

METAL ENCAPSULATING OF MAGNETS IN PERMANENT MAGNET THRUSTERS

FIELD OF THE INVENTION

The present invention relates to a permanent magnet thruster having a rotor yoke
5 comprising a tubular element carrying a plurality of permanent magnets on or at a
lateral surface of the tubular element. In preferred embodiments, the plurality of
permanents magnets are encapsulated in a magnet encapsulation made from
metal having been subjected to HIPping.

10 BACKGROUND OF THE INVENTION

Thrusters are widely used for propulsion and/or manoeuvring marine vessels.
Such thrusters are designed to provide a thrust rotating a number of propellers
blades being submerged into the water below the vessel design water line. Many
of such thrusters comprises a number of permanent magnets arranged on a rotor
15 (rotor yoke). The propeller blades are at one end connected to the rotor and are
at another end connected to a hub, so as to allow rotation of the rotor with
propeller blades around the hub. Rotation is provided by a number of stator coils
being magnetizable by an electric current. Such a configuration of permanent
magnets and magnetizable stator coils are operated as an electrical motor to
20 provide rotation of the rotor.

Permanent magnets are made from materials which when exposed to in particular
seawater (water containing salt) are prone to corrosion. For instance, neodymium
type magnets are so prone to corrosion that even the small amount of moisture in
25 atmospheric air results in corrosion of the magnets. Corrosion of permanent
magnets is highly undesired as the magnets degrades in terms of strength, shape,
size which results in that the magnetic strength of the magnets deteriorate over
time. Besides from this, the chemical substances created as a result of corrosion
may be of a kind that should not be released to the seawater and since such
30 chemical substances may be released from the magnets, formation of such
chemical substances play an additional environmental concern.

As corrosion occurs by intimate contact between the surface of permanent
magnets and seawater, covering of the surfaces of the permanent magnets to
35 avoid such intimate contact could be an option.

However, such a covering should have sufficient strength to withstand the harsh conditions in seawater and should not reduced the magnetic strength of the permanent magnet to a larger extend.

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Further, when considering covering of permanent magnets, the manufacturing process should be relatively simple to avoid introducing excessive manufacturing costs in the production of a thruster.

- 10 Hence, a thruster with improved resistance to corrosion would be advantageous, and in particular a more efficient and/or reliable corrosion resistance of permanent magnets used in a thruster would be advantageous.

OBJECT OF THE INVENTION

- 15 It is an object of the present invention to provide a thruster for maritime use comprising permanent magnets where corrosion of permanent magnets are at least mitigated.

- It is a further object of the present invention to at least mitigate corrosion of
20 permanent magnets in a thruster for maritime use in a manner allowing for use in harsh conditions in seawater.

- It is a further object of the present invention to at least mitigate corrosion of permanent magnets in a thruster for maritime use in a manner preferably without
25 significantly reducing the magnetic strength of the permanent magnets, or even having the same higher magnetic strength.

- It is a further object of the present invention to at least mitigate corrosion of permanent magnets in a thruster for maritime use in a relatively simple
30 manufacturing process.

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

SUMMARY OF THE INVENTION

5 Thus, the above described object and several other objects are intended to be obtained in a first aspect of the invention by providing a permanent magnet thruster, comprising

- a rotor yoke comprising
 - 10 ○ a tubular element carrying a plurality of permanent magnets on or at a lateral surface of said tubular element;
 - a plurality of propeller blades extending inwardly from said tubular element to a hub rotatably arranged on a shaft;
- a stator yoke arranged outside the rotor yoke and comprising a plurality of stator coils being magnetizable by an electrical current,

15 wherein

- said plurality of permanent magnets and the plurality of stator coils are mutually configured so that when said plurality of stator coils are magnetized, the rotor yoke rotates, and

said plurality of permanent magnets are encapsulated in a magnet encapsulation
20 made from metal having been subjected to HIPping, said magnet encapsulation encapsulates at least open surfaces of said permanent magnets facing away from said lateral surface in radial direction, facing in tangential direction and facing in axial direction of said tubular element.

25 The metal from which the magnet encapsulation is preferable made from an alloy being stainless, titanium, bronze, in particular nickel-aluminium-bronze and/or corrosion resistant.

An encapsulation subjected to HIPping has some highly characteristic material
30 properties, such as increase density (due to shrinking) compared to other processes such as sintering or casting, and lower amounts of impurities of adsorbed gasses.

By the presence of the encapsulation encapsulating at least open surfaces of the
35 permanent magnets, and use of HIPping seawater is essentially hindered from

coming into contact with the open surfaces of the permanent magnets. The HIPping provides a shrinking of the encapsulation, whereby an excellent seal is provided at the abutment(s) between the open surfaces of the permanent magnets and interior surfaces of the encapsulation.

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While it is preferred to fully encapsulate the permanent magnets, some surface area of the permanent magnet are placed in intimate contact with a surface of the tubular element, whereby it may be sufficient only to encapsulate some surface area(s) such as open surfaces as disclosed herein. By fully encapsulate is preferably meant that no surface of the permanent magnets is exposed to the outside of the encapsulation.

