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(54) **Title**: POWER UNIT

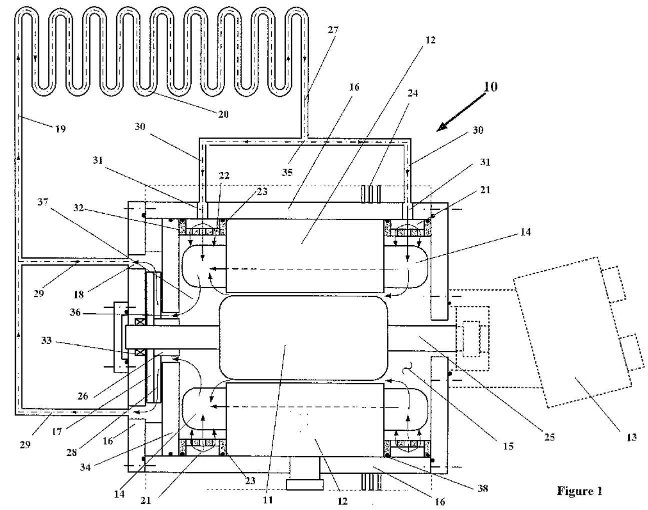

Figure 1

(57) **Abstract**: A hydraulic power unit for subsea use comprises a housing (16) containing a fluid, an electric motor (10) mounted in the housing, a distribution pump (17), a heat exchange unit (20) provided externally to the housing and at least one distribution conduit (32) in fluid communication with the heat exchange unit and the housing.

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Power unit

The present invention relates to a power unit and more specifically, a power unit for use subsea. The power unit may be a hydraulic power unit, high pressure water pump or task specific tooling unit suitable for use in a Remotely Operated Underwater Vehicle (ROV).

ROVs are commonly used to perform many offshore, subsea tasks. In order to perform a variety of tasks such as inspection, repair or installation of new equipment, the ROV will normally have work lights and a camera to assist control of the ROV by an operator on the surface, and a manipulator with which to accomplish the work.

On an ROV, a Hydraulic Power Unit (HPU) is commonly used to drive the thrusters and other hydraulically operated subsystems of the vehicle such as pan and tilt mechanisms for the cameras, and hydraulically operated tooling to enable the ROV to carry out intervention tasks on subsea infrastructure. The thrusters are the main components of the prime mover system used to manoeuvre the ROV in and around a subsea site as necessary to accomplish its designated tasks. The HPU typically consists of an electric motor coupled to a hydraulic pump unit. The motor casing is most commonly oil-filled and this is maintained at a pressure approximately one bar higher than the ambient sea pressure so as to provide a balance between internal and external pressure when the ROV is submerged. This avoids the need for a pressure proof casing and sophisticated shaft seals, as would be the case with a standard casing filled with air at atmospheric pressure as the pressure across the walls of the casing is balanced so consequently the casing need only be designed to cater for the mechanical loads associated with the operation and mounting of the motor. It also enables the HPU to be used if necessary for operations at full ocean depth of many thousands of meters without any additional modification. The pressure differential ensures that any leakage between the casing and the sea water moves from the casing to the sea water, ensuring seawater does not enter the motor casing.

The mechanism for maintaining the oil in the casing at or above the ambient pressure of the surrounding seawater is typically known in the industry as a compensator. Known compensators may typically comprise a spring loaded rolling diaphragm or bellows to maintain the oil in the casing at the required pressure.

Such motors are commonly supplied with a normal use/duty rating. This rating specifies the limits between which the motor should be used in order to prevent overloading and subsequent damage to the motor.

Three of the critical parameters for a competitive ROV system are the size and weight of the ROV and the diameter of the umbilical connecting the ROV to a vessel on the surface, all of which need to be kept to a minimum so as to reduce their effect on the launch and recovery system and on the manoeuvrability of the ROV.

An ROV with a lower in-air weight can use a launch and recovery system with lower power rating and minimises the required deck space on the launching vessel. Also, for every 1kg of weight added to an ROV, approximately 2kg of buoyancy must be added to the ROV to maintain neutral buoyancy when submerged. A smaller ROV also has increased manoeuvrability when working in restricted subsea sites.

Reducing the diameter of the umbilical reduces the drag caused by subsea currents resulting in increased ROV manoeuvrability. Reducing the umbilical diameter also results in a smaller and lighter umbilical winch requiring less deck space and a smaller support structure.

