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(54) **MODULAR, MULTI-STAGE, INTEGRAL SEALED MOTOR PUMP WITH INTEGRALLY-COOLED MOTORS AND INDEPENDENTLY CONTROLLED ROTOR SPEEDS**

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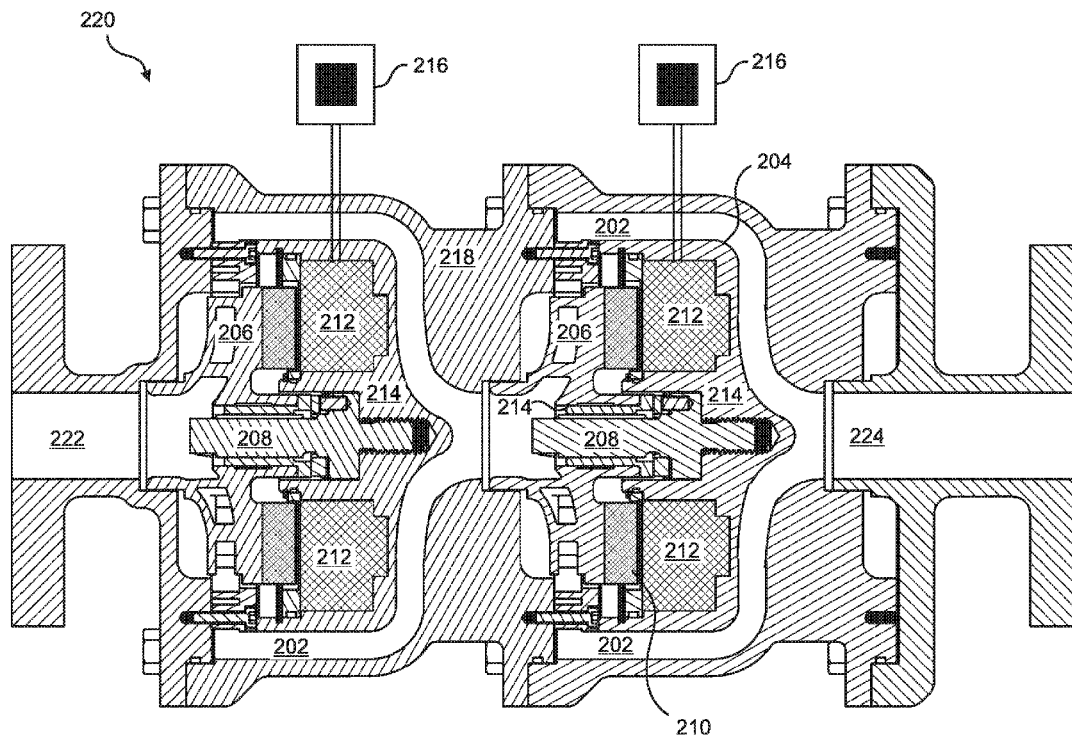
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(57)

ABSTRACT

An integral motor pump module directs at least 90% of its rotor discharge over at least 50% of its motor housing surface, thereby cooling the motor with little or no need for a separate flow path. The discharge can flow through an annulus formed between the motor and pump housings, and can extend over substantially all of the sides and rear of the motor housing. The rotor can be fixed to a rotating shaft, or rotate about a fixed shaft, which can be threaded into the motor and/or module housing. A plurality of the modules can be combined into a multi-stage pump, with rotor speeds independently controlled by corresponding variable frequency drives. The motor can be a radial or axial permanent magnet or induction motor. A separate cooling flow can provide additional cooling e.g. when pumping heated process fluids. Embodiments include guide vanes and/or diffusers.



