

RING PROPELLER COMPRISING BLADES MADE AT LEAST PARTLY FROM FIBRE REINFORCED POLYMER

The present invention relates to ring propeller comprising a plurality of blades made at least partly from a fibre reinforced polymer and each having a tip and a
5 root. A tenon is provided at the root, and the tenon is received in a mortice provided in a hub. A flexible joint is provided between the tenon and said mortice.

BACKGROUND OF THE INVENTION

Propellers for propulsion of a vessel are found in numerous sizes and varieties,
10 such as an open propeller, where the propeller is arranged and rotated by a shaft connected to a machinery, and electromagnetic thrusters, where blades are arranged in a rotor configuration comprising magnets and a stator with electrical coils rotates the rotor. The propeller blades are at their roots connected to a hub. In some situations, the tips of the blades are also connected to an outer tubular
15 element, such as in thrusters, e.g. azimuth thrusters.

The propeller blades generate due to their hydrodynamic shaping a thrust which propels the vessel. However, the blades experiences during generation of the thrust, larger hydrodynamic generated forces, which generate high stresses
20 through-out the blade. Further, high stresses are also generated at the root and tip (if connected to a tubular element) sections due to e.g. a bending moment at the roots and tips generated by the hydrodynamic forces.

Traditionally, propeller blades are made from metal or a metal alloy since the
25 material properties of the metal or metal alloy, such as toughness and ductility, are attractive in an attempt to avoid cracking formation e.g. at the root and/or tip, where the blades are connected.

While propeller blades made from metal or a metal alloy are well functioning for a
30 long service time, there are some drawbacks regarding producing propeller blades from metal or metal alloy. One such important drawback is the substantive weight of the blades made from metal or a metal alloy. Since the blades rotates, the moment of inertia (which is correlated with the weight) is substantial. While this is of less importance for a propeller operating at constant rotational speed, a
35 substantial moment of inertia has a negative effect on propellers operating at

varying speed as a response time is prolonged and power used to change the operating speed is substantial.

Accordingly, it could be advantageous to reduce the "rotating mass" of a propeller
5 and in particular reduce the weight of the blades.

It may be tempting to produce the blades from a fibre reinforced polymer, as such blades are relatively lighter than metal or metal alloys blades. Further, the blades need to be attached to a hub in order to provide rotation and the thrust produced
10 is to be conveyed by the hub to the vessel. During this, blades connected to the hub will be exposed to both tensile and compressive stresses of typical time varying magnitude especially at points or regions where the blades are connected to the hub, or the tips are connected to a tubular element. Accordingly, attempting to use blade made from a fibre reinforced polymer automatically leads
15 to technical problems relating to how to attach the blade to a hub.

Accordingly, it could be advantageous to use blades made from fibre reinforced polymer in a propeller configuration.

20 OBJECT OF THE INVENTION

It is an object of the invention to provide a propeller where the blades are made from fibre reinforced polymer.

It is a further object of the present invention to provide an alternative to the prior
25 art.

In particular, it may be seen as an object of the present invention to provide a propeller having blades made from fibre reinforced polymer that solves or at least mitigates the above-mentioned problems.

30 SUMMARY OF THE INVENTION

Thus, the above-described object and several other objects are intended to be obtained in a first aspect of the invention by providing a ring propeller comprising

- a hub,
- 35 • a tubular element arranged co-axially with the hub, and

- a plurality of blades made at least partly, such as entirely, from a fibre reinforced polymer and each having a tip and a root, the plurality of blades are arranged in between the hub and the tubular element with the tips connected to the tubular element.

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For each of the blades

- a tenon is provided at the root, which tenon is received in a mortice provided in the hub, and
 - a flexible joint is provided between the tenon and the mortice by the tenon has
- 10 a constant thickness and/or is tapering in an inward radial direction of the propeller, in combination with the mortice and the tenon are mutually shaped to provide a first clearance between facing side surfaces of the mortice and the tenon.