Terms used herein are used in a manner being ordinary to a skilled person. Some of the used terms are detailed here below:

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Hot Isostatic Processing abbreviated as HIPping herein refers to a manufacturing process in which one or more permanent magnets are enclosed in a encapsulation preform made from metal, preferably stainless steel. The preform with the magnet(s) is subjected to high temperature to remove adsorbed gasses, if any, and subsequently compressed by exposing the preform to an inert gas, such as argon, at elevated isostatic pressuring while the high temperature is maintained thereby shrinking the preform to form a magnet encapsulation. The magnet encapsulation is accordingly referred to as made by having been subjected to *HIPping* and the material resulting from HIPping is referred to as a *HIPed* material.

Open surface (of a permanent magnet) as used herein is preferably used to reference a surface of a magnet not abutting another surface prior to provision of a magnet encapsulation and/or a surface not facing water during use of the magnet.

Thruster as used herein refers to a marine thruster being a device for producing hydrodynamic thrust, preferably being directional thrust. A thruster is mounted on a vessel and is used for manoeuvring and/or propulsion.

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BRIEF DESCRIPTION OF THE FIGURES

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

Fig. 1 schematically illustrates in a 3-dimensional representation a rotor yoke according to a preferred embodiment of the invention; for clarity reasons, only
10 one propeller blade and three permanent magnets are shown,

Figs. 2A-B schematically illustrates in a 3-dimensional representation a rotor yoke (Fig. 2A) and a corresponding stator yoke (Fig. 2B) according to a preferred embodiment of the invention,

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Figs. 3A-C schematically illustrates a segment according to a preferred embodiment of the invention; Fig. 3A illustrates the segment in a 3-dimensional representation and Fig. 3B illustrates a cross sectional view of the segment in Fig. 3A, Fig. 3C schematically illustrated a segment arranged on a tubular element
20 according to a preferred embodiment,

Figs. 4A-C schematically illustrate steps involved in fabricating a magnet encapsulation segment according to a preferred embodiment. The cross sectional views shown in Figs. 4-C are cross sectional views along the line A-A shown in Fig.
25 3A

Fig. 5 illustrates an embodiment of a magnet encapsulation segment with a orientation of the magnets being different from what is disclosed in Fig. 4B.

30 Fig. 6 illustrates an embodiment of a magnet encapsulation segment with a orientation of the magnets being different from what is disclosed in Fig. 4B.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is made to Fig. 1 schematically illustrating a rotor yoke 2 for a
35 permanent magnet thruster in a first preferred embodiment.

A rotor yoke 2 is a part of a thruster for providing manoeuvring and/or a propulsion of a vessel through a body of water by being submerged into the water and connected to the vessel and having propeller blades being rotated. The
5 thruster may be an azimuth thruster but the invention is not limited to such azimuth thrusters.

In the disclosed embodiment of Fig. 1, the rotor yoke 2 comprises a tubular element 3. The tubular element 3 is typically a tubular structure having a lateral
10 surface facing outward and a lateral surface facing inward. A lateral surface is typically a surface facing in a direction having a normal vector with a component in radial direction of the thruster. The tubular element 3 of Fig. 3 carries a plurality of permanent magnets 4 on or at the lateral surface 5 of tubular element 3 facing outward. However, the permanent magnets 4 may be carried on the
15 lateral surface facing inward. Carries magnet on or at a lateral surface typically refers to a situation where the magnets are connected to the tubular element 3 in a manner so that a rotation moment provided by the magnets (in an electrical motor configuration) provides a rotation of the tubular element 3. "At the lateral surface 5" refers to that the permanent magnets 4 are placed in a distance from
20 the lateral surface 5.

A plurality of propeller blades 10, such as five, six, seven, eight or even more, is provided extending inwardly from tubular element 3 to a hub 11. In the embodiment of Fig. 1, only one such propeller blades 10 is illustrated (for clarity
25 reasons), although more propeller blades are, in fact, provided. Such propeller blades 10 are typically equally spaced in the circumferential direction e.g. to avoid introduction of vibrations during rotation. The propeller blades 10 are each rotatably arranged on a shaft 12. The shaft 12 forms part of a structure (not illustrated) connecting the thruster with the vessel.

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On the outside of the rotor yoke 2, a stator yoke is arranged in a conventional manner for permanent magnet thrusters. The stator yoke comprises a plurality of stator coils being magnetizable by an electrical current. By this, the combination of the rotor yoke 2 and the stator yoke resembles an electrical motor, in the sense
35 that when the stator coils are magnetized, the rotor yoke 2 will rotate (unless

forces acting on the rotor are larger than what can be overcome). Thus, the plurality of permanent magnets 4 and the plurality of stator coils are mutually configured so that when said plurality of stator coils are magnetized, the rotor yoke 2 rotates.

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Permanent magnets are, in general, made from a material being prone to corrosion and such corrosion is clearly a disadvantage as it degrades the magnets both in terms of magnetic properties and in terms of size. Such corrosion is particular pronounced in a maritime environment involving sea water where the salt in the water makes the corrosion to progress fast.

To avoid corrosion of the permanent magnets, the plurality of permanent magnets are encapsulated in a magnet encapsulation 20 made from metal. Such an encapsulation 20 is designed to shield an open surface of a magnet which would, without the encapsulation, be exposed to water during use of the thruster. As will become clear from the following, such shielding may be provided by fully encapsulating the permanent magnets or only encapsulating open surfaces which would otherwise be exposed to water. For the latter case, in one embodiment, the magnets are arranged on the lateral surface 5 so that one or more open surface are outward facing open surfaces and one or more surfaces are inwardly facing, e.g. abutting the lateral surface 5, thereby not in need of a shield against water. In such embodiments, the encapsulation 20 covers the outward facing open surfaces.