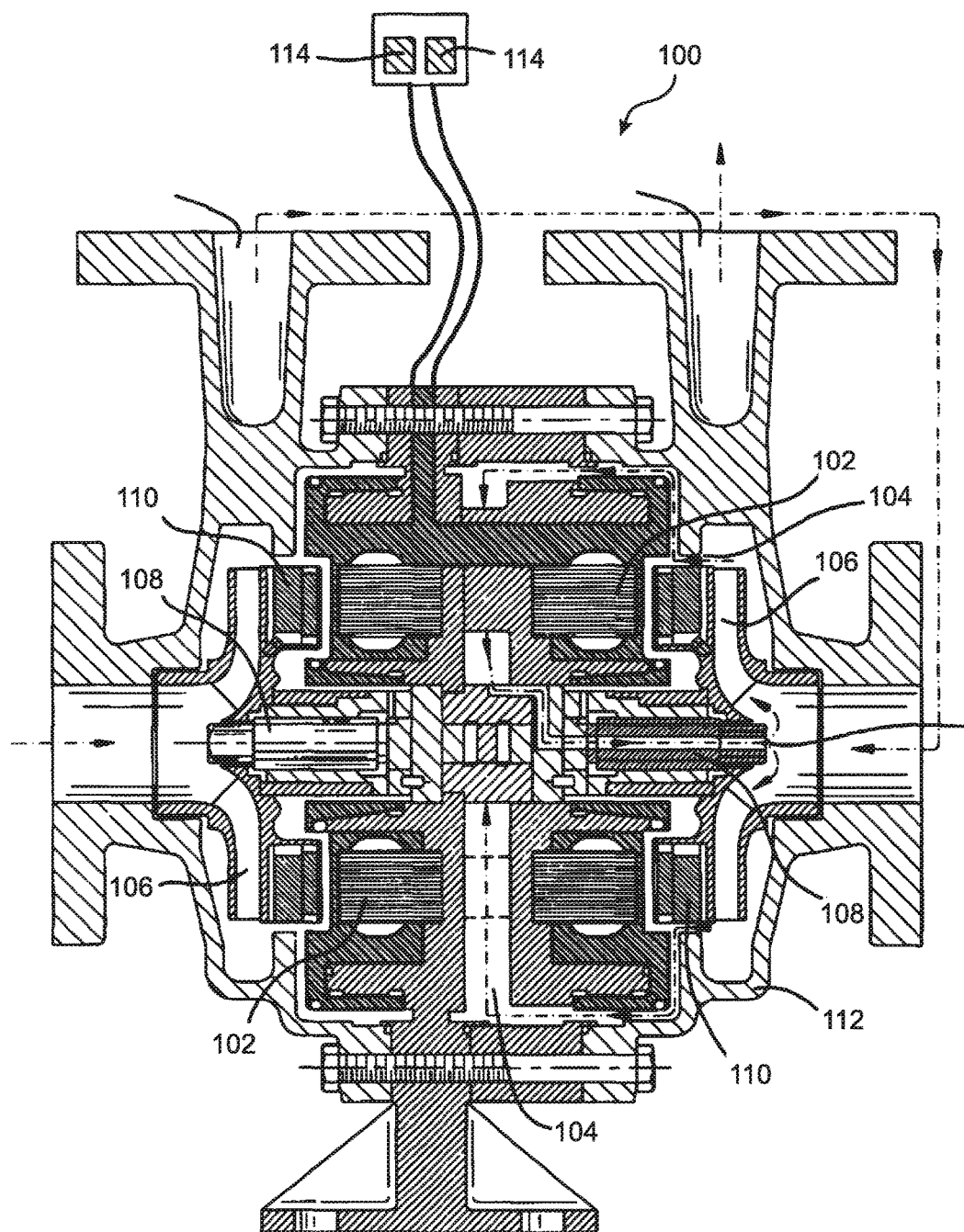


Fig. 1
Prior Art

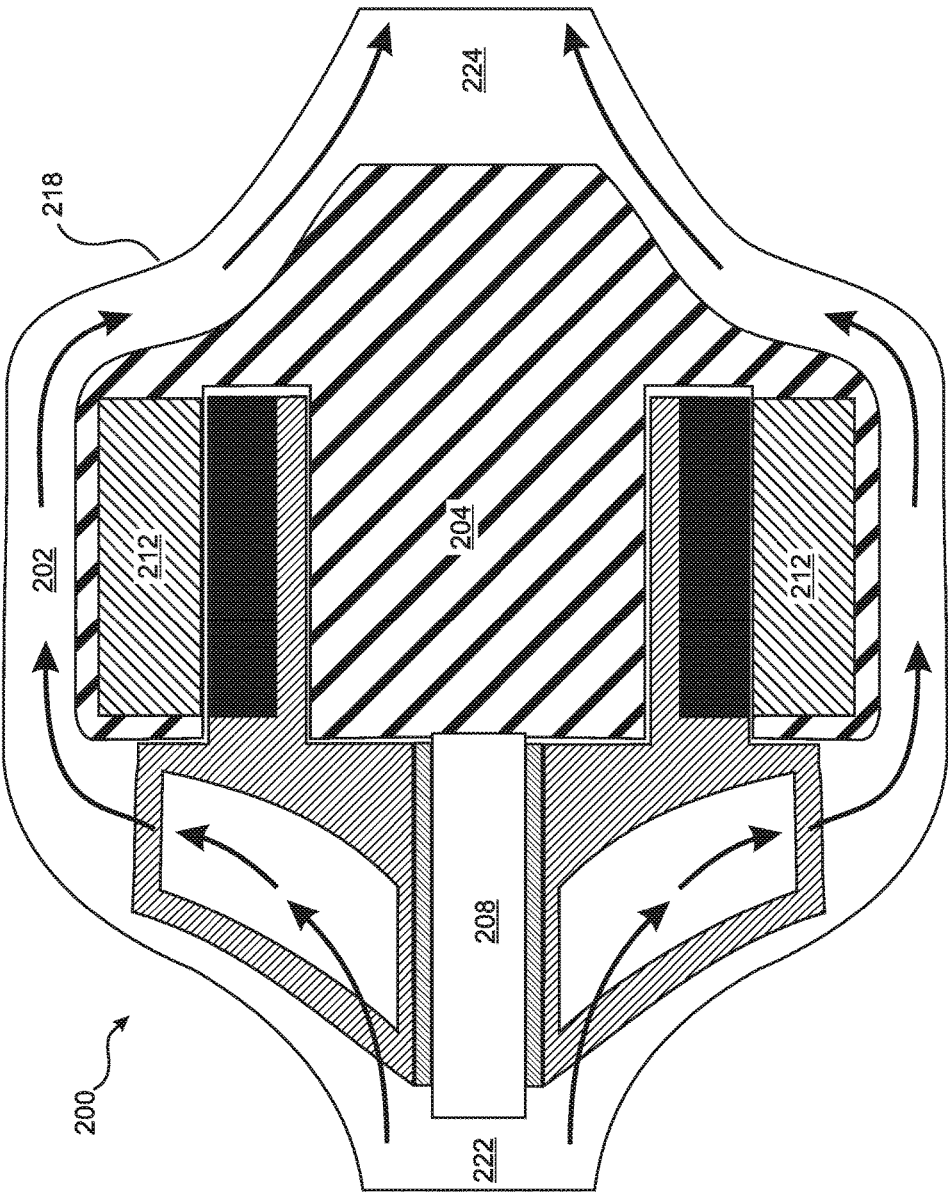


Fig. 2A

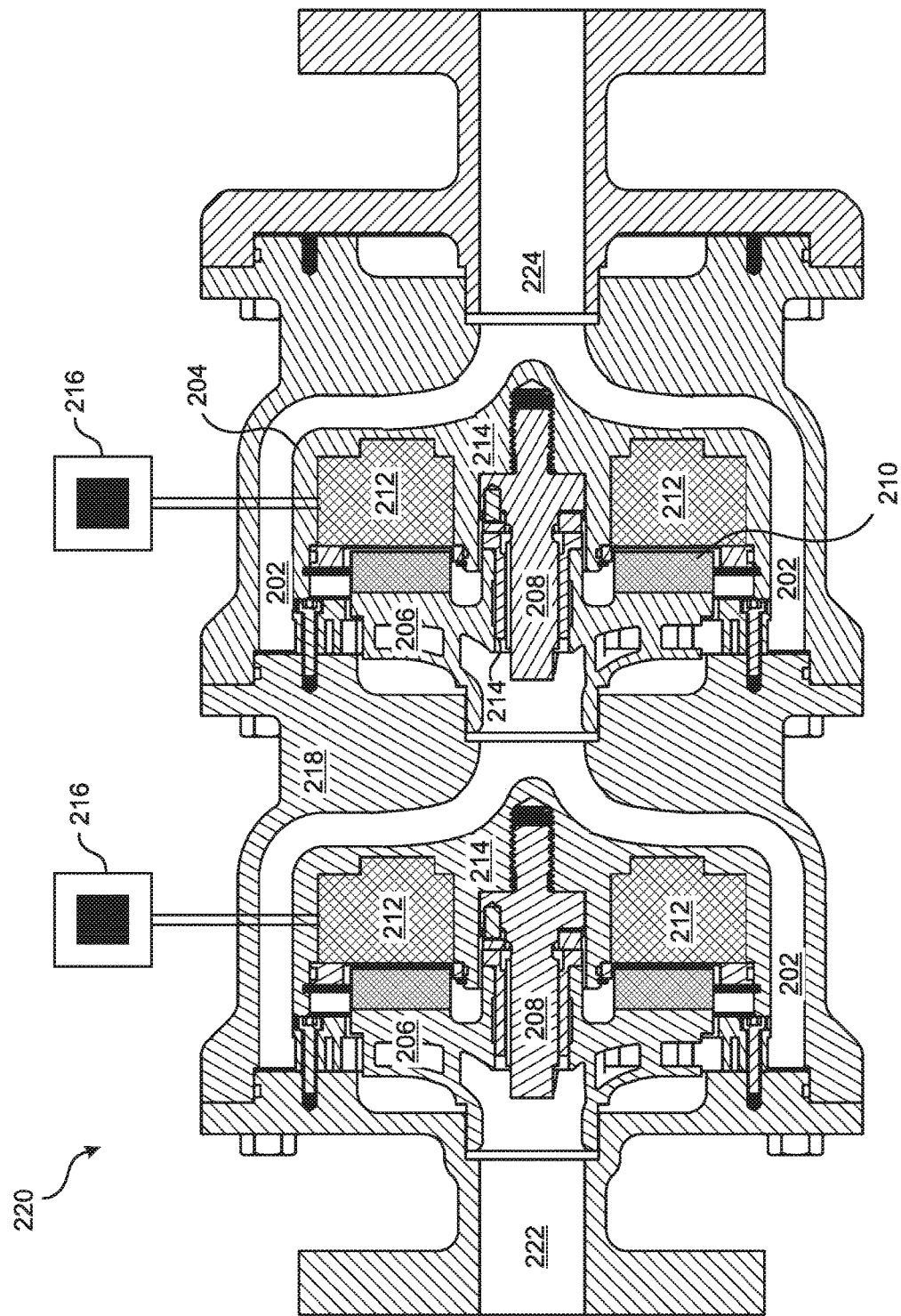


Fig. 2B

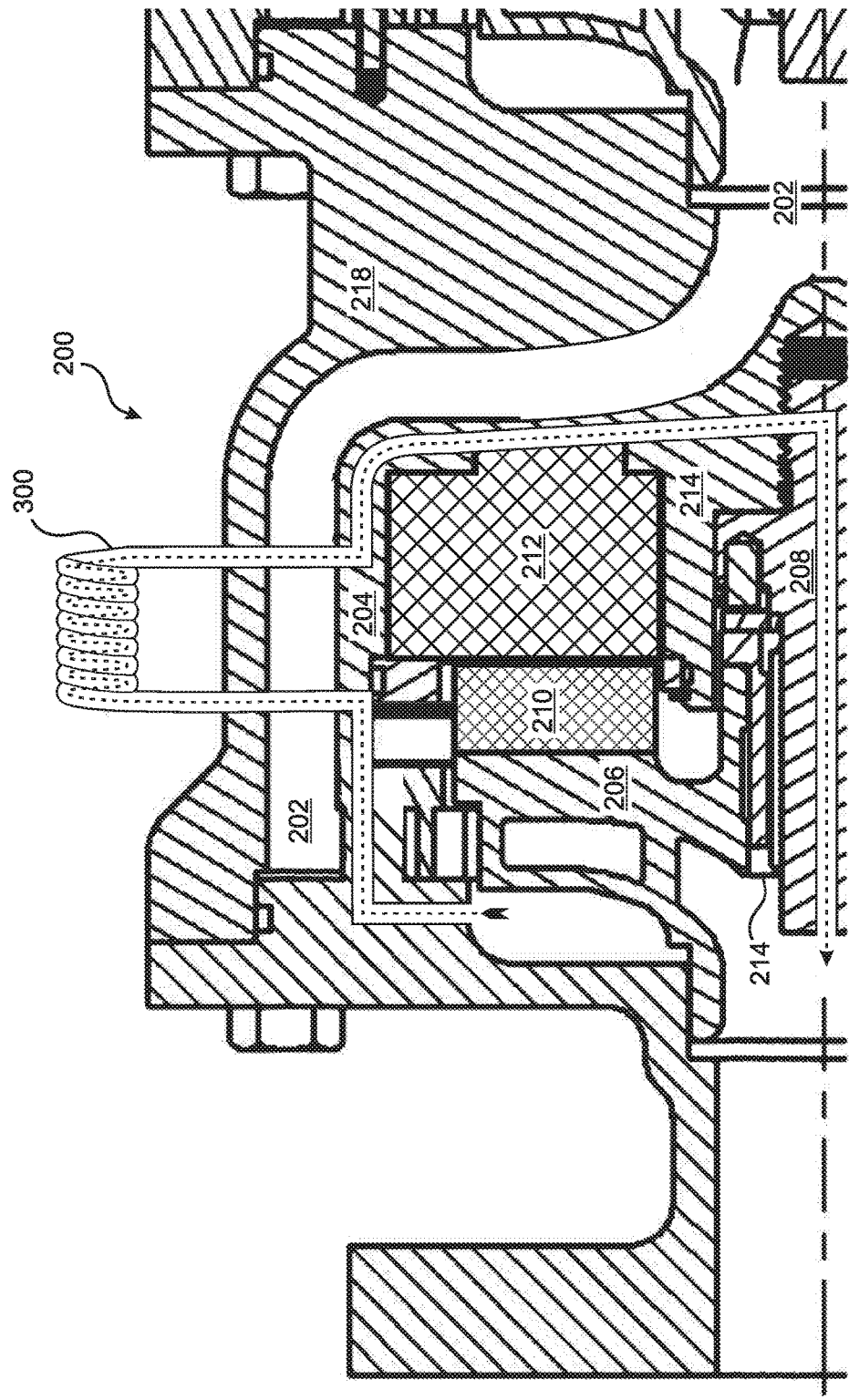


Fig. 3

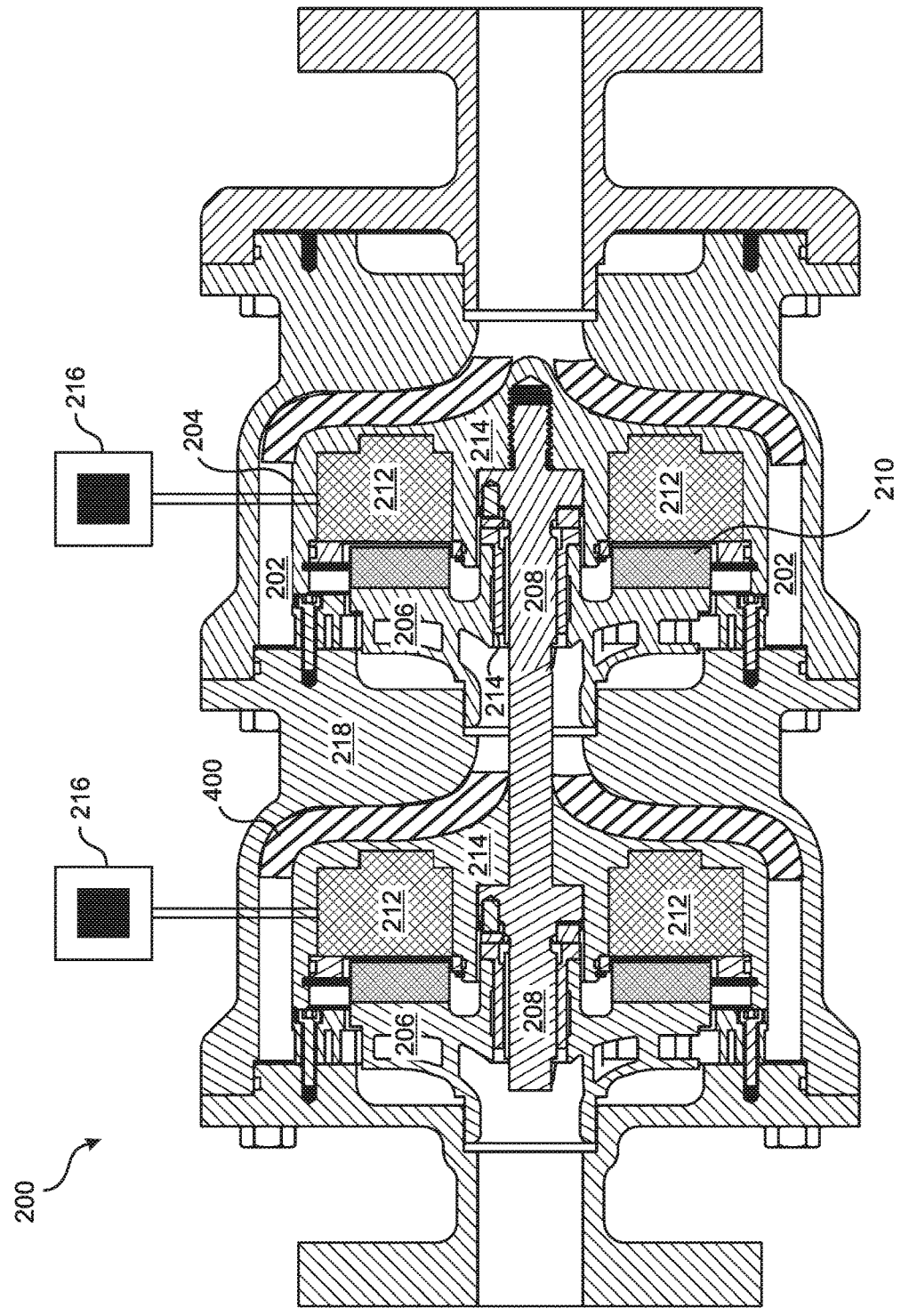


Fig. 4

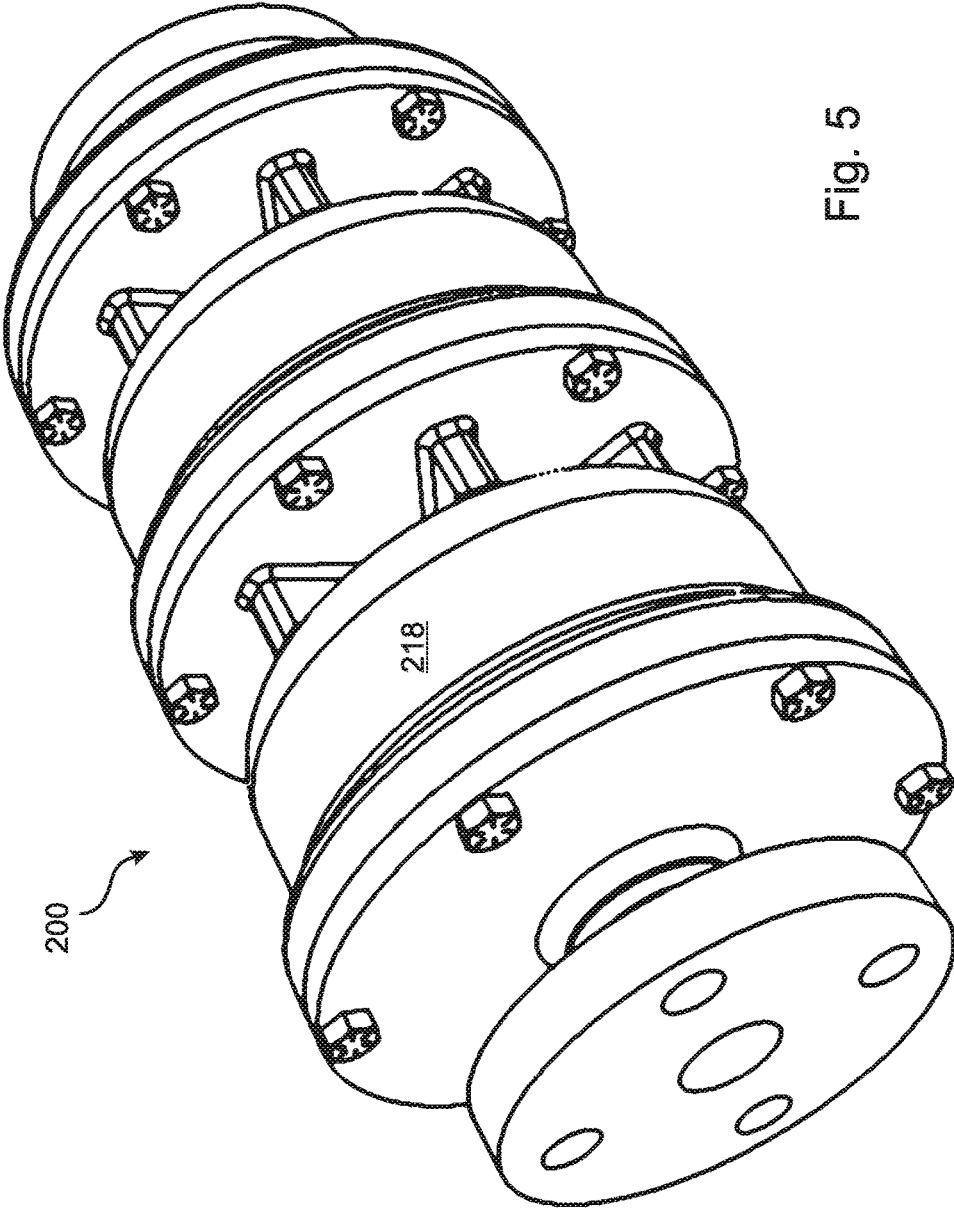


Fig. 5

**MODULAR, MULTI-STAGE, INTEGRAL
SEALED MOTOR PUMP WITH
INTEGRALLY-COOLED MOTORS AND
INDEPENDENTLY CONTROLLED ROTOR
SPEEDS**

FIELD OF THE INVENTION

[0001] The invention relates to pumps, and more particularly, to integral sealed motor pumps.

BACKGROUND OF THE INVENTION

[0002] In a conventional rotodynamic pump design, fluid flow and pressure are generated by an impeller rotating inside a stationary pump casing. The torque required to drive the rotor is provided by an external driver and transmitted through a rotating shaft to the impeller. Higher