Embodiments of the present invention permit increased performance and available power output of existing motors, such as those used on an ROV, without increasing the size of the motor. Alternatively the size and weight of a replacement motor can be reduced while maintaining the same level of power output.

According to a first aspect of the present invention, there is provided a hydraulic power unit for subsea use comprising a housing containing a fluid, an electric motor mounted in the housing, a distribution pump, a heat exchange unit provided externally to the housing and at least one distribution conduit in fluid communication with the heat exchange unit and the housing.

Embodiments of the present invention permit an electric motor with a power rating twice that of a standard motor and four times the rating of an air-cooled motor. The weight and size of the new motors are significantly less than a standard motor, whilst allowing significant gains in performance.

Optionally, the power unit is a Hydraulic Power Unit (HPU), suitable for use in a Remotely Operated Underwater Vehicle (ROV). Improving the efficiency of an HPU has the advantage of increasing the payload of the ROV. Alternatively, since the size of the power unit required for a given ROV can be reduced, the weight of the ROV can also be reduced.

The weight saving according to one embodiment of the invention may be 300kg. Reducing the size of the power unit and increasing the efficiency helps to maximise the Hydraulic Power Unit (HPU) energy density. The energy density of an HPU, according to the prior art, is typically in range of 0.30kW/kg to 0.25 kW/kg. The energy density of an HPU according to the present invention is typically 0.45 kW/kg to 0.35 kW/kg. These figures relate to the complete HPU comprising the motor and pump unit.

Optionally, the electric motor comprises a rotor and stator including stator coils that pass through the stator core and extend beyond its end faces.

Optionally, the electric motor is a standard submerged motor.
Optionally, at least one distribution conduit extends radially around at least one of the stator coils. Typically, there are provided two distribution conduits surrounding each end of the stator.

Typically, the at least one distribution conduit comprises a nozzle ring. The nozzle ring may be U-shaped in cross-section with two upstanding flanges forming an annular chamber with the inner surface of the motor casing or housing, hereinafter referred to as the motor housing. The port or ports in the nozzle ring provide fluid communication between the chamber and the inside of the motor casing.

Typically, the distribution conduit is disposed on an inner wall of the motor casing. Optionally, sealing devices seal off a mating surface between the upstanding flanges and the inner wall of the motor casing.

Advantageously, the ports are circumferentially spaced around the conduit. Typically, the ports direct fluid radially inwards towards the stator coils. Typically, the ports are cylindrical. Optionally, the ports are conical.

According to one embodiment of the invention, nozzle rings are advantageous in that the even distribution of fluid achieved by spraying the fluid from the nozzles of the ring simultaneously around the target being cooled reduces the occurrence of hotspots developing on the stator coils whilst the motor is in use.

Optionally, the heat exchange unit is located outside the casing. Typically, a pipe of the heat exchange unit is serpentine. Typically, the pump circulates the fluid between the motor casing, heat exchange unit and annular chamber of the at least one distribution conduit.
Advantageously, the fluid is also a coolant or heat transfer fluid, the fluid being capable of transferring heat produced by at least one motor rotor bar and/or iron losses in the rotor core, shaft, stator and stator coils, to a heat exchange unit.

Optionally, the fluid may be water, ethylene glycol, hydrochloro-fluorocarbon (HCFC) or other coolant provided that suitable bearing types are used and the winding insulation system is compatible.

Advantageously, the fluid is liquid at room temperature and may be oil. If the fluid is oil, it may be at least one of transformer oil, mineral oil, silicone oil, or synthetic oil with electrical insulating properties. The transformer oil is highly refined and contains few additives giving it the ability to absorb a quantity of water whilst maintaining an acceptable dielectric strength. Hydraulic type oil is not suitable due to the additives it may contain. At the higher running temperatures some of the additives, for example zinc, are deposited onto the hotter internal surfaces such as the windings and this compromises the insulating properties resulting in the early failure of the insulation.

In specific embodiments of the present invention the fluid can have a viscosity in the range 10cSt to 40cSt at 20°C. This ensures adequate lubricity of the shaft bearings and acceptable motor windage losses. Preferably the viscosity is in the range 10cST to 15cSt at 20°C.

Advantageously, the circulating pump used to circulate the fluid is mounted on the motor shaft. Advantageously, the circulating pump is located inside the casing, avoiding the need for pump shaft seals and thus reducing the risk of the circulation fluid becoming contaminated with foreign fluids or solids from outside the casing.

