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(54) Title: SUBSEA COMPRESSOR DIRECTLY DRIVEN BY A PERMANENT MAGNET MOTOR WITH STATOR AND ROTOR SUBMERGED IN LIQUID

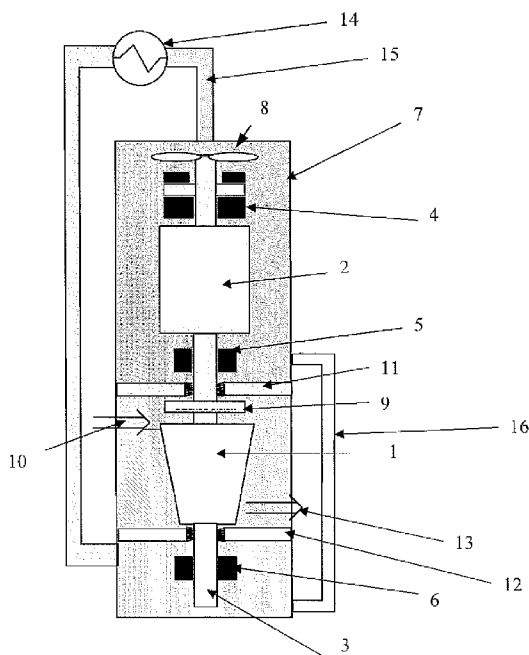


Fig. 1

(57) Abstract: The present invention regards a compressor system comprising a compressor unit and a motor unit arranged on bearings, where motor and bearings are submerged in a cooling, lubricating and barrier liquid enclosed in a housing having a cooling arrangement and a circulation arrangement, wherein the motor unit is a permanent magnet motor unit.

Subsea compressor directly driven by a permanent magnet motor with stator and rotor submerged in liquid

The present invention regards a compressor system specifically adapted for submerged use, for instance subsea use.

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The current solutions for subsea compression are perceived as costly, complex, large and heavy with extensive use of what could be considered as immature technology in relation to subsea oil and gas exploration and subsea processing.

10 One of these known solutions is to have a hermetically sealed compressor/motor solution with the rotor supported by active magnetic bearings. These systems are set in a gas atmosphere within a sealed housing, where the motor and penetrators in most cases are cooled by process gas. One problem with these solutions is that they do not tolerate sour service, due to the sensitive electrical windings and connections
15 in a process gas environment. Active magnetic bearings with an advanced control system would also contribute to complexity and cost of the system. One example of a solution with at least some of these features is described in EP1826887.

20 There is also another known compressor system for subsea use, with two contra rotating electric motors used to generate the relative speed required for gas compression. The motor stator and rotor are submerged in liquid and bearings are of plain liquid lubricated type. However, because the motors are of standard induction type with large diameter rotors and little clearance between stator and rotor, the speed is limited due to the windage losses associated with the viscosity and friction
25 of liquid. In order to obtain the relative speed required for a gas compressor, two contra-rotating motors are used. The contra-rotating principle has some main drawbacks: One is that a balance piston is difficult to incorporate, meaning that thrust bearing is highly loaded. This limits the allowed differential pressure of the system. A second drawback is that the thermodynamic principle can only be based
30 on axially impellers/blades with limited capability to generate differential pressure.

A third drawback is that this known system also has a high complexity and a relative large size.

35 A third known subsea compression concept is an induction motor driven compressor using step-up gearing to increase the speed of the compressor unit.

In a neighbouring field of technologies one may find submerged pumps arranged with an induction motor unit and plain lubricated bearings, all sealed within a
40 housing filled with a liquid acting as a cooling, lubricating and barrier fluid (to protect for ingress of process fluid). However using a compressor unit in this

configuration would not give a desired outcome. An induction motor submerged in a liquid would not be fully compliant with a compressor unit, as the obtainable rotational speed for such motors submerged in a liquid would not be high enough for a compressor unit. There is also from WO2011/019334 known the use of a permanent magnet motor for subsea pump drive.

The present invention has an aim to provide an alternative compressor system for operation as a submerged compressor system, especially suitable for subsea use.

This aim is achieved with a system as defined in the attached claims.