It is generally preferred that the magnet encapsulation 20 encapsulates at least open surfaces of permanent magnets 4 facing away from said lateral open surface 5 in radial direction, in tangential direction and in axial direction of said tubular element 3.

The encapsulation 20 may be a tubular element inside which the permanent magnets are comprised either fully or partly (with surfaces of the permanent magnets facing the lateral surface 5 of the tubular element 3), or the encapsulation 20 may be composed of a number of encapsulation segments 21, as illustrated in Fig. 2A.

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Accordingly, the magnet encapsulation 20 encapsulates at least an open surface of each permanent magnet 4 facing away from said lateral open surface 5 and open surface(s) facing in axial direction of said tubular element 3. However, the magnet encapsulation 20 may, alternatively, fully encapsulates all permanent
5 magnets 4.

The magnet encapsulation 20 is made inter alia by HIPping an encapsulation preform in which one or more permanent magnets are enclosed. The preform is made from metal, preferably stainless steel. The preform may be a machined
10 element, such as a material reducing process or a sintering process and the machined element comprise a compartment configured to receive one more permanent magnets, typically in snug-fit manner. With the permanent magnet(s) arranged in the compartment, the preform with the magnet(s) is subjected to high temperature to remove adsorbed gasses, if any, where after the preform is
15 compressed by exposing the preform to an inert gas, such as argon, at elevated isostatic pressuring while the high temperature is maintained. This provides a shrinking the preform to form a magnet encapsulation.

In embodiments, where the magnet encapsulation 20 is in the form of a tubular
20 element, the magnet encapsulation 20 may be arranged on the tubular element 3 in a press-fit manner, e.g. assisted by heating/cooling one of the elements by a heat shrinking process. Alternatively, or in combination, the magnet encapsulation 20 may be fastened by screws, welding or gluing.

25 As indicated in Fig. 2A the magnet encapsulation may comprise a number of magnet encapsulation segments 21. In Fig. 2A one such encapsulation segments is highlighted by dotted lines. Each of the magnet encapsulation segments 21 is made from metal and have been subjected to HIPping. Such a magnet encapsulation segment 21 may comprise a single permanent magnet or a group of
30 permanent magnets.

In embodiments where only one permanent magnet 4 is encapsulated, the permanent magnet is typically encapsulated by a magnet encapsulation segment 21 (see Fig. 3A) encapsulating at least open surfaces of the permanent magnet 4
35 facing away from said lateral surface 5 in radial direction, facing in tangential

direction and facing in axial direction of said tubular element 3. The directions "radial", "tangential" and "axial" are indicated in Fig. 1. By such an encapsulation, the open surfaces of the magnet which without the encapsulation would be exposed to water is covered by the encapsulation, whereas a surface of the
5 magnet facing the tubular element 3 may not be encapsulated. However, as will be detailed below, it is generally preferred to fully encapsulate the magnet.

When the magnet encapsulation segment 21 comprise a group of permanent magnets, such magnets are typically arranged side-by-side in tangential direction
10 of the tubular element 3 (the orientation of such magnets is indicated in Fig. 1). Also in such embodiments, the magnet encapsulation segment 21 encapsulates at least open surfaces of the group of magnets 4 facing away from said lateral surface 5 in radial direction of the tubular element 3, facing in tangential direction of said tubular element 3 and facing in an axial direction of said tubular element
15 3.

It is noted that although permanent magnets may be cuboid, the invention is not limited to such cuboid shaped magnets. When non-cuboid magnets are used, they will still have open surfaces facing in the above disclosed direction, although such
20 open surfaces may be sections of an otherwise curve open surface.

In summary, a magnet encapsulation segment 21 may, preferably, be disclosed as a structure shielding the magnet(s) from water exposure, when arranged on the tubular segment 3.
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The orientation of the magnets 4, and thereby the magnetization direction of the magnets relatively to the stator yoke can be made in accordance with what is ordinary practice within the technical area of permanent magnet thrusters to provide an electric motor design.
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In some preferred embodiment, the magnet encapsulation segments 20 encapsulates a group of four or more permanent magnets 4 arranged side-by-side in tangential direction of said tubular element 3. The group of four or more permanent magnets may preferably be arranged in two or more sub-groups,
35 wherein a tangential distance between permanent magnets 4 within a sub-group

are smaller, such as essentially zero, than a tangential distance between sub-groups.

In preferred embodiments, the magnet encapsulation segments 21 further
5 encapsulates an open surface of each of the permanent magnets 4 facing towards lateral surface 5 in axial direction of the tubular element 3, whereby the permanent magnet or permanent magnets 4 within the magnet encapsulation segments 21 are fully encapsulated by said magnet encapsulation segment 21.

10 Reference is made to Fig. 3 illustrating a preferred embodiment of a segment 21. Fig. 3A illustrates the magnet encapsulation segment 21 in a three-dimensional view and Fig. 3B is a cross sectional view along the line A-A indicated in Fig. 3A. In the disclosed embodiment of Fig. 3, the magnets are fully encapsulated by the magnet encapsulation segment 21 to form an encapsulated magnet segment.