pressures can be achieved by adding multiple impeller stages in series and using a larger driver to provide torque to all stages through the same shaft. The shaft must get larger in diameter and longer in length to accommodate the combined torque and axial length of all rotor stages. Pumps with high stage counts or a vertical arrangement can use very long shafts that lead to various rotodynamic issues related to shaft deflections and critical speeds. Furthermore, dynamic seals are required to maintain the pressure boundary at the locations where the rotating shaft penetrates the stationary pump casing. These seals are a source of leakage and other failure modes. In addition, rigid baseplates are required to allow the pump and motor to be mounted and aligned with each other so as to avoid vibration issues. Even with rigid baseplates, nozzle loads on the pump can cause alignment problems between the driving motor and mechanical seals.

[0003] Some of these issues of conventional pumps are eliminated by designs that do not include shaft seals. Magnetic coupling drives, for example, do not require dynamic seals on the pump shaft, because the driving torque of the motor is coupled magnetically through the pump housing to the internal shaft. However, these designs still suffer from issues arising from the use of a single, long shaft to drive all of the pump stages, and they still require careful alignment of the motor with the pump housing so as to couple the motor and pump shafts as efficiently as possible. Even then, significant energy is lost due to the lack of a physical coupling between the motor and the pump shaft. Also, the components used for magnetic coupling and product lubricated bearings add complexity to the design.

