# PATENT SPECIFICATION

Convention Date (Germany): July 25, 1933.

443,362

Application Date (in United Kingdom): July 19, 1934. No. 21195/34.

Complete Specification Accepted: Feb. 19, 1936.

COMPLETE SPECIFICATION

## Improvements in a Combined Device of a Ship's Propeller Enclosed by a Nozzle

I, LUDWIG KORT, of Jakobistrasse 7, Hannover, Germany, of German nationality, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

Nozzle-shaped appendages to a ship's hull which are open at both ends and enclose the screw propeller or propellers are known. These nozzles are in some cases so shaped and arranged that the propeller operates at about the narrowest cross section of its nozzle which surrounds its disc area with but little play. In some cases also the area of the nozzle cross section aft of the propellers does not increase at all or only increases slightly, whilst in front of it these areas increase constantly and materially, the longitudinal cross-sections of the wall of such nozzles having in some cases also for at least part of their circumference airplane wing profiles with high depth-width ratio, a well rounded leading edge and the pressure side outside.

According to other proposals the propellers are surrounded by rings, straight or conical tubes or the like.

All of these combinations had as their aim to increase the propulsive efficiency of the propeller and yet they all failed in practical use as none of them disclosed a way of properly combining and shaping the nozzle, the propeller and the adjacent parts of the ship's hull in such a manner as to ensure an additional thrust on the ship without any increase in the torque applied to the propeller shaft.

It is therefore the object of my invention to show, out of the known forms of nozzles, the correct basic form, to show what improvements are necessary on it and how properly to combine, arrange and shape the propeller, the nozzle and the adjacent parts of the ship's hull in relation to each other with a view to obtaining an improvement in the combined propulsive effect on the ship.

My invention further relates to ways and means by which the above mentioned combination may be made adaptable to varying speeds and loads on the propeller.

My invention finally relates to the proper shaping and combining of the three elements in question to render the combination adaptable to certain types of ships and certain conditions of navigation under which such ships may usually work.

For the better understanding of the invention reference is to be had to the accompanying drawings forming part of this specification and described hereafter.

In these drawings, in the various figures of which similar characters of reference indicate corresponding parts,

Fig. 1 is a diagrammatic horizontal section taken about the height of the propeller shaft through the stern of the ship and showing the improved propelling device.

Fig. 1a is a diagrammatic view at the stern of a ship fitted with a nozzle according to Fig. 1.

Fig. 2 is a side elevation of a detail of the arrangement shown in Fig. 3.

Fig. 3 is a horizontal section through the stern of a twin screw shallow draught vessel with the nozzle surrounding the propelling screws.

Fig. 4 is a rear elevation of the vessels shown in Figs. 2 and 3.

Figs. 5 and 6 show an end elevation and a longitudinal section respectively of a modified form of the arrangement.

Fig. 7 is a side elevation of a detail of a further form of the invention.

Fig. 8 is a horizontal sectional view of the arrangement shown in Fig. 7.

Fig. 9 is an end elevational view of the arrangement shown in Fig. 7.

Fig. 10 is a diagrammatic view showing how the speed $v_1$ of the water entering the mouth 6, 7 of the nozzle shown in Fig. 7 varies due to the wake of the hull between the parts of said opening near the ship's hull and those further away from the hull.

Fig. 11 is a view looking aft inside a nozzle with the propeller just in front of the narrowest cross section, showing its areas immediately forward and aft of the

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propeller.

Fig. 12 is a horizontal section of a detail of the nozzle illustrated in Fig. 11 showing how the propelling screw operates between the circular sections B and C.

Fig. 13 is the enlarged and developed vertical area of the cylindrical cross section 10—11 through one of the propeller blades shown in Figs. 11 and 12.

Fig. 14 is a side elevational view of a further modified form showing the term of a shallow draught, single screw vessel with a nozzle surrounding the propeller.

Fig. 15 serves illustrative purposes only, does not form part of the invention and is a sectional plan view of the stern of a twin screw ship with nozzles surrounding the propellers, modified from Fig. 2.

Fig. 16 is a diagrammatic view of the whirling motion of the entering water at cross section B of Fig. 15 looking aft.

Fig. 17 shows a sectional plan view of the stern of a twin screw boat with nozzles surrounding the propellers, the centre lines of the aft end of the nozzles and the centre lines of the propeller shafts being set at an angle to each other diverging towards the rear of the boat.