15 A flexible bonding material is provided to substantially fill the first clearance.

A *ring propeller* is a propeller where blades are connected to the hub at their roots and the tips of the blades are connected to a tubular element, which often is referred to as a ring, hence the naming "ring propeller". An embodiment of a ring

20 propeller is illustrated in Fig. 1 and Fig.s 2A-D.

In preferred embodiments, a ring propeller is a ring propeller for a vessel, such as a waterborne vessel, such as a boat, a ship, a hover craft, a planning vessel, a submissible vessel or a submarine. In such embodiments, the ring propeller may

25 be configured and used for propelling the vessel by rotating the ring propeller. Vessel typically refers to a vehicle designed for travel across or through a body of water.

"made at least partly from a fibre reinforced polymer" may refer to that the blade

30 may be made, preferably essentially entirely, from fibre reinforced polymer, or the parts or sections of the blade may be made from fibre reinforced polymer. The latter may be achieved by e.g. a shell construction, where the blade comprises a shell, which may or may not comprise a core material, such as a foam, e.g. a polyurethane foam. In preferred embodiments, the entire outer shape of the blade

35 is provided by fibre reinforced polymer. Hence, in such embodiments, a trailing

edge, a leading edge and regions connecting the leading edge and trailing edge are provided by fibre reinforced polymer.

“flexible bonding material” preferably refers to a polymer. Which polymer to
5 choose for a given application may typically depend on the geometries of the parts and on the expected loads and deformations during use. A particular used polymer can be determined as part of the design process by use of computer simulations and/or experiments. In some embodiments, the flexible bonding material provides an adhesive bond. The polymer is preferably a settable, such as
10 curable polymer having flexibility in the set, such as in the cured state.

BRIEF DESCRIPTION OF THE FIGURES

The present invention and in particular preferred embodiments thereof will now be disclosed in more details with regard to the accompanying figures. The figures
15 show ways of implementing the present invention and are not to be construed as being limiting to other possible embodiments falling within the scope of the attached claim set.

Fig. 1 is a 3-dimensional view of a ring propeller according to a first embodiment;
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Fig. 2A is a 3-dimensional view of the ring propeller illustrated in Fig. 1. In Fig. 2A the plane G-G is illustrated according to which plane the cross sectional view of Fig. 2B is made. Fig. 2C and Fig. 2D are close-up views of Fig. 2B.

25 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is made to Fig. 1 illustrating a first embodiments of ring propeller according to the present invention. The ring propeller 1 comprising a hub 2. As illustrated, the hub 2 has an opening 24 and this opening 24 is shaped to receive a shaft (not illustrated). The shaft may be a drive shaft for rotating the propeller
30 or may be a rotatable shaft to allow for rotation of the propeller e.g. when the ring propeller is used in an electromagnetic thruster configuration.

The ring propeller 2 comprises a tubular element 4 arranged co-axially with the hub 2, and a plurality of blades 5. The blades 5 are made at least partly from a
35 fibre reinforced polymer and has each a tip 6 and a root 7. The plurality of blades

5 are arranged in between the hub 2 and tubular element (4) with tips 6 connected to the tubular element 4.

As perhaps most clearly visible in Fig.s 2A-D, each of the blades 5 has a tenon 9 provided at the root 7, which tenon 9 is received in a mortice 8 provided in said hub 2.

Propeller experiences due to the hydrodynamic forces relatively high load and especially root sections of the blades may be exposed to bending moments. To accommodate for such loads, a flexible joint is provided between the tenon 9 and the mortice 8. In preferred embodiments, each of the tenons 9 has a constant thickness and in other embodiments, each of the tenons 9 is tapering in an inward radial direction of said propeller 1. In the embodiment shown in Fig.s 2A-D, the tenons 9 have a constant thickness. The tenons 9 are shaped and dimensioned mutually with the mortices 8 to receive the tenons 9 so as to provide a first clearance $\delta 1$ between facing side surfaces 12 of the mortice 8 and tenon 9 as illustrated in Fig.s 2A-D. The clearance $\delta 1$ is filled substantially with a flexible bonding material 10 so as to substantially occupy the clearance $\delta 1$. The flexibility of the bonding material 10 allows for some movement of the tenon 9 within the mortice 8 which has been found to have a positive effect on stress reduction in the root section during use of the propeller.