[0004] Another approach for avoiding dynamic seals is to include the motor itself within the pump housing. Some of these so-called “canned motor” approaches use a radial motor design whereby permanent magnets are attached at or near the outer radius of the rotor, and an electromagnetic stator surrounds the rotor. Other approaches implement an axial motor design whereby a disk or “pancake” permanent-magnet, brushless DC motor is included within the housing of a centrifugal pump to provide high power density and create the most compact and lightweight single stage pump units possible.

[0005] These so-called “integral motor” or “canned motor” pumps eliminate dynamic shaft seals, but they still typically use only a single shaft to drive all rotor stages. Also, it can be difficult to cool a motor of a canned motor pump, because the motor is inside of the pump housing. Typically, special flow paths must be provided within the

pump to shunt some of the working fluid from the pump discharge into the pump suction flow through grooves in submerged product lubricated bearings and/or through another appropriate path to extract heat arising from the motor stator. The shunted working fluid is heated by convection from the outer stator wall and carries the heat to the suction chamber to be expelled by being pumped away along with the unshunted working fluid. However, as the shunted fluid passes from the pump discharge chamber, through the passages adjacent to the outer stator wall, and through a hollow rotating shaft, the shaft bearings, and/or other appropriate path to the suction chamber, a phase change may occur due to the combination of fluid heating and pressure drop due to the transition from discharge to suction pressure. This exposure to fluid in the vapor phase can result in overheating and/or bearing failure. Furthermore, the requirement of diverting a certain fraction of the pump output into a cooling flow necessarily reduces the efficiency of the pump.

[0006] Head generation and flow delivery for disk motor pumps is limited by the amount of torque which the motor, at a given diameter, can develop. The total head generated is a function of the rotor diameter and its rotation speed. The flow delivery for a given diameter and speed is determined by the impeller width. The speed of rotation is limited by both the frequency limitations of the inverter used to drive the motor and the NPSH (Net Positive Suction Head) available at the inlet of the impeller. Use of larger diameter impellers (motor disks) to develop higher pump head requires use of larger and thicker case and structural components to contain the developed head pressure as well as higher suction pressure.

[0007] One way to reduce the size and weight of the pump casing and components, when high heads are required, is to use small diameter impellers operating at high speeds. However, for integral disk motor designs, smaller diameter impellers provide smaller available disk areas to house the permanent-magnet disk motor, thereby limiting the torque that can be developed by the motor. Another limitation is the relative unavailability of disk motor designs (magnetic rotors and stators) that can deliver a range of pressures and flow rates.

[0008] In conventional pumps, these limitations are typically overcome by including a plurality of pump stages within the pump, and one large motor to drive the combined torque required by all stages. However, due in large part to the added complexities associated with integrated motors, most canned motor pump designs are either single-stage pumps, or include only one motor that drives several rotors fixed to a common shaft. However, multi-stage pumps are limited due to the requirement that all of the rotors must turn at the same rate. Furthermore, a failure of any one stage will cause an immediate and total failure of the entire pump.

[0009] With reference to FIG. 1, one approach that mitigates these issues to some extent is to include two centrifugal pump stages within a single canned motor design **100**, whereby each stage is driven by its own motor **102**, and whereby the two stages are positioned back-to-back, such that the motors **102** are included within a common central space within the housing **112**, and can be cooled by a common process flow path **104**. In the example shown in FIG. 1, the two rotors **106** face in opposite directions and each includes permanent magnets **110** attached to a rear side thereof. In some versions, the motors **102** are controlled by

separate variable frequency drives (“VFD’s”) **114** and each of the rotors **106** rotates about a separate, fixed shaft **108**, while in other versions the motors share a common controller and/or shaft. By placing the two motors **102** within the same volume, the cooling path **104** in this approach is only slightly more complex than the cooling path in a single stage integral motor design, and the loss of efficiency due to diverting flow into the cooling path is minimized. However, this approach is, by its nature, limited to only two stages.

[0010] What is needed, therefore, is an integral motor pump design that is extendable to more than two stages, each stage having its own motor, without requiring an increasingly complex, dedicated motor cooling flow path.

SUMMARY OF THE INVENTION

[0011] An integral motor pump module is disclosed that directs the discharge of process fluid from the rotor over the surface of the motor housing, thereby reducing or eliminating any need for a separate, dedicated motor cooling flow path. In embodiments, more than 80% of the fluid that enters the module inlet is directed through a discharge path to the module outlet, and at least 20% of the motor housing is in direct contact with the discharge path. In embodiments, more than 90% of the fluid that enters the module flows from the inlet to the outlet through the discharge path, and more than 50% of the motor housing is in direct contact with the discharge path. In various embodiments, more than 80% of the motor housing is in direct contact with the discharge path.

[0012] In some embodiments, a central axis of the motor is substantially collinear with the axis of rotation of the rotor, and the discharge path surrounds the motor housing such that the process fluid from the rotor flows axially over the motor housing through an annular region formed between the motor housing and the pump housing, whereby at least 90% of an axially-centered circumference of the motor housing is in direct contact with the process fluid. In embodiments, substantially the entire circumference is in direct contact with the process fluid.

[0013] In some embodiments, the rotor in the module is fixed to a rotating shaft, while in other embodiments it rotates on bearings about a stationary shaft, which can be threaded into the motor housing and/or the pump or pump module housing. In still other embodiments, there is no shaft, and instead a wear ring clearance on the front of the impeller acts as the primary radial and axial bearing.

[0014] In embodiments, the disclosed module is implemented as a single stage pump, while in other embodiments a plurality of the disclosed modules are combined to form a multi-stage pump that is extendable to an arbitrary number of pump stages. In some of these embodiments, the motor in each stage can be independently driven, such that the rotor speed of each stage can be separately controlled.

[0015] In some embodiments, the disclosed pump module includes a radial motor design, whereby a plurality of permanent magnets are attached at or near the periphery of the rotor, and the rotor is surrounded by an electromagnet stator. In other embodiments, the disclosed module includes an axial, “disk” motor, whereby a plurality of permanent magnets are attached to a rear side of the rotor, and are caused to pass close to electromagnetic coils of an axially adjacent stator as the rotor is rotated.

[0016] Rotors in other embodiments include induction motors that utilize non-permanent magnets, such as “squirrel

cage” rotor coils in which currents are induced by the stator electromagnets during pump operation. Torque is thereby transmitted directly from the electromagnet stator coils of the motor to the rotor without the use of a rotating shaft. In embodiments, the motor coils are sealed from the working fluid using static sealing methods, which eliminates any need for dynamic mechanical seals, and avoids the problems of alignment, leakage, and/or maintenance that would otherwise arise therefrom.