Optionally, the distribution pump is a centrifugal pump.
Optionally, fins can be provided on the outer surface of the casing, increasing the effective surface area of the casing and thereby providing additional cooling of the fluid inside the casing.

The Hydraulic Power Unit (HPU) may drive hydraulic thrusters used for manoeuvring a Remotely Operated Vehicle (ROV) in and around a subsea site as necessary to accomplish its designated tasks. Typically, the ROV has two or more vertical and/or horizontal thrusters.

Optionally, the ROV has one or more manipulating or cutting arms, a water sampler, light and temperature sensors.

Optionally the power unit may comprise at least two pumps. In a preferred option the power unit comprises two pumps mounted in the housing.

Conveniently, each pump may be adapted to pump fluid along an associated circuit between the housing and the heat exchange unit.

Independent heat exchange units and/or distribution conduits may be associated with each pump.

According to a second aspect of the present invention, there is provided a method of cooling a hydraulic power unit for use in a Remotely Operated Underwater Vehicle, the method comprising the steps of:

(a) circulating fluid inside a housing;

(b) transferring heat from one or more of the motor rotor, stator and one or more stator coils of a motor mounted in the housing to the fluid;

(c) circulating the fluid through a heat exchange unit provided externally of the housing to cool the fluid by losing heat to the surrounding water;

(d) passing the cooled fluid through a distribution conduit inside the housing.

In some embodiments of the present invention, the distribution conduit has at least one distribution port.

The motor may be part of a Hydraulic Power Unit (HPU) of a Remotely Operated Vehicle (ROV). Typically, the cooled fluid is directed from the at least one distribution port onto the motor parts within the motor casing.

Currently, the rating of a motor used in a ROV is based on submerged use where cooling is provided only by the surrounding water. Heat produced by the motor is dissipated through the motor casing to the water in which the ROV is operating. The movement of oil inside the motor casing relies upon convection currents. The circulation of oil is therefore limited and hot-spots can develop.

In some embodiments of the present invention, method steps (a), (c) and (d) may be achieved with the use of a pump. Optionally the pump is a centrifugal pump.

In one embodiment of the present invention method step (c) can include circulating the fluid through a heat exchange unit located outside the motor casing.

In some embodiments of the present invention the distribution conduit of method step (d) can be a nozzle ring.

Embodiments of the present invention will now be described by way of example only and with reference to and as shown in the accompanying drawings, in which:-

> Figure 1 is a sectional view of a hydraulic power unit in accordance with one aspect of the present invention;
> Figure 2 is a cross-sectional view of an end of the stator of the hydraulic power unit of figure 1; and
> Figure 3 is a sectional view of an alternative hydraulic power unit in accordance with another aspect of the present invention.

Figure 1 shows an exemplary embodiment of a hydraulic power unit for use subsea use comprising an electric motor 10 and pump 17 used to move oil 15 around inside a motor casing 16. When in use, the motor 10 generates heat which is transferred to the oil 15 in contact with the motor 10 inside the casing 16. The oil 15 is cooled by passing it through a heat exchange unit 20.

The particular embodiment described herein comprises an electric motor 10 inside a peripheral motor casing 16, within which a cylindrically shaped rotor 11 is mounted. Annular stator 12 surrounds the rotor 11 within the motor casing 16. Annular stator 12 has ends 14 that extend beyond the ends of the rotor 11, towards the casing 16.

The casing 16 is filled with oil 15, although it should be noted that other fluids may be used, for example transformer oil, mineral oil, silicone oil, or synthetic oils with electrical insulating properties.

In the embodiment shown, the rotor 11 is centrally mounted within the casing 16. A shaft 25 extends from the centre of the rotor 11 into a hydraulic pump 13 which is mounted on the end of or adjacent to the motor casing 16. The other end of the shaft 25 is mounted in an annular bearing 33 in a wall of the casing 16. Abutting the bearing 33 on the inside wall of the motor casing 16 is an impeller 17 of a centrifugal pump 27. The shaft 25 passes through the centre of the impeller 17. The skilled reader will realise that the centrifugal pump 27, in accordance with this embodiment of the present invention, may be another type of rotodynamic pump, positive displacement pump or any other device for moving fluids. The shaft 25 is supported at one end of the casing by a central boss 26 inside an endplate 34 and bearings 33 in the casing wall 16. The endplate 34 forms a pump chamber 28 in which the impeller 17 is mounted. Positioned radially outside the central boss 26 are ports 36 allowing oil 15 to move from the motor chamber 37 to the pump chamber 28.
Two outlet ports 18 positioned at the top and bottom of the chamber 28 allow fluid communication between the chamber 28 and two ducts 29 on the outside of the casing 16. The two ducts 29 that extend from outlet ports 18, converge into one pipe 19. The pipe 19 is in fluid communication with a heat exchange unit 20.