Referring now more particularly to the drawings, in which similar reference numerals designate corresponding parts throughout the several views.

As shown in Fig. 1, the area of the nozzle cross section aft of the propellers does not increase at all, although it may do so slightly, whilst in front of it these areas increase constantly and materially to an inlet opening of larger size than the outlet with a well rounded bulbous edge. The external walls connect up with the rounded front edge and taper therefrom to the inner edge of the outlet opening. The arrangement is such that the longitudinal sections of the nozzle body are directly comparable, at least for a part of the circumference of the nozzle, with the profiles of airplane wings having a high length depth ratio, a well rounded leading edge, the suction sides being turned towards the inside of the nozzle and the pressure sides forming its outside surface. This form of profile is known to have but little sensibility to a change in its angle to the direction of flow. It thus becomes possible, within certain limits, for the quantity and speed of the water entering the nozzle through the mouth " A " to become adapted automatically and with a minimum loss to variations of speed and of resistance of the ship.

It is therefore desirable to use the thick air-foil section for as great a part of the circumference as practicable. Actually, however, this is not always possible, since for good propulsive efficiency a large propeller is chosen and, as it is not desirable for the nozzle body to project below the keel line, the section of the body at the bottom may have to be flattened as shown in Figs. 2 and 7. On the other hand Fig. 1a and Fig. 5 show how the change from the thick to the flat cross section is effected gradually.

The water enters the nozzle in Fig. 1 at the opening A with the speed $v_1$ multiplied by the wake factor, enters the propeller at the cross section B and leaves the propeller at the cross section C with the increased speed $v_2$, which speed is somewhat higher than that at the widened cross section D of the exit opening. At the mouth A of the nozzle the transverse section of the hull has the area E.

The best efficiency of the nozzle with the given propeller characteristics will be reached, if the mouth A, measured transversely to the flow of the water, is made about so large that for the desired service speed of the ship the amount of water required to leave the propeller at E the increased speed $V_2$ can enter without being accelerated in front of the nozzle by the suctional effect of the propeller or in other words, that $v_1$ is made to be about equal to the service speed $v$ of the ship less the wake speed running in front of the nozzle and in the direction of the ship's path.

If the relation between the entrance opening A and the smallest cross section C as stated above is not adhered to, or in the other words, if the mouth A is made for instance too large, there will be a braking back current in front of the nozzle. If, on the other hand, the mouth A is made too narrow, part of the water required for the propulsion will have to be accelerated in front of the nozzle and the decreased hydrostatic pressure will have a braking-effect on the ship (in shipbuilding practice called " thrust reduction "); in addition the propulsive-effect of the nozzle will decrease.

Usually a nozzle as described above will have its place at the ship's stern and in most cases part of the ship's stern especially that part surrounding the tail-shaft of the propeller will extend into the mouth of the nozzle.

The acceleration of the water produced by the action of the propeller between the mouth of the nozzle and the propeller disc area causes a reduction in the pressure in this region so that there is a resultant force acting in the direction of the ship's path on the inside walls of the nozzles; at the same time however, this reduction of pressure acts as a braking force on the ship by its action on the aforementioned

extension of the ship's stern which projects into the nozzle as shown in Fig. 1 with the cross section E at the mouth of the nozzle. The total pressure on the walls of the nozzle due to the suction of the propeller is (A—C) $\Delta p$ where "$p$" is the normal hydrostatic pressure and $\Delta p$ denotes the decrease of this pressure inside the nozzle due to the acceleration of the water between its mouth "A" and the opening "C." The difference between this value (A—C) $\Delta p$ and E $\Delta p$, i.e. the value of the braking force or "thrust reduction" acting on the stern of the ship, gives the resultant additional forward thrust due to the effect of the nozzle.

Actually the acceleration of the water and therefore the decrease of the hydrostatic pressure is bound to be a maximum in the regions of the maximum wake, i.e. in the regions of the highest skin-friction of the hull, and therefore the braking influence of the said hull extensions inside the nozzle is especially large.

Thus it is necessary that the cross section E in Fig. 1, i.e. the cross section of the end of the hull extending into the nozzle measured at the mouth of the nozzle should as far as possible be cut down to a minimum so as not to exceed the difference between the external pressure on the external rear walls of the nozzle and the value (A—C) $\Delta p$ from which the additional propulsive effort is obtained.