[0017] Axial and radial locating of the rotor is provided in embodiments by product-lubricated bearings on each rotor stage. By using individual bearings in embodiments for each rotor stage, the bearings in each stage can be designed to handle the loads from that stage only, and the risk of overloading bearings from combined stage loading in a multistage arrangement is completely eliminated. Using the working fluid as a lubricant for the bearings in embodiments eliminates the need for an external oil lubrication system and greatly simplifies the overall pump design.

[0018] Motor cooling in embodiments directed to pumping of heated process fluid can be further augmented by including an externally cooled fluid path through which either process fluid or a separate, dedicated cooling fluid is circulated. Fluid cooling of the motor allows higher performance limits and greater power density in the overall pump.

[0019] In embodiments, the pump includes a plurality of completely modular pump stages whereby any number of the stages can be combined in series without adding additional complexity or complications to the design, operation, and maintenance of the pump. In particular, high stage counts do not raise any issues regarding shaft size, shaft deflection, rotordynamics, bearing loads, motor alignment, or alignment between stages.

[0020] Embodiments include a plurality of variable frequency drives (VFD’s), and in some of these embodiments the motor in each stage of the pump is independently controlled by a dedicated VFD. One of the key benefits in some of these embodiments is that the first stage can run at lower speeds than the rest of the pump, so as to accommodate low net positive suction head (“NPSH”) and off-peak conditions. In some applications, varying the speed of only the final stage provides a useful approach precisely controlling the output pressure and/or flow.

[0021] Providing individual VFD drives for each stage can also serve as a fail-safe redundancy, whereby if one stage fails, the rest will continue to operate and the pump will continue to function. The continued function after failure of a pump stage may be with reduced head and flow, or the speed of the remaining stages can be increased to compensate for the lost head and flow of the failed stage. This approach creates a failure scenario wherein the pump continues to operate, possibly at reduced head and flow, until an operator, after becoming aware of the stage failure, has time to safely shut down the system. In contrast, the failure of one stage in a traditional pump would result in failure of the entire pump, with a complete loss of performance and a sudden, uncontrolled shutdown of the system.

[0022] In embodiments, the motor in each pump stage is an axial disk or “pancake” style motor. Permanent magnet motors are included in some embodiments while induction motors are used in other embodiments. Some embodiments that include permanent magnet motors further include variable speed drives that enable the synchronous operating speeds of the pump stages to rise above 3600 rpm.

[0023] In various embodiments, the pump stages are centrifugal designs having radial flow impellers. Some of these embodiments include impellers with specific speeds below about 2,000 US units. Other embodiments include pump stages with radial flux motor designs and higher specific speed mixed flow impeller designs.

[0024] In embodiments, one way thrust bearings are used in place of separate axial and radial bearings. Pump stage embodiments include stationary shafts inserted through the impeller hub and threaded into the pump stage housing, which facilitates easy assembly and maintenance without special tools. Using a sensorless motor along with an appropriate VFD also reduces the instrumentation required on each stage in various embodiments.

[0025] Certain embodiments include stages having an inverted rotor/stator configuration, whereby the rotor and the stator can both rotate independently from each other in opposite directions. And some embodiments include a plurality of rotors fixed to a common fixed or rotating shaft, combined in some embodiments with stators and/or diffusers that rotate individually. In some of these embodiments, the diffusers are implemented in a manner similar to the disclosure of patent application U.S. Ser. No. 15/101,460.

[0026] A first general aspect of the present invention is a pump module having an integral motor. The pump module includes a module housing, a rotor suspended within the module housing, a front face of the rotor being oriented toward a proximal end of the pump module, a motor within the module housing, the motor being configured to drive a rotation of the rotor, the motor comprising a motor housing located within the module housing, a stator within the motor housing, the stator comprising an electromagnet directed toward the rotor, and a magnetic device fixed to the rotor and configured to pass in proximity to the electromagnet as the rotor rotates, and a process flow path extending between the module housing and the motor housing over a length of the motor housing, and over at least 20% of a surface of the motor housing, the process flow path being configured such that at least 80% of the process fluid that flows through the pump module from a module inlet to a module outlet is caused by the rotor to flow through the process flow path in direct physical contact with the motor housing.

[0027] In embodiments, the rotor is a centrifugal rotor configured to drive the process fluid from a central region thereof to a periphery thereof.

[0028] In any of the above embodiments, the rotor can be suspended by a rotatable shaft, and the rotor can be fixed to the shaft. Or the rotor can be suspended by a fixed shaft, and the rotor can be configured to rotate about the shaft. In some of these embodiments, the rotor is supported on the fixed shaft by a pair of bearings, one of which maintains an axial position of the rotor while the other of which provides radial support of the rotor. In other of these embodiments, the rotor is supported on the fixed shaft by a single, one-way thrust bearing. In any of these embodiments, the rotor can be supported on the fixed shaft by at least one bearing that is lubricated by the process fluid. In any of these embodiments, the fixed shaft can be fixed to at least one of the motor housing and the module housing. And in any of these embodiments, the fixed shaft can be fixed to at least one of the motor housing and the module housing by threaded attachment.

[0029] In any of the above embodiments, the magnetic device can be fixed to the rotor can be a permanent magnet or a squirrel cage coil.

[0030] In any of the above embodiments, the process flow path can extend over at least 50% of a surface of the motor housing, and at least 90% of the process fluid that flows through the pump module from the module inlet to the module outlet can be caused to flow through the process flow path in direct physical contact with the motor housing.

[0031] In any of the above embodiments, the process flow path can extend over at least 90% of an entire circumference of the motor housing.

[0032] In any of the above embodiments, the process flow path can be the only flow path within the pump module through which the process fluid flows from the module inlet to the module outlet.

[0033] Any of the above embodiments except the previous one can further include a cooling flow path distinct from the process flow path, the cooling flow path being configured to enable an exchange of heat between the motor housing and a cooling fluid that is lower in temperature than the process fluid flowing in the process flow path.

[0034] Any of the above embodiments can include guide vanes within the process flow path that are configured to direct flow of the process fluid through the flow path.

[0035] In any of the above embodiments, the stator can be configured to rotate independently of the rotor and in a direction that is opposite to a rotation of direction of the rotor.

[0036] Any of the above embodiments can further include a diffuser that is cooperative with the rotor but is driven by a separate diffuser motor and is thereby able to rotate independently of the rotor.

[0037] In any of the above embodiments, the motor can be a radial motor, whereby the electromagnet is directed toward a radial periphery of the rotor; and the magnetic device is fixed near the radial periphery of the rotor. Or, the motor is an axial motor, whereby the electromagnet is directed toward a distal side of the rotor; and the magnetic device is fixed to the distal side of the rotor.

[0038] A second general aspect of the present invention is a pump comprising a plurality of interconnected pump modules according to the first general aspect.

[0039] In embodiments, at least two of the motors of the pump modules can be independently controlled so as to cause the corresponding rotors to rotate at different rates. In some of these embodiments, the two, independently controlled pump modules are controlled by separate variable frequency drives. And in some of these embodiments, all of the pump modules can be independently controlled. For example, each of the pump modules can be controlled by a corresponding variable frequency drive.

[0040] In any of the above embodiments, all of the pump modules can be substantially identical to each other.