According to the invention there is provided a compressor system comprising a compressor unit and a motor unit. The motor rotor and compressor rotor in one embodiment may be made out of a common shaft or connected with a coupling but still having a common axis of rotation, another alternative is to have them connected with a coupling and with different axis of rotation. According to one aspect of the invention the compressor and motor may operate at same speed, thereby creating no need for an arrangement to increase the compressor speed relative to the motor speed.

The rotor system, the rotor part of the motor unit and rotating parts of the compressor, is according to the invention supported by plain lubricated bearings. The motor and compressor units are installed within a common housing, hermetically sealed against the surroundings, if used subsea sealed against the seawater environment. The motor unit and bearings are submerged in a liquid within the housing, which liquid would act as a cooling, lubricating and barrier liquid. This liquid is hereafter designated as barrier liquid. The barrier liquid is enclosed within the housing, and in one embodiment with mechanical seals as barriers towards the gas compression section of the unit. The barrier liquid may be kept at a pressure equal to or above the pressure of a process fluid possibly with a small defined leakage from motor and bearing compartment into the process. This ensures that contaminants from process can not emerge into the barrier liquid. A hydraulic power unit externally to the compressor unit may control the barrier fluid pressure and replace any barrier liquid leaked to the process. There is according to the invention in relation to the housing and thereby the liquid, provided a cooling arrangement and a circulation arrangement. According to the invention the motor unit is a permanent magnet motor unit.

The permanent magnet motor unit to be used in the invention is characterized by high density magnetic flux. This enables the rotor to be made more compact than an induction motor with similar rating. Rotor windage loss increases with approximately the diameter in 4th power, thereby a low diameter compact rotor have much less losses and can operate at higher speed until the drop in efficiency

gets critical. Additionally, a permanent magnet motor allows for a larger gap between rotor and stator without sacrificing the power factor. This gives an additional reduction in windage losses. Features of such a permanent magnet motor are described in WO2010014640, applicant Direct Drive Systems Inc.

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According to an aspect of the invention the barrier liquid circulation arrangement may comprise a circulation impeller attached to the rotor of the motor. This circulation impeller will act on the liquid and set the liquid in motion. The impeller may be attached on an extension of the rotor, with the same rotation axis, or there may be a link, giving the impeller a different rotation axis and or rotation speed compared with the rotor. The circulation impeller may be positioned within the housing or possibly in a pipe connected to the housing. There may also be the possibility of forming for instance the housing and elements within the housing such that there will be a natural convective circulation of the liquid due to hot and cold parts of the housing and elements within the housing, this forming the circulation arrangement and cooling arrangement of the invention. Such principles for circulation are known as heat pipe principle or thermo siphon principle. Another possibility may be to provide a separate circulation unit either within or in association with the housing, forming the circulation arrangement of the invention. In one possible embodiment the housing may be formed such that it together with the circulation impeller creates a circulation of the liquid within the housing. One possibility of this is to form the housing with a funnel shaped element leading towards the circulation impeller, thereby creating an increased flow of the barrier liquid within the housing. There may in one embodiment also be guide channels towards and away from the circulation impeller. According to the invention there may also be more than one circulation impeller forming the circulation arrangement.

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According to another aspect of the invention the cooling arrangement may comprise a cooling unit arranged in a fluid loop extending outside the housing. The barrier liquid within the housing would then be lead through this fluid loop and be cooled by this process. Another possibility is to have the housing at least in one section formed as a cooling unit. i.e. that the cooling arrangement may comprise a cooling unit arranged at or in the wall of the housing. One possibility is to form this cooling unit with fins in the surface either within and or outside to increase the heat transfer through the wall of the housing. Another possibility is to have a fluid loop for the surrounding fluid extending into and through the housing leading outside fluids through the housing, with a circulation unit within this fluid loop and providing a flow of cooling fluid through this fluid loop. Another possibility is to have a combination of some or all these possibilities. According to an aspect of the invention the circulation arrangement and cooling arrangement may be formed in a common arrangement or be separate elements, or a combination of this. Additionally there may be one, two, three or four or more of them.

According to one aspect, the system may comprise pressure means adapted to provide a pressure in the barrier liquid within the housing at a pressure at or above the pressure of a process fluid at the inlet of the compressor unit.