In cases where there are larger variations of speed or resistance the mouth at A may be enlarged or diminished by making a part or parts of the circumference of the mouth as streamline-shaped adjustable flaps. Fig. 2 and 3 show such an arrangement, wherein 2 denotes a vertical flap turning about the axle 3, and 4 —as an alternative—a horizontal flap turning about line 5.

Fig. 5 and 6 show the possibility of using the nozzle as an instrument for equalising the speed of the water which enters at the same time the various points of the propeller areas. This is achieved by making the mouth "A" especially wide in the zones of the greatest wake e.g. near the counter of the stern. The effect is that the slower moving water will undergo greater increase of speed after entering the nozzle by the greater contraction of the streamlines within the nozzle at these points. Figs. 7 and 10 show another way of equalising the speed of the water at B. Fig. 10 shows diagrammatically about how the speed $v_1$ of the water entering the nozzle at "A" may be distributed between the points 6 and 7. The corresponding points at B, i.e. the plane where the water reaches the propeller, are 8 and 9. As the suction of the propeller largely depends on its pitch it may be assumed that the hydrostatic pressure tends to be equal at 8 and 9 and is smaller there than at 6 and 7, whilst the pressure at 6 is larger than at 7. Thus there is a greater difference in pressure between points 6 and 8 and a smaller difference between 7 and 9. Hence follows the tendency of the water to accelerate especially between 6 and 8 and if the nozzle between sections A and B is made long enough the equalisation of the speed of the water will result automatically.

As on the other hand the elongation of the nozzle will increase the friction of the water on its walls there is of course an economical limit to the elongation.

The aforementioned friction on the walls of the nozzle as well as on these parts of the hull which are around the propeller shaft has a tendency to decrease the speed of the water within these zones which may be regarded as extending chiefly cylindrically around the propeller shaft. This differentiation of the speed of the water entering the disc area of the propeller can be offset economically by giving the propeller a pitch which first increases radially and then decreases towards the blade tips.

The usual way in designing a propeller is to make the cylindrical sections through the blades straight on the pressure side and rounded on the foreside. A propeller of this kind is shown in Figs. 11, 12 and 13. From Fig. 13 it will be seen that the middle lines of the blade section is not straight but curved. The tangents on this curve through the points 10 and 11 intersect at an angle.

It is substantially by this angle $\alpha$ measured on the periphery of the cylindrical section, that the effective pitch increases from the entrance side to the exit side of the propeller. This means that the water will undergo an additional acceleration while passing through the blades, and the jet of water leaving the propeller will be contracted accordingly in diameter.

It will therefore be well to differentiate the areas B and C accordingly i.e., to make C smaller than B. Should this be omitted there will be a danger of the jet of water separating itself from the walls of the nozzle, or of the leading edges of the blades having to work so much harder and less economically. On the other hand, with C smaller than B, there will be a gain in propulsive action expressed by the product of the difference of area between B and C and the decrease of hydrostatic pressure within this ring-zone.

Fig. 1 and others show the nozzle-body to be double walled, i.e., with an inner

part properly nozzle-shaped and an outer hull by which the nozzle is fastened to the ship. For ships with medium and large speeds the shape of the outer hull should be adapted to the natural flow of the water which has to pass it. The natural tendency of this flow is that the water from both sides of the nozzle will unite aft of it at an angle $\beta$ which is shown in Fig. 1. If the corresponding angle $\gamma$ on the hull of the nozzle is made too small, the flow of the water will result with a decrease of hydrostatic pressure and accordingly a braking effect on the hull. If, however, the angle $\gamma$ is made a little larger than the natural direction of the streamlines would call for, the result will be a diminution of speed and an increase of the hydrostatic pressure. As this pressure acts upon the outer rear side of the nozzle, it will add to the propulsive powers of the hull.

This latter case is shown by Fig. 1 where $\beta$ denotes the angle of the natural flow of the stream lines and $\gamma$ the somewhat larger angle of the outer hull of the nozzle. It is a matter of course that $\gamma$ should not be made so large that the water might separate from the nozzle as it passes by, which would be detrimental to the propulsive effect.

Fig. 14 shows the combination of a screw tunnel and a nozzle for shallow draught ships. In such cases the highest inside part of the nozzle rises higher than the level of the water outside the nozzle. Line 13 indicates how in this case the upper edge of the mouth of the nozzle is turned forward and runs below the water surface until it meets with the hull body proper. If in a similar way the after opening of the nozzle is turned downward in its upper part, as indicated by line 14, the power for lifting the water in front of the propeller will be constantly regained without requiring any power from the ship's engine.