15 Fig. 3B also discloses an optional backing element 22. As illustrated, the magnet encapsulation segments 21 further encapsulates the backing element 22 which is arranged between said lateral surface 5 of the tubular element 3 (when the segment is arranged on the tubular element 3 as illustrated in Fig. 2) and abuts
20 surfaces of the permanent magnets 4 facing towards the lateral surface 5 of the tubular element 3. In the illustrated embodiment, the magnets encapsulation segments 21 further encapsulates a surface of the backing element 22 facing towards the lateral open surface 5 and surfaces of the backing element 22 facing in axial and tangential direction of the tubular element 3, whereby the permanent
25 magnets 4 and the backing element 22 within each of the segments 21 are fully encapsulated by said magnet encapsulation segment 21.

The backing element 22 is particular useful in embodiments wherein a magnet encapsulation segment 21 with permanent magnets 4 is to be fastened to the
30 rotor yoke 2 by screws. In such embodiments, an internal thread may be provided in the backing elements accessible by an opening providing in the part of the magnet encapsulation segment 21 facing towards the lateral surface 5. By this, the magnet encapsulation segment 21 may be attached by screws extending through the tubular element 3 as indicated by the screws 18 illustrated in Fig. 2A.

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The backing element 22 made from a material being useable in connection with HIPping by which is meant that when the magnet encapsulation segment is subjected to HIPping, the compression of the backing element 22 is comparable to the compression of the permanent magnets to avoid or at least minimize

5 geometrical distortion of the magnet encapsulation segment 22 as a result of HIPping. Preferably, the backing element 22 is made from the same metal as the encapsulation although another metal, preferably being a different metal than the metal of the magnet encapsulation, such as carbon steel, may be used.

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In preferred embodiments, at least some of said permanent magnets 4 are arranged side-by-side in tangential direction of said tubular element 3 with a tangential distance between permanent magnets 4 being larger than zero. In such embodiments, the permanent magnets 4 are preferably equidistantly arranged in
15 the tangential direction.

In a preferred configuration of the permanent magnets, at least some of the permanent magnets 4, such as all of the permanent magnets 4, each has two side surfaces facing in tangential direction of the tubular element 3 and wherein at
20 least some of the permanent magnets 4, such as all of said permanent magnets (4), are arranged so that two permanent magnets 4 neighbouring each other abut each other along at least a part of the side surfaces.

As many preferred embodiments of the thruster are to be used in seawater, and
25 while it may be accepted that some corrosion takes place in the magnet encapsulation or magnet encapsulation segments it is generally preferred to prevent or at least mitigate corrosion of the magnet encapsulation/magnet encapsulation segments. To accomplish this, the metal from which the magnet encapsulation/magnet encapsulation segments is/are made is a corrosion
30 resistant material such as stainless steel.

As presented herein, the permanent magnets 4 are preferably arranged side-by-side on an exterior side of the tubular element 3 or interior side of the tubular element 3. However, due to increased efficiency, it is preferred to arrange the

permanent magnet on the exterior side of the tubular element 3. Interior side refers to a side facing towards the hub 11; exterior refers to the opposite side.

Since the tubular element 3 on or at which the magnet encapsulation 20 is or the
5 magnet encapsulation segments 21 are to be arranged typically has a curvature, e.g. the radius of the tubular element 3, it may be preferred to shape an exterior surface 6 of the magnet encapsulation 20 or the magnet encapsulation segments 21 to have a curvature (R) in tangential direction of the tubular element 3. However, in the embodiment shown in Fig. 3A-C the part of the
10 magnet encapsulation segment to face the tubular element 3 (a bottom surface) is made flat. The surface of the tubular element 3 is shaped to mimic the flat surface by comprising piecewise flat surfaces as shown in Fig. 3C (where only one magnet encapsulation element 21 is shown to render the surface of the tubular element 3 visible. It is also preferred to provide the surface of the encapsulation
15 20 or the encapsulation segment 21 to have a curvature at the surface distant from the tubular element 3 as this will allow for a smaller clearance between the rotor yoke 2 and the stator yoke.

Fabrication of a magnet encapsulation 20 or magnet encapsulation segment 21
20 encapsulating permanent magnets will now be detailed with reference to the magnet encapsulation segment disclosed in Fig. 3 and as illustrated in Fig. 4. To maintain an easy reference to Fig. 3, the process in Fig. 4 is shown with same orientation of the magnet encapsulation segment 21, although in a practical implementation, the magnet encapsulation segment 21 may advantageously be
25 fabricated while orientated upside down (relative to the orientation of Fig. 4).

In Fig. 4B an example on an orientation of the poles of the magnets 4 are also indicated by the symbols "N" for north pole and "S" for south pole. The opposite polarity shown in Fig. 4B is achievable through magnetization. A device is used to
30 presses down on the magnet encapsulation segment 21 and magnetizes the individual magnets below. If the magnets were loose objects, they would move and attract each other. However, since the magnets are essentially stuck in place within the magnet encapsulation segment, they are not able to move and will therefore create the necessary magnetic field to allow rotation later.