The heat exchange unit 20 is a continuous serpentine length of pipe. The particular embodiment described herein refers to a tubular heat exchange unit 20. The skilled reader will realise the heat exchange unit 20 could be a plate, shell, adiabatic, phase change or other type of device for the efficient transfer of heat from one medium or fluid to another.

The other end of the heat exchange unit 20 is in fluid communication with pipe 27 which is also in fluid communication with fluid diverter 35, from which extend two ducts 30. Inlet ports 31 are provided in the casing 16, for connection to the ducts 30.

Inside the motor casing 16, there are located two distribution conduits 32, each distribution conduit 32 encompassing the ends 14 of the stator 12. The distribution conduits 32 are U-shaped in cross-section. Two upstanding flanges 23 extend from each distribution conduit 32 and adjoin at seals 38 with the inner surface of the casing 16, forming annular chambers 21. Each chamber 21 is in fluid communication with a duct 30, through an inlet port 31. Each distribution conduit 32 forms one chamber 21 and has three circumferential rows of radial apertures 22, between the two flanges 23. The skilled reader will realise that any number of apertures could be used. The apertures 22 provide fluid communication between the chamber 21 and the inside of the casing 16, proximal to the ends 14 of the stator 12. The distribution conduits 32 shown in Figure 1 are nozzle rings with apertures or distribution ports 22, cylindrical in shape. In an alternative embodiment the apertures 22 are conical in shape. Any number of apertures or ports 22 are suitable.
The outer surface of the casing 16 is covered with fins 24 which increase the surface area of the casing 16 and thus provide improved cooling.

In use, circular motion of shaft 25 is used to power centrifugal pump 27. Oil 15 is moved around motor casing 16 by the centrifugal pump 17, during which time it is heated through contact with rotor 11 and stator 12 of the motor 10.

The oil 15 contacts pump impeller 17 adjacent to the shaft 25 and is accelerated by the rotating impeller 17 into pump chamber 28. The oil 15 is then forced through outlet ports 18 in the casing 16 and into two ducts 29. The oil 15 is then pumped along pipe 19 and through the coils of a heat exchange unit 20. As the oil 15 passes along the pipework of the heat exchange unit 20 the temperature of the oil 15 is reduced by the transfer of heat from the oil 15, through the walls of the heat exchanger 20 and into the relatively cold surrounding water (not shown). The oil 15 cools as it passes along the tortuous path of the pipe in the heat exchange unit 20.

Once the oil 15 has cleared the end of the coils of the heat exchange unit 20, it moves along a pipe 27 before being divided between two ducts 30. The cool oil 15 then passes through inlet ports 31 into chambers 21 of the nozzle rings 32. The oil 15 in chambers 21 is then pumped through apertures 22 and sprayed into the casing.

The oil 15 leaving the apertures 22 is homogeneously distributed over both ends of 14 of the stator 12. After contact with the ends 14, the oil 15 is able to circulate inside the casing 16, and in particular to flow along the length of the stator coils 14, before again being drawn into the pump chamber 28 for recirculation and cooling.

In use the oil 15 helps to cool the components of the motor 10, so allowing the motor 10 to continue to run without damage at much higher loadings than those determined by its normal rating.

Figure 2 shows a cross-sectional view of an end 14 of the stator 12. Stator slots 41 in the stator 12, receive stator coils 40.

Figure 3 shows an exemplary embodiment of a hydraulic power unit 10 comprising all the features shown in Figure 1 with the following differences. Ports 18 provide fluid communication between the pump chamber 28 and a circulation chamber 43. An outlet port 44 provides fluid communication between the circulation chamber 43 and duct 19 on the outside of the casing 16. The pipe 19 is in fluid communication with the heat exchange unit 20.

In use, the oil 15 enters pump chamber 28 and is then forced through outlet ports 18 in the casing 16 and into circulation chamber 43. The oil 15 then leaves the circulation chamber 43 through port 44 into pipe 19 and through the coils of the heat exchange unit 20.