[0041] In any of the above embodiments, at least two of the rotors of the pump modules can be supported by a common shaft. And in some of these embodiments the shaft is a rotatable shaft.

[0042] The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the

specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] FIG. 1 is a cross-sectional illustration drawn to scale of a prior art two-stage integral motor pump cooled by a dedicated cooling flow;

[0044] FIG. 2A is a cross-sectional, simplified illustration of a single-stage module of the present invention having a radial motor design;

[0045] FIG. 2B is a cross-sectional illustration drawn to scale of a two-stage embodiment of the present invention having an axial motor design;

[0046] FIG. 3 is a cross-sectional illustration drawn to scale of an embodiment similar to FIG. 2, but including a separate cooling flow path (cooling path not drawn to scale);

[0047] FIG. 4 is a cross-sectional illustration drawn to scale of an embodiment similar to FIG. 2, but including guide vanes in the process flow path; and

[0048] FIG. 5 is a perspective view drawn to scale of the outer housing of the pump of FIG. 2.

DETAILED DESCRIPTION

[0049] The present invention is an integral motor pump or pump module that is configured to direct the discharge of process fluid from a rotor over the surface of the integral motor housing, thereby reducing or eliminating any need for a separate, dedicated motor cooling flow path. For example, in the embodiment of FIG. 2A, the discharge **202** from the rotor **206** is directed to pass over and around the motor housing **204** of the module, so that the motor **212** is directly cooled by the discharge of the impeller **206**, and does not require a separate, dedicated cooling fluid path.

[0050] In embodiments, more than 80% of the fluid that enters the module inlet **222** is directed through the discharge path **202** to the module outlet **224**, and at least 20% of the motor housing **204** is in direct contact with the discharge path **202**. In embodiments, more than 90% of the fluid that enters the module **200** flows from the inlet **222** to the outlet **224** through the discharge path **202** and at least 50% of the motor housing **204** is in direct contact with the discharge path **202**.

[0051] In the two-module pump **220** of FIG. 2B, a central axis of the motor **212** in each stage is substantially collinear with the stationary shaft **208** about which the rotor **206** is rotated, such that the process fluid from the rotor **206** flows axially over the motor housing **204** through an annular region **202** formed between the motor housing **204** and the pump housing **218**, whereby at least 90% of an axially-centered circumference of the motor housing **204** is in direct contact with the process fluid. In the embodiment of FIG. 2, the annular discharge flow region **202** surrounds substantially the entire circumference of the motor housing **204** in each stage, so that substantially the entire circumference of the motor housing **204** along its length and rear surface is in direct contact with the process fluid.

[0052] In the embodiment of FIG. 2A, the rotor **206** is fixed to a rotating shaft, while in the embodiment of FIG. 2B, it rotates on bearings **214** about a stationary shaft **208**, which in the embodiment of FIG. 2B is threaded into the motor housing **204**. In similar embodiment, the shaft **208** is threaded or otherwise supported by the pump or pump

module housing **218**, or by any combination of the pump or pump module housing **218** and the motor housing **204**. In still other embodiments, there is no shaft, and instead a wear ring clearance on the front of the impeller acts as the primary radial and axial bearing.

[0053] In embodiments, the disclosed module is implemented as a single stage pump, while in other embodiments, such as FIG. 2B, a plurality of the disclosed modules are combined to form a multi-stage pump. While only two stages are shown in FIG. 2B for convenience of illustration, it will be understood that embodiments are extendable to an arbitrary number of pump stages. In some of these embodiments, the rotor **206** in each stage is independently driven, such that the rotor speed of each stage can be separately controlled. For example, a separate variable frequency drive (“VFD”) **216** can be dedicated to the control of each stage of the pump.

[0054] In the embodiment of FIG. 2B, in each stage of the pump **220** a plurality of permanent magnets **210** are attached to a rear side of the rotor **206**, and are caused to pass close to electromagnetic coils **212** of an adjacent stator **214** as the rotor **206** is rotated. Rotors **206** in other embodiments include induction motors that utilize non-permanent magnets **210** such as “squirrel cage” rotor coils in which currents are induced by the stator electromagnets **212** during pump operation. Torque is thereby transmitted directly from the electromagnet motor coils **212** to the rotor **206** without the use of a rotating shaft. In embodiments, the motor coils **212** are sealed from the working fluid using static sealing methods **204**, which eliminates any need for dynamic mechanical seals, and avoids the problems of alignment, leakage, and/or maintenance that would otherwise arise therefrom.

[0055] Axial and radial locating of the rotor **206** is provided in the embodiment of FIG. 2 by product-lubricated bearings **214** in each rotor stage. By using individual bearings **214** for each rotor stage, the bearings **214** in each stage can be designed to handle the loads from that stage only, and the risk of overloading bearings from combined stage loading in a multistage arrangement is completely eliminated. Using the working fluid as a lubricant for the bearings **214** in embodiments eliminates the need for an external oil lubrication system and greatly simplifies the overall pump design.

[0056] With reference to FIG. 3, motor cooling in embodiments directed to pumping of heated process fluid can be further augmented by including an externally cooled fluid path **300** through which either process fluid or a separate, dedicated cooling fluid is circulated. Fluid cooling of the motor allows higher performance limits and greater power density in the overall pump.

[0057] With reference to FIG. 4, embodiments include guide vanes. In the illustrated embodiment, guide vanes **400** control the flow of the process fluid in a section of the flow path **202** at the end of the motor **212** that turns radially inward toward the centerline of the module. The guide vanes **400** break the flow path into a plurality of separate but symmetric passages until the flow reaches the centerline and flows axially into the next stage. In embodiments, the guide vanes **400** direct the process fluid within the flow path **202** into close proximity with the motor housing **218**. The guide vanes **400** can also provide a casing wall that can be used to route power cables from the sealed motor cavity **212**, through the fluid passages **202**, and out of the pump casing **218** to the variable frequency control **216**. In embodiments,

the guide vanes **400** can also act as fins to provide additional convective surface area to cool the motor **212**, and/or to provide space for integral cooling passages **300** connected to an external cooling fluid source.

[0058] In the embodiments of FIGS. 2B-4, the pump **220** includes a plurality of completely modular pump stages. While only two stages are shown in these figures, it can be easily seen that any number of the stages can be combined in series without adding additional complexity or complication to the design, operation, and maintenance of the pump **220**. In particular, high stage counts according to the disclosed design do not raise any issues regarding shaft size, shaft deflection, rotordynamics, bearing loads, motor alignment, or alignment between stages. FIG. 5 is a perspective view of the pump of FIG. 2.

[0059] With reference again to FIGS. 2B and 4, embodiments include a plurality of variable frequency drives (“VFD’s”) **216**, and in some of these embodiments the motor **212** in each stage of the pump is independently controlled by a dedicated VFD **216**. One of the key benefits in some of these embodiments is that the first stage can run at lower speeds than the rest of the pump, so as to accommodate low net positive suction head (“NPSH”) and off-peak conditions. In some applications, varying the speed of only the final stage provides a useful approach precisely controlling the output pressure and/or flow.