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In Fig. 5 an example on another orientation of poles within the magnet encapsulation segment 21, indicated by the symbols N" for north pole and "S" for south pole, is disclosed. Fig. 5 illustrates the same cross sectional view A-A as used for Fig. 4B

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In Fig. 6 an example on another orientation of poles within the magnet encapsulation segment 21, indicated by the symbols N" for north pole and "S" for south pole, is disclosed. Fig. 5 illustrates the same cross sectional view A-A as used for Fig. 4B

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First, a pre-form 27 is fabricated. The pre-form 27 may be provided by a sintering process or a material reducing process such as milling or lathing. The pre-form contains a cavity 29 shaped and dimensioned to receive the permanent magnets 4 and the backing element 22, preferably both in a snug-fit manner. The pre-form

15 27 is shown in a cross sectional view in Fig. 4A.

With the pre-form 27 fabricated and with reference to Fig. 4B, the permanent magnets 4 are placed in the cavity 29 orientated and placed in the position intended in the magnet encapsulation segment 21. Thereafter, the backing
20 element 22 is placed in the cavity and abutting the surfaces of the permanent magnets 4 as illustrated. A closure member 28 is placed to close the opening of the cavity having received the permanent magnets 4 and the backing element 22. The closure member 28 is then welded to the preform 27 to create a sealed evacuated unit, that is consolidated by HIPping.

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It is noted, that the closure member 28 and the pre-form preferably are made from the same material.

A method of providing an magnet encapsulation segment 21 may be applied to a
30 single permanent magnet or a group of permanent magnets, such as a plurality of permanent magnets. As illustrated in Fig. 4B, a group of two permanent magnets 4 are arranged side-by-side in the pre-form 24. While it is considered to be within the scope of the present invention to encapsulates different magnets within an encapsulation segment 21, and use different magnets for permanent magnet
35 thruster, it is generally preferred to encapsulates magnets of the same material in

an encapsulation segment 21, and use magnets of the same material for a permanent thruster.

The pre-form 27 with magnets, backing element 22 and closure member 28 is
5 subjected to HIPping as illustrated in Fig. 4C. The HIPping is carried out in a pressure tank 30 configured to withstand the relatively high pressure and temperature prevailing during HIPping. During the HIPping, the pressure (indicated by arrows labelled "P") is increased as well as the temperature (indicated by an arrow labelled "Q").

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The HIPping process is typically carried out at 900-1100 Celsius, and with HIPping pressures of 100-200 MPa using argon gas, and for a dwell time of 2-5 hours. After the HIP stage, the furnace is turned off and allowed to cool slowly to room temperature, to avoid any residual stresses or cracking of the magnets. While
15 suitable cooling rate(s) for "slow cooling" may be found experimentally, the HIP furnace is in preferred embodiments turned off and the encapsulated magnet(s) cools from e.g. 1000°C to room temperature (e.g. 20°C) over the course of 5 hours. Thus, in preferred embodiments, a cooling rate of 200°C per hour is used. However, cooling rates within the range of 100-300° per hour are found suitable
20 in connection the present invention.

Because of the snug-fit mentioned above, the contraction and shape change after HIPping is minimized and this allows easier final machining, if required. The HIPping step also benefits the magnets themselves by removing any internal
25 porosity and improving their magnetic properties.

A permanent magnet used in connection with preferred embodiments of the present invention is preferably a neodymium magnet (NeFeB) made from an alloy of neodymium, iron and boron to form a Nd₂Fe₁₄B tetragonal crystalline structure,
30 a samarium-cobalt (SmCo₅) magnet and/or an AlNiCo (aluminum, nickel, cobalt) magnet. A permanent magnet in connection with the present invention is preferably in a solid form, that is not a powdery material, prior to being encapsulated.

Prior to encapsulating one or more magnets in a magnet encapsulation segment 21 and performing a HIPping process as presented herein, the magnets may preferably demagnetised (if not already non-magnetic or demagnetized). Such a demagnetization has numerous advantages. As a neodymium magnet has a very high magnetic strength (when magnetized), placement of e.g. two magnets in the preform shown in Fig. 4A and arranging a closure member 28 on the preform may be a very challenging task if the magnets are not-demagnetized. This is particular challenging where the magnets are to be spatially separated as shown in Fig. 4A and 4B and/or where the material for the encapsulation has magnetic properties. However when demagnetized, the handling of the magnets is rendered technically easier and possess less safety issues.

After the HIPping process, the permanent magnet(s) magnetized. However, it is generally preferred to perform the magnetization after the encapsulated magnet segment(s) 21 has(have) been arranged on a rotor yoke, as this renders the application of the magnets onto the rotor yoke technically easier than if the magnets are magnetized before being applied to the rotor yoke. When delaying the magnetization to when the encapsulated magnet segments have been arranged on the rotor yoke, the magnet encapsulation segments 21 may be machined, if needed, without having to take into account difficulties arising from the encapsulated magnet segment is fastened to each other and/or to machinery used for machining the encapsulated magnet segments by magnetic forces.

The magnetization is carried by exposing the encapsulated magnets in a magnetic field.

It is noted, that depending on the permanent magnet used and the temperature during the HIPping process, the temperature of the magnet(s) may exceed the Curie temperature at which the magnets are demagnetized. Thus, the demagnetization actively carried out does in such embodiment not introduce unwanted side-effect(s).