While the lower ends of the tenons 9 may in some embodiments abut a bottom surface of the mortice 8, a clearance may be provided. This may be accomplished by the mortises 8 and the tenons 9 are dimensioned to provide a second clearance $\delta 2$ between facing lower surfaces 13 of the mortises 8 and the tenons 9. A flexible bonding material 10 is provided to substantially fill the second clearances $\delta 2$ so as to substantially occupy the clearance $\delta 2$.

The bonding material in combination with the first clearance $\delta 1$ and/or the second clearance $\delta 2$ and/or a third clearance $\delta 3$ (as disclosed below) besides adding flexibility to the joint may also prevent direct contact between the surfaces of the tenons 9 and the surfaces of the mortices 8, which could otherwise deteriorate the surfaces due to abrasion.

During rotation of the propeller, the propeller blade may have a tendency to bent in radial and/or tangential direction and such bending may provide a stress concentration in the root area of the blade. Such a stress concentration may be increased if the root section of a blade 5 abuts an edge of the hub formed in hard material, such as stainless steel. This may potentially occur at an outer edge of the mortice 8. To alleviate such potential stress concentration the mortises 8 and the tenons 9 are mutually dimensioned to provide a third clearance $\delta 3$ between facing side surfaces 12 of the mortises 8 and the tenons 9. The third clearance $\delta 3$ is provided at an upper end 14 of the mortise and extends in a radial direction of the propeller to an outer surface 15 of the hub 2. Preferably, the third clearance $\delta 3$ has an increasing width in the radial direction. This third clearance $\delta 3$ may be substantially filled with the bonding material 10, so as to substantially occupy the third clearance $\delta 3$.

The forces acting on a propeller blade 5 during use is often relatively high at the root e.g. due to a bending moment. As the blades are made from fibre reinforced polymer, it has been found advantageous that each of the blades 5 comprising a transition root section 19 at the root 7 which may be considered as a thickening of the blade 5 at the root 7 to allow the blade 5 to better take-up the forces acting at the root 7. The transition root section 19 preferably extends a distance in a radial direction of the propeller from above the mortise 8 to a section of the blade 5 being shaped to provide thrust upon rotation.

An abrupt change in geometry in a stressed object may provide a local stress concentration. To alleviate such effect in embodiments comprising a transition root section, a transition region 20 is provided located where the transition root section 19 runs into the section of the blade 5 being shaped to provide thrust. The transition region preferably proceed with a curvature, preferably a continuous curvature, to reduce stress concentration in the transition region 20.

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Often blades are twisted in the sense that the evolution of the chord along the length of the blades turns. This often means that the chord line at the root of the blade is angled relatively to the axial direction of the propeller. In preferred embodiments, this is accounted for by aligning the mortice 8 and tenon 9 with the orientation of a chord line at the root of the blade 5.

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In many preferred embodiments the fibre reinforced polymer is a carbon fibre reinforced polymer, although other fibres, such as Kevlar, glass fibres or even combinations thereof are used in other embodiments. It is further noted that
5 blades 5 may not be made massively or entirely from fibre reinforced polymer, as the blades may be a core structure, e.g. a hollow core.

Preferably, each tip 6 is connected to the tubular element 4 by being received in a groove 22 provided in the tubular element 4. As disclosed in connection with the
10 mortices 8 and tenons 9, clearance(s) may also be provided in grooved connection (combination of groove 22 and tip 6) preferably together with a bonding material.

The tip 6 may comprise at an outermost position of the blade 5 a connecting section 23. Such a connecting section typically has a larger width w_c than a
15 thickness t_b of the blade 6 measured immediately inward of said connection section 23. At least a section of the connection section 23 is received in the groove 22 preferably together with the bonding material.

