is connected with the structure 2, and accordingly the stern fins 9 can be made of lighter construction.

The embodiment of Fig. 14B is effective for a hull form causing particular violent disturbance of the wake field at the upper portion of the stern, and the embodiment of Fig. 14C is particularly effective for a hull form causing not only violent disturbance of the wake at the upper portion of the stern but also violent disturbance of the wake field at the forward upper portion of the structure and the flow welling up from the hull bottom.

Fig. 15 shows an embodiment wherein an annular structure 2 is mounted immediately in front of the propeller 3 and another small annular structure 10 is mounted forwardly thereof. There may, in fact, be more than one additional annular structure.

According to this embodiment, the flow at the stern is controlled in two stages by means of the two annular structures 10 and 2, resulting in further improvement.

In our copending application No. 7687/79 (Serial No. 1561506) we describe certain of the above embodiments and claim certain aspects of the above described invention.

WHAT WE CLAIM IS:-

1. A surface ship provided with a propeller and having a generally annular structure which is directly connected to and extends from the hull on both sides and is symmetrical about the central vertical longitudinal plane of the ship, the structure being mounted forward of the propeller and there being a gap between the propeller and the rearward end of the structure, the structure, as the ship is viewed in side elevation, at least partly overlapping a stern portion of the hull, and the inlet area of the structure at its forward end, that is the open area between the structure and hull in the transverse plane at the forward end, being not greater than the outlet area at the rearward end of the structure.

2. A ship according to claim 1 wherein at, at least one position where the structure is connected to the hull, at least 20% of the minimum length of the structure as viewed in side elevation overlaps the hull.

3. A ship according to claim 1 or 2 wherein, the axial length (ℓ) of the structure is within the range of

$$\ell = (0.2 - 1.0) D_p$$

where D_p is the diameter of the propeller.

4. A ship as claimed in claim 1, 2 or 3 wherein the structure in transverse cross-section, is of circular or other curved shape such as elliptical.

5. A ship according to claim 1, 2 or 3, wherein the structure, in transverse cross-section, comprises a plurality of mutually inclined segments of which some are straight.

6. A ship as claimed in claim 1, 2, 3, 4 or 5 wherein the structure, when viewed in sectional side elevation, is longer at the upper portion thereof than at the lower portion, the length gradually reducing from the upper portion to the lower portion.

7. A ship as claimed in any preceding claim wherein the structure has an outer peripheral surface which, when viewed in plan at any horizontal plane therethrough, is inclined to the centre line of the hull at an angle from 10° forwardly and inwardly to 30° forwardly and outwardly.

8. A ship as claimed in any preceding claim, wherein the inner diameter D_1 of the annular structure has a range of

$$D_1 = (0.6 \sim 1.5) D_p$$

where D_p is the diameter of the propeller.

9. A ship according to any preceding claim wherein the outer face of the annular structure, when viewed in sectional side elevations, has varying inclinations to horizontal planes at the height of the sections.

10. A ship according to claim 9 wherein the outer surface is directed downwardly and forwardly at the lower part of the structure.

11. A ship according to any one of claims 1 to 8 wherein the axis of the annular structure is inclined downwardly and forwardly relative to that of the ship.

12. A ship according to any preceding claim wherein the annular structure is directly fixed to the hull at its upper portion, and is connected to the hull via a support member at its lower portion.

13. A ship according to any preceding claim wherein the annular structure has a convex inner face and straight outer face when viewed in section.

14. A ship according to any preceding claim, wherein, in section the annular member has a hydrofoil section.

15. A ship according to claim 13 or 14 wherein the inner face of the structure, in section, is defined by straight lines.

16. A ship according to claim 13, 14 or 15 wherein the interior of the structure diverges outwardly and rearwardly at the aft end of the structure.

17. A ship according to any preceding claim and including a plurality of said annular structures arranged along the length of the hull.

18. A ship according to any preceding claim wherein the propeller is mounted within a duct.

19. A ship according to any one of claims 1 to 17 wherein stern fins are provided above the annular structure.

20. A ship according to claim 19 wherein the stern fins are integrally connected to the upper part of the annular structure to extend backward or forward therefrom.

21. A ship according to claim 19 wherein the stern fins are integrally connected to the

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upper part of the structure and extend both forward and backward therefrom.

22. A ship substantially as hereinbefore described with reference to and as shown by any one of Figures 1 to 15 and 18 to 26 of the accompanying drawings.

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Printed for Her Majesty's Stationery Office,
by Croydon Printing Company Limited, Croydon, Surrey, 1980.
Published by The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.