In preferred embodiments, the HIPping process demagnetize the magnet(s) to provide demagnetized permanent magnet(s) by the temperature during the HIPping process exceeds the Curie temperature for the permanent magnet(s).

The permanent magnets are preferably each a solid of magnetizable material, that is that is not a powdery material, prior to said encapsulation and said HIPping.

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Preferably, the permanent magnets each are neodymium magnets, samarium-cobalt magnets and/or AlNiCo magnets. While it is considered to be within the scope of the present invention to encapsulate different magnets within an encapsulation segment 21, it is generally preferred to encapsulate magnets of
10 the same material in an encapsulation segment 21.

Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is set out by the
15 accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the
20 invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

ITEMIZED LIST OF PREFERRED EMBODIMENTS

Item 1. A permanent magnet thruster, comprising

- a rotor yoke (2) comprising
 - a tubular element (3) carrying a plurality of permanent magnets (4) on
5 or at a lateral surface (5) of said tubular element (3);
 - a plurality of propeller blades (10) extending inwardly from said tubular
element (3) to a hub (11) rotatably arranged on a shaft (12);
- a stator yoke arranged outside the rotor yoke (2) and comprising a plurality of
stator coils being magnetizable by an electrical current,

10 wherein

- said plurality of permanent magnets (4) and the plurality of stator coils are
mutually configured so that when said plurality of stator coils are magnetized,
the rotor yoke (2) rotates, and
- said plurality of permanent magnets are encapsulated in a magnet
15 encapsulation (20) made from metal having been subjected to HIPping, said
magnet encapsulation (20) encapsulates at least open surfaces of said
permanent magnets (4) facing away from said lateral surface (5) in radial
direction, facing in tangential direction and facing in axial direction of said
tubular element (3).

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Item 2. A permanent magnet thruster (1) according to item 1, wherein said
magnet encapsulation (20) comprises a number of magnet encapsulation
segments (21) made from metal and each having been subjected to HIPping,
where each of said segments encapsulates a single or a group of said permanent
25 magnets arranged side-by-side in tangential direction of the tubular element (3),
said single or each of said group of permanent magnets being encapsulated by a
magnet encapsulation segment (21) encapsulating at least open surfaces of each
said permanent magnet or said group of magnets (4) facing away from said
lateral surface (5) in radial direction of the tubular element (3), facing in
30 tangential direction of said tubular element (3) and facing in an axial direction of
said tubular element (3).

Item 3. A permanent magnet thruster (1) according to item 2, wherein each of
said magnet encapsulation segments (21) encapsulates a group of four or more
35 permanent magnets (4) arranged side-by-side in tangential direction of said

tubular element (3) and wherein said group of four or more permanent magnets are arranged in two or more sub-groups, wherein a tangential distance between permanent magnets (4) within a sub-group are smaller, such as essentially zero, than a tangential distance between sub-groups.

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Item 4. A permanent magnet thruster according to item 2 or 3, wherein each of said magnet encapsulation segment (21) further encapsulates an open surface of each of said permanent magnets (4) facing towards said lateral open surface (5) in axial direction of said tubular element (3), whereby said permanent magnets
10 (4) within said magnet encapsulation segments (21) are fully encapsulated by said magnet encapsulation segment (21).

Item 5. A permanent magnet thruster according to item 2 or 3, wherein said magnet encapsulate segments (21) further encapsulates a backing element (22)
15 arranged between said lateral surface (5) of the tubular element (3) and abutting surfaces of the permanent magnets (4) facing towards said lateral surface (5) of the tubular element (3), and wherein each of said magnets encapsulation segments (21) further encapsulates a surface of the backing element (22) facing towards said lateral open surface (5) and surfaces of the backing element (22)
20 facing in axial and tangential direction of the tubular element (3), whereby said permanent magnets (4) and said backing element (22) within each of said segments (21) are fully encapsulated by said magnet encapsulation segment (21).

Item 6. A permanent magnet thruster according to item 5, wherein said backing
25 element (22) is made from metal, preferably being a different metal than the metal of the magnet encapsulation, such as carbon steel.

Item 7. A permanent magnet thruster (1) according to any one of the preceding items, wherein said permanent magnets are fully encapsulated by said magnet
30 encapsulation.

Item 8. A permanent magnet thruster according any one of the preceding items, wherein said metal from which the magnet encapsulation is made, is selected from the group consisting of stainless steel, titanium and bronze, in particular
35 nickel-aluminium-bronze.

Item 9. A permanent magnet thruster according to any one of the preceding items, wherein said permanent magnets (4) are arranged side-by-side on an exterior side of the tubular element (3) or interior side of the tubular element (3).

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Item 10. A permanent magnet thruster according to item 9, wherein an exterior surface (6) of the magnet encapsulation (20) or when dependent on any one of claims 2-6 said magnet encapsulation segments (21) has/have a curvature (R) in tangential direction of the tubular element (3).

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Item 11. A permanent magnet thruster (1) according to any one of the preceding items, wherein at least some of said permanent magnets (4) are arranged side-by-side in tangential direction of said tubular element (3) with a tangential distance between permanent magnets (4) being larger than zero, said

15 permanent magnets (4) being preferably equidistantly arranged in said tangential direction.