Modifications and improvements may be made to the foregoing without departing from the scope of the invention as defined by the claims. In the embodiments above, the hydraulic power unit is described as comprising an electric motor 10 and a pump 17. It is envisaged that in one embodiment of the present invention a second pump may be provided within the hydraulic power unit. Each pump may be independently controlled and may also be adapted to pump fluid to the heat exchange unit, through the same distribution conduit and back to the housing. Alternatively each pump may be adapted to pump fluid around an independent circuit from the housing to the same or independent heat exchange units through the same or independent distribution conduits and back to the housing.

By increasing the fluid flow within the hydraulic power unit, the power output can be increased without increasing the operating Pressure. Off the shelf components are cost effective for operating at pressures of up to about 300 bar. Above this rating, the components tend to be more specialised and therefore more expensive. Therefore by incorporating a second pump and increasing the effective flow rate through the hydraulic power unit, whilst operating at a pressure rating in line with off the shelf components such as around 250 bar, this allows more tooling to be operated simultaneously and also results in a reduced utilisation factor for individual components which extends their reliability and operational lifespan.

Such an additional pump may be mounted adjacent the first, with a consequential increase in rotor shaft length to accommodate the pump or alternatively the housing of the hydraulic power unit may be extended on the opposite side from the first pump to provide a seat for a second pump within the housing.

CLAIMS

1. A hydraulic power unit for subsea use comprising a housing containing a fluid, an electric motor mounted in the housing, a distribution pump, a heat exchange unit provided externally to the housing and at least one distribution conduit in fluid communication with the heat exchange unit and the housing.

2. A hydraulic power unit according to claim 1, wherein the at least one distribution conduit comprises a nozzle ring.

3. A hydraulic power unit according to any preceding claim, wherein the electric motor comprises a rotor and a stator, the stator including one or more stator coils and wherein the distribution conduit extends radially around one or more of the motor rotor, the stator and the one or more stator coils.

4. A hydraulic power unit according to any preceding claim, wherein the distribution conduit is disposed on an inner wall of the housing.

5. A hydraulic power unit as claimed in any preceding claim, wherein the power unit is a hydraulic power unit with an energy density between 0.45 kW/kg and 0.35 kW/kg.

6. A hydraulic power unit according to any preceding claim wherein the fluid is any one or more of a coolant and heat transfer fluid.

7. A hydraulic power unit as claimed in any preceding claim comprising at least two pumps.

8. A hydraulic power unit as claimed in claim 7, each pump is adapted to pump fluid along an associated circuit between the housing and the heat exchange unit.

9. A hydraulic power unit as hereinbefore described with reference to and as shown in the accompanying drawings.

10. A Remotely Operated Underwater Vehicle comprising a hydraulic power unit according to any preceding claim.

11. A method of cooling a hydraulic power unit for use in a Remotely Operated Underwater Vehicle, the method comprising the steps of:

(a) circulating fluid inside a housing;

(b) transferring heat from one or more of a motor rotor, a stator and one or more stator coils of a motor mounted in the housing to the fluid;

(c) circulating the fluid through a heat exchange unit provided externally of the housing to cool the fluid by losing heat to the surrounding water;

(d) passing the cooled fluid through a distribution conduit inside the housing.

12. A method according to claim 11, wherein steps (a), (c) and (d) are achieved with the use of a pump.

13. A method according to any of claims 11 and 12, wherein the cooled fluid is directed from the distribution conduit onto one or more of the motor rotor, the stator and the stator coils.

14. A method accordingly to claim 13, wherein the cooled fluid is sprayed onto one or more of the motor rotor, the stator and the stator coils.

15. A method of cooling a hydraulic power unit for use in a Remotely Operated Underwater Vehicle as hereinbefore described.