In preferred embodiments, the bonding material is a polymer.
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In preferred embodiments, the hub 2 may be made from metallic material, such as stainless steel. The tubular element 4, may be made from fibre-reinforced polymer composite or metallic material, such as stainless steel.

25 In preferred embodiments, the invention relates to a permanent magnet thruster having a propeller 1 according to a preferred embodiment of the invention. In such embodiments, the thruster comprises a shaft on which the hub 2 is rotatably arranged. A plurality of permanent magnets 4 are provided on or at a lateral surface of the tubular element 3. The magnets are preferably encapsulated in a
30 cover, whereby the magnets are not exposed to water during use.

The permanent magnet thruster also has a stator yoke (not illustrated) arranged outside the tubular element 3 and the magnets (including the optional cover). The stator yoke has a plurality of stator coils being magnetizable by an electrical
35 current. The plurality of permanent magnets 4 and the plurality of stator coils 16

are mutually configured so that when said plurality of stator coils are magnetized, the rotor yoke rotates the propeller 1.

In preferred embodiments, the invention relates to a vessel propulsion system
5 comprising a propeller according to a preferred embodiment. In such
embodiments, the propeller is arranged on a shaft rotatable by motor, such as an
electrical motor, a hydraulic motor, a combustion engine, such an Otto engine or
a Diesel engine.

10 Assembly of a ring propeller according to preferred embodiments of the invention
may be carried out in the following manner. Initially the tenons 9 of the propeller
blades are introduced into the mortices 8 provided in the hub 2. The tubular
element is preferably pre-cast ready to be applied to the ring propeller. In some
15 over the tip of the propeller blades to position the tip of the blades at the inner
surface of the tubular element, where after the tip of the blades are bonded to the
tubular element by a flexible bonding material.

In other embodiments, the tip of the blades is to be introduced in a slot formed
20 tubular elements as disclosed in regards to Fig.s 2A-D, where a part of the
connection section 23 is introduced into the groove 22. In such embodiments, the
second clearances δ_2 are dimensioned so that the tenons 9 can be displaced
radially inward to an extent providing the tubular element 4 to be arranged in a
position encircling the tips 6. This typically means that the size of the second
25 clearance δ_2 is larger than or substantial equal to the depth of the groove 22.

With the blades 6 and the tubular element 4 so arranged, the blades 6 are moved
radially outwardly so that a part of the connection sections 23 are introduced into
the grooves 22. This movement may advantageously be provided by one or more
30 jacking screws (not illustrated) extending from the inside of the hub and into the
mortices 8. By tightening such jacking screws, the end of the jacking screws abut
undersides of the tenons 9, whereby the blades are forced radially outwardly
introducing the part of the connection sections 23 into the grooves 22. The
grooves 22 are, preferably, pre-filled with a bonding material to fixate a part of
35 the connection sections 23 in the grooves 22, preferably in a flexible manner.

With the part of the connection sections 23 positioned in the grooves 22, a flexible bonding material is applied into the mortices 8 to fill the clearances $\delta 1$, $\delta 2$ and, if provided, also $\delta 3$. The bonding material may advantageously be filled into the clearances under elevated pressure to avoid formation of voids in the bonding material. When the bonding material has set, the jacking screws can safely be removed.

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List of reference symbols used:

- 1 Ring propeller
- 15 2 Hub
- 4 Tubular element
- 5 Blade
- 6 Tip (of blade)
- 7 Root (of blade)
- 20 8 Mortice
- 9 Tenon
- 10 Bonding material
- 12 Facing side surfaces
- 13 Lower surfaces
- 25 15 Outer surface
- 19 Transition root section
- 20 Transition region
- 22 Groove
- 23 Connection section
- 30 24 Opening
- $\delta 1$ First clearance
- $\delta 2$ Second clearance
- $\delta 3$ Third clearance