Item 12. A permanent magnet thruster according to any of the preceding items, wherein at least some of said permanent magnets (4), such as all of said

20 permanent magnets (4), each has two side open surfaces facing in tangential direction of said tubular element (3) and wherein at least some of said permanent magnets (4), such as all of said permanent magnets (4), are arranged so that two of said permanent magnets (4) neighbouring each other abut each other along at least a part of said side open surfaces.

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Item 13. A permanent magnet thruster according to any one of the preceding items, wherein said permanent magnets (4) are cuboid.

Item 14. A permanent magnet thruster according to any one of the preceding

30 items, wherein said permanent magnets each is a solid of magnetizable material prior to said encapsulation.

Item 15. A permanent magnet thruster according to any one of the preceding items, wherein said permanent magnets each are neodymium magnets,

35 samarium-cobalt magnets and/or AlNiCo magnets.

Item 16. A method of providing a segments comprising a plurality of permanent magnets, where said permanent magnet(s) is(are) arranged side-by-side and
5 being encapsulated by a magnet encapsulation segment (21) encapsulating fully said each said permanent magnet(s) (4), the method comprising:

- subjecting said encapsulated magnet(s) to a temperature within the range of 900-1100 Celsius, and a pressure in the range of 100-200 MPa in a argon gas atmosphere for a dwell time of 2-5 hours, and
- 10 • subsequently allow said encapsulated magnet(s) to cool, such cool to a temperature in the order of 20°C, to avoid any residual stresses or cracking of the magnets, preferably at a cooling rate within the range of 100-300° per hour.

15 Item 17. A method according to item 16, wherein said HIPping demagnetize said magnet(s) to provide demagnetized permanent magnet(s), typically by said temperature exceeds the Curie temperature for the permanent magnet(s).

Item 18. A method according item 16, wherein said encapsulation segment (21)
20 comprising a pre-form (27) configured to receive said magnets side-by-side and a closure member (28) configured to close the pre-form (70), the method comprising prior to said HIPping the succeeding steps of:

- demagnetizing said permanent magnets to provide demagnetized permanent magnets;
- 25 • arranging said demagnetized magnets in said pre-form (27) and close said encapsulation segment (21) by connecting, preferably by welding, said closure member (28) to said pre-form (27).

Item 19. A method according to item 16 or 17, wherein said demagnetized
30 magnets after HIPping are magnetized.

Item 20. A method according to item 19, wherein said magnetization is carried out after said encapsulated magnet segment is arranged on a rotor yoke of a permanent magnet thruster according to any one of the preceding items 1-15.

Item 21. A method according to any one of the preceding items 16-20, wherein said permanent magnets each is a solid of magnetizable material prior to said encapsulation and said HIPping.

- 5 Item 22. A method according to any one of the preceding items 16-21, wherein said permanent magnets each are neodymium magnets, samarium-cobalt magnets and/or AlNiCo magnets.

List of reference symbols used:

	1	Thruster
	2	Rotor yoke
	3	Tubular element
5	4	Permanent magnet
	5	Lateral surface
	6	Exterior surface
	10	Propeller blades
	11	Hub
10	12	Shaft
	18	Screw
	20	Magnet encapsulation
	21	Magnet encapsulation segment
	22	Backing element
15	24	Axial direction
	25	Radial direction
	26	Tangential direction
	27	Preform
	28	Closure member
20	29	Cavity
	30	Pressure tank
	R	Curvature

1. A permanent magnet thruster, comprising
 - a rotor yoke (2) comprising
 - a tubular element (3) carrying a plurality of permanent magnets (4) on or at a lateral surface (5) of said tubular element (3);
 - 5 ○ a plurality of propeller blades (10) extending inwardly from said tubular element (3) to a hub (11) rotatably arranged on a shaft (12);
 - a stator yoke arranged outside the rotor yoke (2) and comprising a plurality of stator coils being magnetizable by an electrical current,wherein
- 10 • said plurality of permanent magnets (4) and the plurality of stator coils are mutually configured so that when said plurality of stator coils are magnetized, the rotor yoke (2) rotates, and
- said plurality of permanent magnets are encapsulated in a magnet encapsulation (20) made from metal having been subjected to HIPping, said
- 15 magnet encapsulation (20) encapsulates at least open surfaces of said permanent magnets (4) facing away from said lateral surface (5) in radial direction, facing in tangential direction and facing in axial direction of said tubular element (3).
- 20 2. A permanent magnet thruster (1) according to claim 1, wherein said magnet encapsulation (20) comprises a number of magnet encapsulation segments (21) made from metal and each having been subjected to HIPping, where each of said magnet encapsulation segments (21) encapsulates a single or a group of said permanent magnets arranged side-by-side in tangential direction of the tubular
- 25 element (3), said single or each of said group of permanent magnets being encapsulated by said magnet encapsulation segment (21) encapsulating at least open surfaces of each said permanent magnet or said group of magnets (4) facing away from said lateral surface (5) in radial direction of the tubular element (3), facing in tangential direction of said tubular element (3) and facing in an axial
- 30 direction of said tubular element (3).
3. A permanent magnet thruster (1) according to claim 2, wherein each of said magnet encapsulation segments (21) encapsulates a group of two, four or more permanent magnets (4) arranged side-by-side in tangential direction of said
- 35 tubular element (3) and wherein said group of four or more permanent magnets

are arranged in two or more sub-groups, wherein a tangential distance between permanent magnets (4) within a sub-group are smaller, such as essentially zero, than a tangential distance between sub-groups.