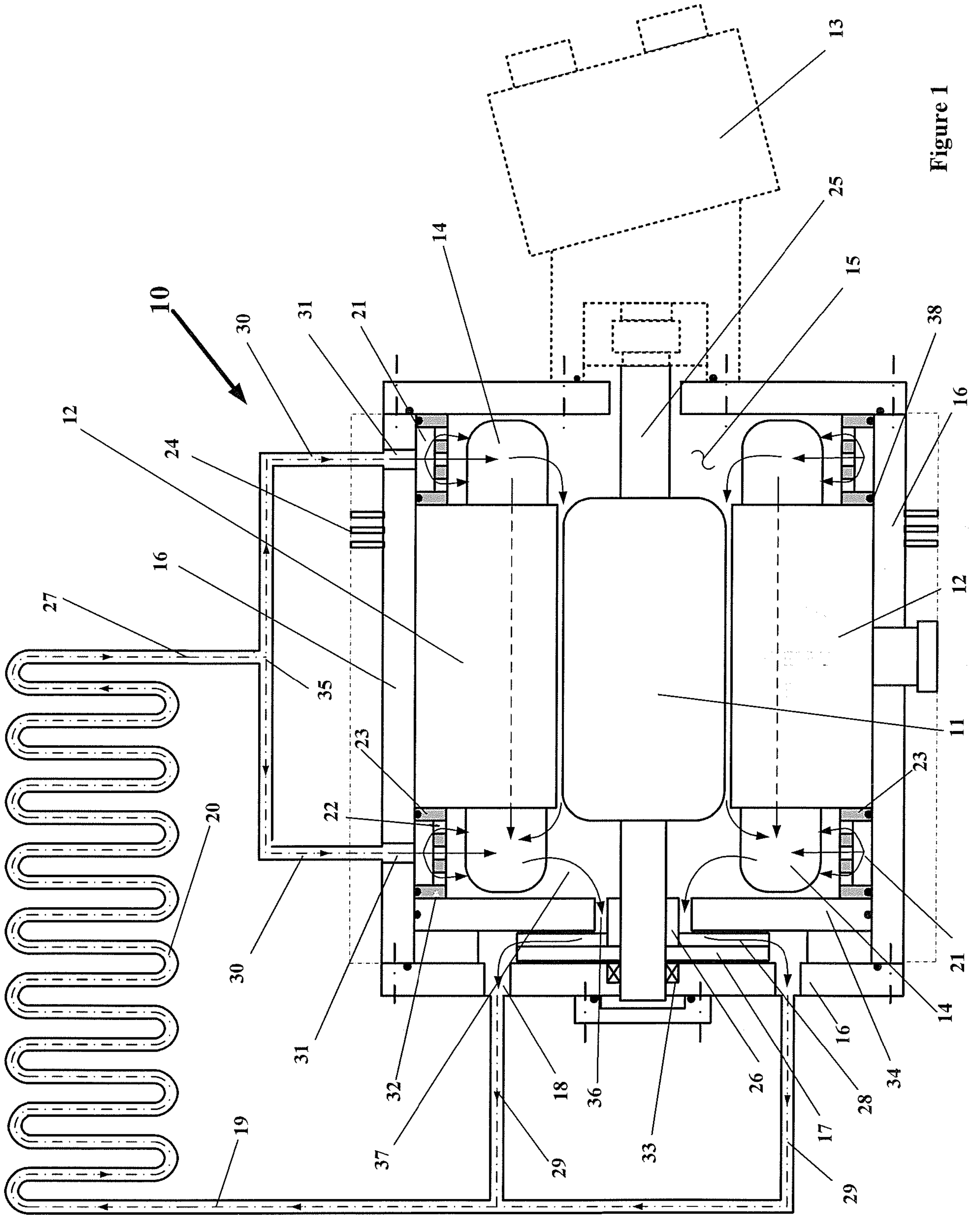
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Figure 1