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CLAIMS

1. A ring propeller (1) comprising
 - a hub (2),
 - a tubular element (4) arranged co-axially with said hub (2), and
- 5 • a plurality of blades (5) made at least partly from a fibre reinforced polymer and each having a tip (6) and a root (7), said plurality of blades (5) are arranged in between said hub (2) and said tubular element (4) with said tips (6) connected to the tubular element (4),
wherein for each blade (5)
 - 10 • a tenon (9) is provided at said root (7), which tenon (9) is received in a mortice (8) provided in said hub (2), and
 - a flexible joint is provided between said tenon (9) and said mortice (8) by said tenon (9) has a constant thickness and/or is tapering in an inward radial direction of said propeller (1), in combination with said mortice (8) and said
 - 15 tenon (9) are mutually shaped to provide a first clearance ($\delta 1$) between facing side surfaces (12) of said mortice (8) and said tenon (9), and a flexible bonding material (10) is provided to substantially fill said first clearance ($\delta 1$).
2. A ring propeller according to any one of the preceding claims, wherein for each
20 blade (2) said mortise (8) and said tenon (9) are dimensioned to provide a second clearance ($\delta 2$) between facing lower surfaces (13) of said mortise (8) and said tenon (9), wherein said flexible bonding material (10) is provided to substantially also fill said second clearance ($\delta 2$).
- 25 3. A ring propeller according to any one of the preceding claims, wherein for each blade (2) said mortise (8) and said tenon (9) are mutually dimensioned to provide a third clearance ($\delta 3$) between facing side surfaces (12) of said mortise (8) and said tenon (9), said third clearance ($\delta 3$) being provided at an upper end (14) of said mortise and extends in a radial direction of said propeller to an outer surface
30 (15) of said hub (2), wherein third clearance has an increasing width in said radial direction.
4. A ring propeller according to any one of the preceding claims, wherein each of said blades (5) comprising a transition root section (19) at said root (7), said
35 transition root section (19) extends a distance in a radial direction of said

propeller from above said mortise (8) to a section of the blade (5) being shaped to provide thrust upon rotation.

5. A ring propeller according to claim 4, wherein a transition region (20) located
5 where said transition root section (19) runs into said section of the blade (5) being shaped to provide thrust, proceed with a curvature, preferably a continuous curvature, to reduce stress concentration in the transition region (20).

6. A ring propeller according to any one of the preceding claims, wherein for each
10 of said blades (5), said mortice (8) and tenon (9) are aligned with an orientation of a chord line at the root of said blade (5).

7. A ring propeller according to any one of the preceding claims, wherein the fibre reinforced polymer is a carbon fibre reinforced polymer.

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8. A ring propeller according to any one of the preceding claims, wherein for each blade said tip (6) is connected to said tubular element (4) by being received in a groove (22) provided in said tubular element (4) preferably together with a bonding material.

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9. A ring propeller according to claim 8, wherein for each blade said tip (6) comprising at an outermost position of the blade a connecting section (23), said connecting has a larger width (w_c) than a thickness (t_b) of said blade (6) measured immediately inward of said connection section (23), and wherein at
25 least a section of said connection section (23) is received in said groove (22) together with said bonding material.

10. A ring propeller according to any one of the preceding claims, wherein the bonding material is a polymer.

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11. A ring propeller according to any one of the preceding claims, wherein said hub is made from metallic material, such as stainless steel and/or said tubular element is made from fibre-reinforced polymer composite or metallic material, such as stainless steel.

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12. A permanent magnet thruster comprising a propeller (1) according to any one of the preceding claims, further comprising

- a shaft on which the hub (2) is rotatably arranged;
 - a plurality of permanent magnets (4) provided on or at a lateral surface (5)
- 5 of said tubular element (3);
- a stator yoke (15) arranged outside said tubular element (3) and comprising a plurality of stator coils (16) being magnetizable by an electrical current,

wherein

- said plurality of permanent magnets (4) and the plurality of stator coils are
- 10 mutually configured so that when said plurality of stator coils are magnetized, the rotor yoke rotates said propeller (1).

13. A vessel propulsion system comprising a propeller according to any one of the preceding claims 1-11, wherein said propeller is arranged on a shaft rotatable by

15 motor, such as an electrical motor, a hydraulic motor, a combustion engine, such an Otto engine or a Diesel engine.