5 According to an aspect the compressor unit may have one, two, three, four, five, six, seven, eight, nine or more compressor stages or compressor impellers within in the compressor unit. The compressor unit is according to one aspect of the invention based on radial centrifugal compressor principle with shrouded or unshrouded
10 impellers with or without guide vanes, and with open or vaned diffusers. There may also be more than one compressor unit in the housing. The compressor unit may have compressor impellers and they may be arranged in-line or back-to-back. In one embodiment a compressor unit may be positioned in each end of a motor unit. Any combination of the above mentioned features are possible.

15 According to another aspect there may be arranged a balancing piston on the shaft or rotor of the system. Another possibility may be to have the compressor unit divided in two parts and these two parts arranged as a back to back solution.

20 According to yet another aspect the rotor element of the compressor unit and the motor unit may be arranged with a direct connection between the motor unit and the compressor unit as a flexible coupling, stiff coupling or common shaft. The compressor unit and the motor unit may have a common shaft.

25 The invention shall now be explained with a non-limiting embodiment and with reference to the attached drawing showing a schematic drawing of a compressor system in accordance with the invention.

The compressor system comprises a compressor unit 1 and a permanent magnet
30 motor unit 2 both arranged with a common rotor axel or shaft 3. The compressor unit 1 has a process fluid inlet 12 and a process fluid outlet 13. The rotor 3 is arranged on plain lubrication bearings, first bearing 4 on one side of the motor unit 2, a second bearing 5 between the motor unit 2 and the compressor unit 1, and a third bearing 6 on the opposite side of the compressor 1, compared with the motor
35 unit 2. The motor unit 2 and first, second and third bearings 4, 5, 6 are all arranged within a housing 7, filled with a liquid. These are the bearing also for the rotor part of the compressor unit. This liquid will act as a lubricator for the bearings 4, 5, 6. In addition will the liquid also act as a barrier fluid, as it is kept at a pressure equal to or above a pressure of the process fluid, at the outlet 13 of the compressor unit 1. This will prevent the process fluid from entering the housing and therefore keep any
40 damaging elements within the process fluid away from the elements within the housing. The liquid will also act as a cooling liquid for the motor unit 2 and other elements within the housing, as there is provided a cooling arrangement, with liquid

loops 15, 16 extending outside the housing, to a cooling unit 14 to cool the liquid and to provide for a circulation of the liquid. The housing 7 is divided in three main chamber by two dividers or seal elements 11,12, with the motor unit on one side of the dividers 11 the compressor unit 1 between the two dividers 11,12 and the third bearing 6 in the last chamber. The liquid loops are configured such that one first loop 15 connects the chamber with the motor unit 2 with the chamber with the third bearing 6 and a second loop 6 connects this chamber with the third bearing 6 with the chamber with the motor unit 2. There is also provided a barrier fluid impeller 8 within the housing 7 to keep the barrier fluid in circulation as long as the compressor system is used. The impeller 8 will also assist in creating a flow through the liquid loops 15,16 , thereby cooling the liquid. The barrier fluid impeller 8 is in this embodiment attached directly to the axel or shaft 3. As the compressor unit 1 in this embodiment is one unit there is provided a balancing piston 9 to balance out axial forces from the compressor unit as it is operated.

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The invention is now explained with reference to anon-limiting embodiment a skilled person will understand that there may be made alternations and modifications to the embodiment that are within the scope of the invention as defined in the attached claims. Other number of bearings, as four or five bearings and or more dividers or mechanical seals may be possible if rotor dynamic issues require this, as for instance if there is a flexible coupling, a long shaft, long compressor rotor or other issues. The cooling and circulation arrangements may be formed in a different manner than what is schematically sketched on the attached figure. There may for instance be no specific cooling pipes outside the housing as such as these may be positioned in the surface or wall of the housing.