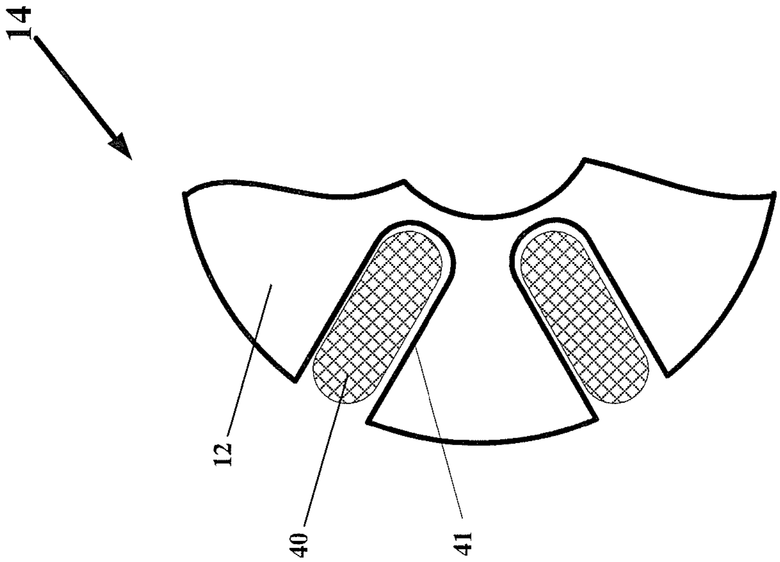

Figure 2

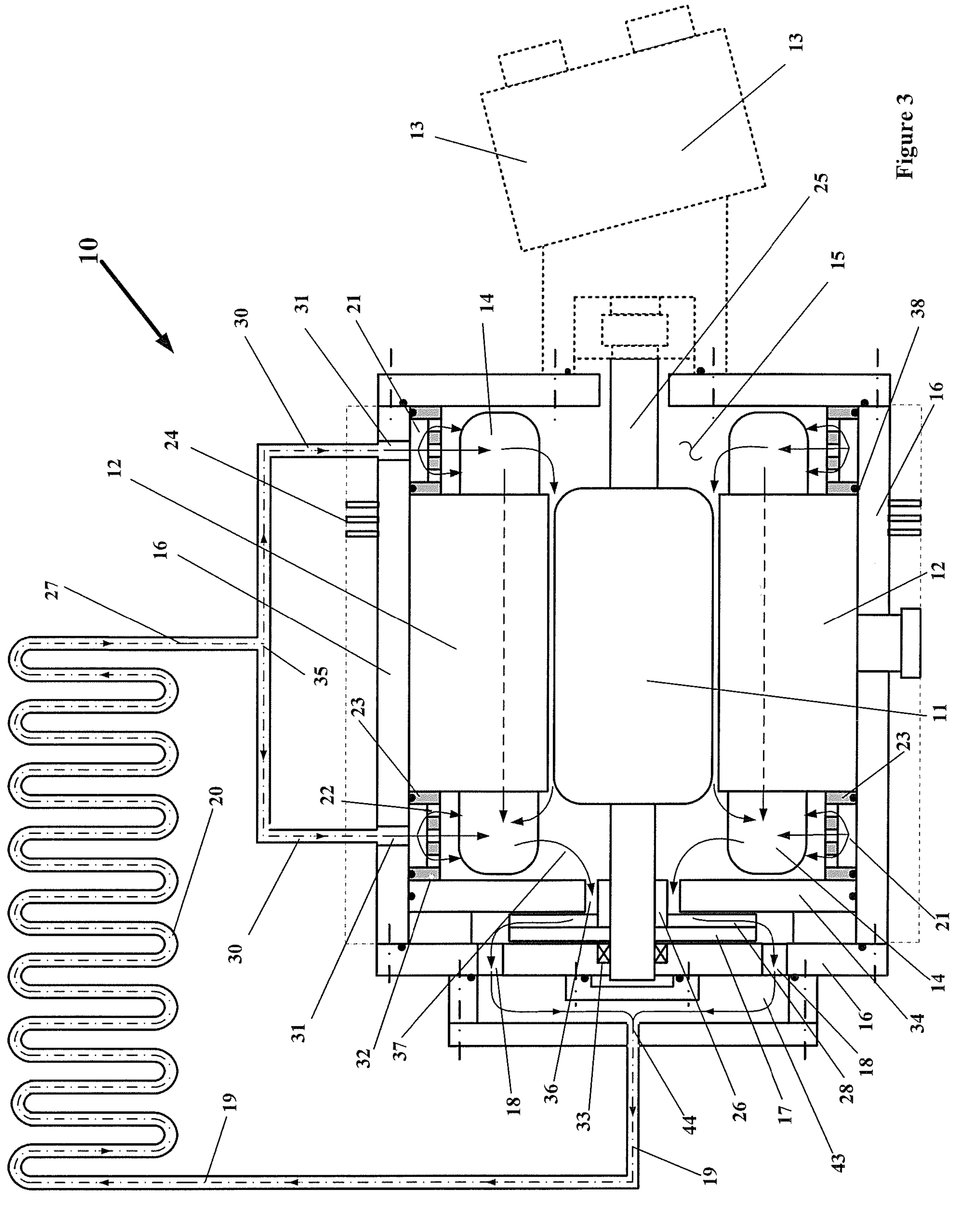
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Figure 3