5 4. A permanent magnet thruster according to claim 2 or 3, wherein each of said magnet encapsulation segment (21) further encapsulates an open surface of each of said permanent magnets (4) facing towards said lateral open surface (5) in axial direction of said tubular element (3), whereby said permanent magnets (4) within said magnet encapsulation segments (21) are fully encapsulated by said
10 magnet encapsulation segment (21).

5. A permanent magnet thruster according to claim 2 or 3, wherein said magnet encapsulate segments (21) further encapsulates a backing element (22) arranged between said lateral surface (5) of the tubular element (3) and abutting surfaces
15 of the permanent magnets (4) facing towards said lateral surface (5) of the tubular element (3), and wherein each of said magnets encapsulation segments (21) further encapsulates a surface of the backing element (22) facing towards said lateral open surface (5) and surfaces of the backing element (22) facing in axial and tangential direction of the tubular element (3), whereby said permanent
20 magnets (4) and said backing element (22) within each of said segments (21) are fully encapsulated by said magnet encapsulation segment (21).

6. A permanent magnet thruster according to claim 5, wherein said backing element (22) is made from metal, preferably being a different metal than the
25 metal of the magnet encapsulation, such as carbon steel.

7. A permanent magnet thruster (1) according to any one of the preceding claims, wherein said permanent magnets are fully encapsulated by said magnet encapsulation.
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8. A permanent magnet thruster according any one of the preceding claims, wherein said metal from which the magnet encapsulation is made, is selected from the group consisting of stainless steel, titanium and bronze, in particular nickel-aluminium-bronze.
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9. A permanent magnet thruster according to any one of the preceding claims, wherein said permanent magnets (4) are arranged side-by-side on an exterior side of the tubular element (3) or interior side of the tubular element (3).

5 10. A permanent magnet thruster according to claim 9, wherein an exterior surface (6) of the magnet encapsulation (20) or when dependent on any one of claims 2-6 said magnet encapsulation segments (21) has/have a curvature (R) in tangential direction of the tubular element (3).

10 11. A permanent magnet thruster (1) according to any one of the preceding claims, wherein said permanent magnets (4) are arranged side-by-side in tangential direction of said tubular element (3) with a tangential distance between permanent magnets (4) being larger than zero, said permanent magnets (4) being preferably equidistantly arranged in said tangential direction.

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12. A permanent magnet thruster according to any of the preceding claims, wherein at least some of said permanent magnets (4), such as all of said permanent magnets (4), each has two side open surfaces facing in tangential direction of said tubular element (3) and wherein at least some of said permanent
20 magnets (4), such all of said permanent magnets (4), are arranged so that two of said permanent magnets (4) neighbouring each other abut each other along at least a part of said side open surfaces.

13. A permanent magnet thruster according to any one of the preceding claims,
25 wherein said permanent magnets (4) are cuboid.

14. A permanent magnet thruster according to any one of the preceding claims, wherein said permanent magnets each is a solid of magnetizable material prior to said encapsulation.

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15. A permanent magnet thruster according to any one of the preceding claims, wherein said permanent magnets each are neodymium magnets, samarium-cobalt magnets and/or AlNiCo magnets.

16. A method of providing a magnet encapsulation segment comprising a single permanent magnet or a group of permanent magnets, such as a plurality of permanent magnets, said magnets of said group of permanent magnets are arranged side-by-side, said magnet or group of magnets being encapsulated by a magnet encapsulation segment (21) encapsulating fully said each said permanent magnet(s) (4), the method comprising:

- HIPping said encapsulated magnet(s) (4) by subjecting said encapsulated magnet(s) segment to a temperature within the range of 900-1100 Celsius, and a pressure in the range of 100-200 MPa in a argon gas atmosphere for a dwell time of 2-5 hours, and
- subsequently allow said encapsulated magnet(s) segment to cool, such cool to a temperature in the order of 20°C, to avoid any residual stresses or cracking of the magnets, preferably at a cooling rate within the range of 100-300° per hour.

17. A method according to claim 16, wherein said HIPping demagnetize said magnet(s) to provide demagnetized permanent magnet(s), typically by said temperature exceeds the Curie temperature for the permanent magnet(s).

18. A method according claim 16, wherein said encapsulation segment (21) comprising a pre-form (27) configured to receive said magnets side-by-side and a closure member (28) configured to close the pre-form (70), the method comprising prior to said HIPping the succeeding steps of:

- demagnetizing said permanent magnet(s) to provide demagnetized permanent magnet(s);
- arranging said demagnetized magnet(s) in said pre-form (27) and close said encapsulation segment (21) by connecting, preferably by welding, said closure member (28) to said pre-form (27).

19. A method according to claim 16 or 17, wherein said demagnetized magnets after HIPping are magnetized.

20. A method according to claim 19, wherein said magnetization is carried out after said encapsulated magnet segment is arranged on a rotor yoke of a permanent magnet thruster according to any one of the preceding claims 1-15.

21. A method according to any one of the preceding claims 16-20, wherein said permanent magnets each is a solid of magnetizable material prior to said encapsulation and said HIPping.

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22. A method according to any one of the preceding claims 16-21, wherein said permanent magnets each are neodymium magnets, samarium-cobalt magnets and/or AlNiCo magnets..