Line 15 in Fig. 14 which is a line joining the highest points of the cross section of the nozzle, indicates how the back end of the nozzle should be formed in this instance, i.e. as usual on tunnels for shallow draught ships in which the propeller circle is partly above the surface of flotation of the ship. In such cases the tunnel behind the propeller is gradually carried down to the height of the water surface outside of the ship in a curve which as far as possible follows the natural curve of the water, under the combined influence of its horizontal speed when leaving the propeller and the downwardly acting force of its weight.

Fig. 2, 3, 4 and 17 show twin-screw ships with nozzles. In using this kind of arrangement it is necessary that the water flowing towards the nozzles should be turned into the direction of the propeller shafts before it enters into the mouth of the nozzle. If this rule is not followed there will be a poor propulsive effect. It will be noted that in Fig. 15, which illustrates how it should not be done, there is a sharp horizontal turn in the entry part of the nozzles which produces on the inner walls (towards the centre line of the ship) due to the centrifugal force, a double-turn whirling effect, which is particularly illustrated in Fig. 16. This whirling effect prevents the water from entering the propeller area at B in the proper shaft. Fig. 3, on the other hand, shows how this whirling effect is avoided by a proper mutual arrangement and shaping of the propeller, the nozzle and the ship's hull in front of it i.e. by having the propeller near the narrowest inner cross section by placing the area of the mouth of the nozzle substantially vertical to the centre line of the propeller shaft and by arranging or shaping the hull in front of said mouth in such a way that the water, under the influence of the ship's speed and the direction given to it by the ship's sides, reaches said mouth when moving in a direction substantially parallel to the propeller shaft.

It is but natural for the same reasons that the same rule must apply to single screw ships as well. This is another reason why in Figs. 1 and 1a the cross section E of the ship's hull at the mouth of the nozzle must be made as small as possible.

If a twin-screw arrangement with nozzles is used for shallow water, it will be well as shown by Fig. 2, 3, and 4 to vary gradually the cross section of the rear part of the nozzle between C and D while making this distance sufficiently long to enable the cross section of the nozzles to be raised in such a way that their two rear openings C merge into an area located in a common surround of oval or rectangular shape which may however be divided by the rudder. By this method the danger is overcome that the space between the two water jets from the propellers might not be filled out quickly enough and cause a braking back current.

Fig. 17 shows a twin screw arrangement with nozzles for a tugboat wherein the two nozzles are set at an acute angle to each other the propeller shafts being united by gear wheels 17 and driven by a common engine 16. This arrangement saves one engine and the water jet leaving the nozzles will not meet with the bow of the barge, which may be towed on a short tow rope behind the tug. The re-

sistance of the barge will thereby be diminished.

Figs. 5, 7, 8 and 9 show how for single screw ships the body of the nozzle may be rigidly and homogeneously united with the hull of the ship. The water lines in the upper part and above the nozzle are drawn out to unite as far as practicable behind the nozzle. The result of this method is not only a rigid connection between nozzle and ship but at the same time the resistance of the ship in combination with the nozzle will be materially decreased by the long water lines.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. A ship driven by one or more screw-propellers comprising in combination the features that the or each of said propellers is disposed within the length of a tubular nozzle arranged longitudinally of the propeller shaft, said nozzle being connected to the ship's hull, that the inner cross sectional areas of said nozzle towards its outlet do not change substantially and the inner cross sectional areas towards its mouth increase rapidly to present an entrance opening the size of which is substantially larger than that of the outlet, that the inlet edge of the mouth is rounded off with sectional curves of comparatively large radii which join the exterior surface of the nozzle body and this exterior surface tapers down gradually to the said outlet, (the wall thus having airplane wing sections with a high depth-width ratio and the pressure sides outside), that the said propeller is arranged to work with only a small tip clearance within or immediately in front of that part of the nozzle which has the substantially constant minimum cross sectional areas, and that the ship's hull at and in front of the nozzle is shaped and reduced in cross sectional area so as to turn the stream of water before it enters the mouth of the nozzle into a direction substantially parallel to the propeller shaft.

2. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in claim 1, wherein the outside surfaces of the nozzle body are inclined to the streamlines of the water which flows towards the outer edge of the mouth of the nozzle at an outside angle which at its maximum exceeds only slightly an angle of 180 degrees (see Fig. 1, angle $\frac{\gamma}{2}$ minus $\frac{\beta}{2}$).

3. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in either of the preceding claims, wherein adjustable flaps are arranged on the nozzle body to form part of the circumference of its mouth, said flaps being adapted to permit variation of the inlet area of the latter.

4. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, wherein the cross sectional area of the nozzle inlet opening is so distributed around the propeller shaft that the largest distances of its circumference from the propeller shaft are situated in the zone of the greatest wake thus producing in this part the greatest reduction in area between the inlet and the plane of the propeller.

5. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, wherein the upper inner surface of the nozzle is constituted by the hull of the ship and the waterlines of the hull immediately above the nozzle converge aft thereof.

6. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, wherein the upper inner surface of the nozzle is constituted by the hull of the ship and the upper part of the edge of the mouth of the nozzle instead of being in a vertical plane has its upper part extending substantially horizontally towards the ship's hull, said horizontal portion having a well rounded off edge which is lower at any given point than the highest point of the cross section of the nozzle in the plane of revolution of the propeller.

7. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in claim 6, characterized by the fact that the upper edge of the outlet of the nozzle extends rearwardly in a substantially horizontal plane, the two sides converging towards the rear and being lower at any given point than the highest point of the nozzle in the plane of revolution of the propeller.

8. A screw-propelled ship with a nozzle arranged around each propeller as claimed in any of the preceding claims characterized by the fact that when twin screws are employed the outlet parts of the nozzles aft of the propellers gradually change in cross section until they practically merge into a common outlet opening of rectangular or oval outline with a view to avoiding the formation of eddies between the streams of water issuing from the two nozzles.

9. A screw-propelled ship with a

sistance of the barge will thereby be diminished.

Figs. 5, 7, 8 and 9 show how for single screw ships the body of the nozzle may be rigidly and homogeneously united with the hull of the ship. The water lines in the upper part and above the nozzle are drawn out to unite as far as practicable behind the nozzle. The result of this method is not only a rigid connection between nozzle and ship but at the same time the resistance of the ship in combination with the nozzle will be materially decreased by the long water lines.

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2. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in claim 1, wherein the outside surfaces of the nozzle body are inclined to the streamlines of the water which flows towards the outer edge of the mouth of the nozzle at an outside angle which at its maximum exceeds only slightly an angle of 180 degrees (see Fig. 1, angle $\left(\frac{\gamma}{2} \text{ minus } \frac{\beta}{2}\right)$.

3. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in either of the preceding claims, wherein adjustable flaps are arranged on the nozzle body to form part of the circumference of its mouth, said flaps being adapted to permit variation of the inlet area of the latter.

4. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, wherein the cross sectional area of the nozzle inlet opening is so distributed around the propeller shaft that the largest distances of its circumference from the propeller shaft are situated in the zone of the greatest wake thus producing in this part the greatest reduction in area between the inlet and the plane of the propeller.

5. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, wherein the upper inner surface of the nozzle is constituted by the hull of the ship and the waterlines of the hull immediately above the nozzle converge aft thereof.

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7. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in claim 6, characterized by the fact that the upper edge of the outlet of the nozzle extends rearwardly in a substantially horizontal plane, the two sides converging towards the rear and being lower at any given point than the highest point of the nozzle in the plane of revolution of the propeller.

8. A screw-propelled ship with a nozzle arranged around each propeller as claimed in any of the preceding claims characterized by the fact that when twin screws are employed the outlet parts of the nozzles aft of the propellers gradually change in cross section until they practically merge into a common outlet opening of rectangular or oval outline with a view to avoiding the formation of eddies between the streams of water issuing from the two nozzles.

9. A screw-propelled ship with a

nozzle arranged around each propeller as claimed in any of the preceding claims, characterized by the fact that when twin screws are employed, the two nozzles are arranged to diverge rearwardly in known manner.

10. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, characterized by the fact that the propeller blades are of less pitch at their roots and/or at their tips than at intermediate parts.

11. A screw-propelled ship with a nozzle arranged around the or each propeller as claimed in any of the preceding claims, characterized by the fact that the pitch of the propeller blades increases from the leading to the trailing edge and the nozzle has the known form in which the cross sectional area in a plane immediately behind the propeller is less than that in a plane immediately in front of it.

Dated this 19th day of July, 1934.

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Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1936

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