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CLAIMS

1. Compressor system comprising a compressor unit and a motor unit arranged on bearings, where motor and bearings are submerged in a cooling, lubricating and barrier liquid enclosed in a housing having a cooling arrangement and a circulation arrangement, wherein the motor unit is a permanent magnet motor unit.
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2. Compressor system according to claim 1, wherein the compressor and motor operates at same speed.
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3. Compressor system according to claim 1 or 2, wherein the compressor unit is a radial centrifugal unit.
4. Compressor system according to one of the preceding claims, wherein the circulation arrangement comprises a circulation impeller attached to the rotor of the motor.
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5. Compressor system according to one of the preceding claims, wherein the cooling arrangement comprises a cooling unit arranged in a fluid loop arrange in relation to the housing.
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6. Compressor system according to one of the preceding claims, wherein the cooling arrangement comprises a cooling unit arranged at the wall of the housing.
7. Compressor system according to one of the preceding claims, wherein the system comprises pressure means adapted to provide a pressure in the liquid within the housing at a pressure at or above the pressure of a process fluid at the outlet of the compressor unit.
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8. Compressor system according to one of the preceding claims, wherein there is arranged a balancing piston on the rotor of the system.
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9. Compressor system according to one of the preceding claims, wherein the compressor unit and motor unit is arranged with a common rotor.
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10. Compressor system according to one of the preceding claims, wherein the compressor unit is arranged as a back to back solution.
11. Compressor system according to one of claims 1 to 9, wherein the compressor unit is arranged as an in-line solution.
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12. Compressor system according to one of the preceding claims, wherein one compressor unit is arranged on each end of the motor unit.

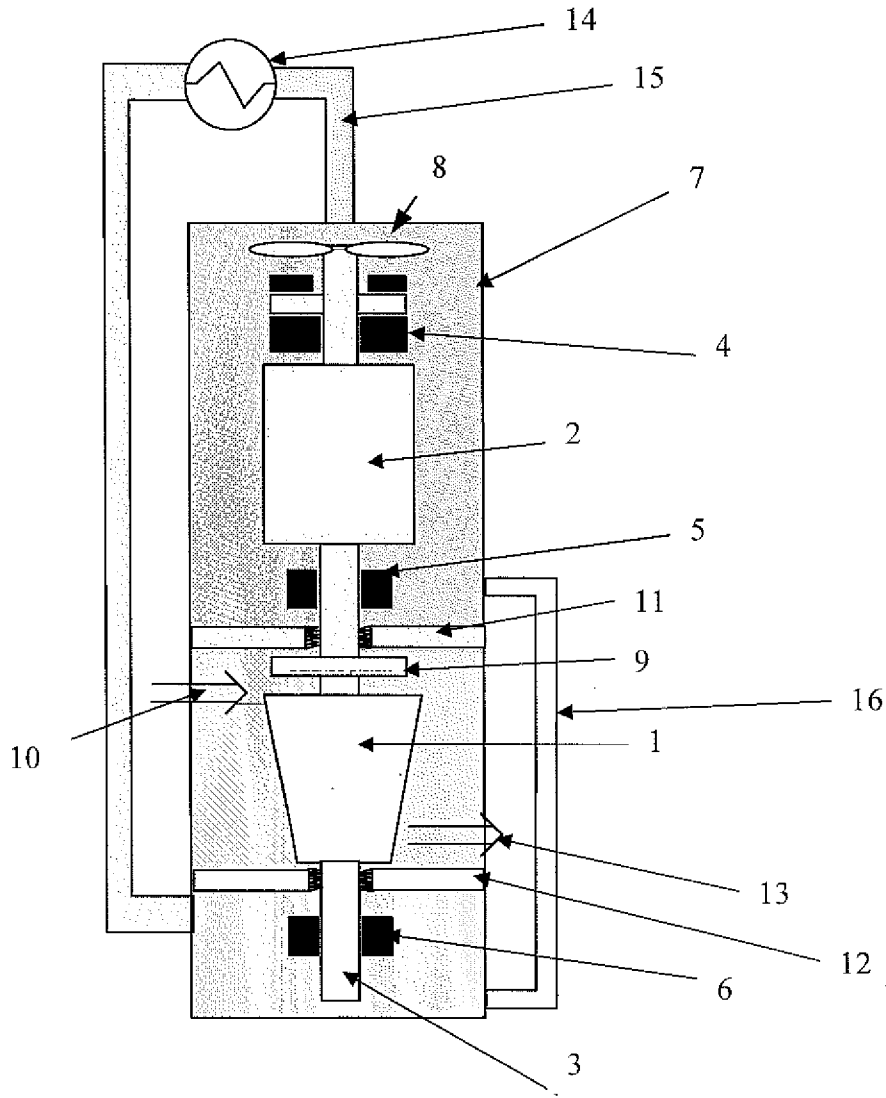


Fig. 1