[0060] Providing individual VFD drives **216** for each stage can also serve as a fail-safe redundancy, whereby if one stage fails, the rest will continue to operate and the pump will continue to function. The continued function after failure of a pump stage may be with reduced head and flow, or the speed of the remaining stages can be increased to compensate for the lost head and flow of the failed stage. This approach creates a failure scenario wherein the pump continues to operate, possibly at reduced head and flow, until an operator, after becoming aware of the stage failure, has time to safely shut down the system. In contrast, the failure of one stage in a traditional pump typically results in failure of the entire pump, with a complete loss of performance and a sudden, uncontrolled shutdown of the system.

[0061] In the embodiment of FIG. 2A, the motor is a radial motor that includes permanent magnets mounted about the periphery of the rotor, while the embodiments of FIGS. 2B-4 include motors in each pump stage that are disk or “pancake” style motors that include permanent magnets **210** mounted on the rear surfaces of the rotors **206**. Induction motors are used in other embodiments. Some embodiments include variable speed drives that enable the synchronous operating speeds of the pump stages to rise above 3600 rpm.

[0062] In the embodiment of FIGS. 2A-5 the pump stages are centrifugal designs having radial flow impellers **206**. Some of these embodiments include impellers with specific speeds below about 2,000 US units. Other embodiments include pump stages with radial flux motor designs.

[0063] In the embodiment of FIGS. 2B-4, combined radial and one-way thrust bearings **214** are used in place of separate axial and radial bearings. The illustrated embodiments include stationary shafts **208** inserted through the hubs of the impellers **206** and threaded into the pump stage housing **218**, which facilitate easy assembly and maintenance without special tools. Using a sensor-less motor along with appropriate VFD drives **216** also reduces any requirement for instrumentation on each stage in the illustrated embodiments.

[0064] Certain embodiments include stages having an inverted rotor/stator configuration, whereby the rotor and the stator can both rotate independently from each other in opposite directions. And some embodiments include a plurality of rotors fixed to a common fixed or rotating shaft, combined in some embodiments with stators and/or diffusers that rotate individually, for example with separate motors driving the rotors and diffusers. In some of these embodiments, the diffusers are implemented in a manner similar to the disclosure of patent application U.S. Ser. No. **15/101,460**.

[0065] The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. Each and every page of this submission, and all contents thereon, however characterized, identified, or numbered, is considered a substantive part of this application for all purposes, irrespective of form or placement within the application. This specification is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of this disclosure.

[0066] Although the present application is shown in a limited number of forms, the scope of the invention is not limited to just these forms, but is amenable to various changes and modifications without departing from the spirit thereof. The disclosure presented herein does not explicitly disclose all possible combinations of features that fall within the scope of the invention. The features disclosed herein for the various embodiments can generally be interchanged and combined into any combinations that are not self-contradictory without departing from the scope of the invention. In particular, the limitations presented in dependent claims below can be combined with their corresponding independent claims in any number and in any order without departing from the scope of this disclosure, unless the dependent claims are logically incompatible with each other.

I claim:

1. A pump module having an integral motor, the pump module comprising:
 - a module housing;
 - a rotor suspended within the module housing, a front face of the rotor being oriented toward a proximal end of the pump module;
 - a motor within the module housing, the motor being configured to drive a rotation of the rotor, the motor comprising:
 - a motor housing located within the module housing;
 - a stator within the motor housing, the stator comprising an electromagnet directed toward the rotor; and
 - a magnetic device fixed to the rotor and configured to pass in proximity to the electromagnet as the rotor rotates; and
 - a process flow path extending between the module housing and the motor housing over a length of the motor housing, and over at least 20% of a surface of the motor housing, the process flow path being configured such that at least 80% of the process fluid that flows through the pump module from a module inlet to a module outlet is caused by the rotor to flow through the process flow path in direct physical contact with the motor housing.
2. The pump module of claim 1, wherein the rotor is a centrifugal rotor configured to drive the process fluid from a central region thereof to a periphery thereof.

3. The pump module of claim 1, wherein the rotor is suspended by a rotatable shaft, and the rotor is fixed to the shaft.

4. The pump module of claim 1, wherein the rotor is suspended by a fixed shaft, and the rotor is configured to rotate about the shaft.

5. The pump module of claim 4, wherein the rotor is supported on the fixed shaft by a pair of bearings, one of which maintains an axial position of the rotor while the other of which provides radial support of the rotor.

6. The pump module of claim 4, wherein the rotor is supported on the fixed shaft by a single, one-way thrust bearing.

7. The pump module of claim 4, wherein the rotor is supported on the fixed shaft by at least one bearing that is lubricated by the process fluid.

8. The pump module of claim 4, wherein the fixed shaft is fixed to at least one of the motor housing and the module housing.

9. The pump module of claim 4, wherein the fixed shaft is fixed to at least one of the motor housing and the module housing by threaded attachment.

10. The pump module of claim 1, wherein the magnetic device fixed to the rotor is a permanent magnet.

11. The pump module of claim 1, wherein the magnetic device fixed to the rotor is a squirrel cage coil.

12. The pump module of claim 1, wherein the process flow path extends over at least 50% of a surface of the motor housing, and at least 90% of the process fluid that flows through the pump module from the module inlet to the module outlet is caused to flow through the process flow path in direct physical contact with the motor housing.

13. The pump module of claim 1, wherein the process flow path extends over at least 90% of an entire circumference of the motor housing.

14. The pump module of claim 1, wherein the process flow path is the only flow path within the pump module through which the process fluid flows from the module inlet to the module outlet.

15. The pump module of claim 1, further comprising a cooling flow path distinct from the process flow path, the cooling flow path being configured to enable an exchange of

heat between the motor housing and a cooling fluid that is lower in temperature than the process fluid flowing in the process flow path.

16. The pump module of claim 1, further comprising guide vanes within the process flow path that are configured to direct flow of the process fluid through the flow path.

17. The pump module of claim 1, wherein the stator is configured to rotate independently of the rotor and in a direction that is opposite to a rotation of direction of the rotor.

18. The pump module of claim 1, further comprising a diffuser that is cooperative with the rotor but is driven by a separate diffuser motor and is thereby able to rotate independently of the rotor.

19. The pump module of claim 1, wherein the motor is a radial motor, whereby the electromagnet is directed toward a radial periphery of the rotor; and the magnetic device is fixed near the radial periphery of the rotor.

20. The pump module of claim 1, wherein the motor is an axial motor, whereby the electromagnet is directed toward a distal side of the rotor; and the magnetic device is fixed to the distal side of the rotor.

21. A pump comprising a plurality of interconnected pump modules according to claim 1.

22. The pump of claim 21, wherein at least two of the motors of the pump modules can be independently controlled so as to cause the corresponding rotors to rotate at different rates.

23. The pump of claim 22, wherein the two, independently controlled pump modules are controlled by separate variable frequency drives.

24. The pump of claim 22, wherein all of the pump modules can be independently controlled.

25. The pump of claim 24, wherein each of the pump modules is controlled by a corresponding variable frequency drive.

26. The pump of claim 21, wherein all of the pump modules are substantially identical to each other.

27. The pump of claim 21, wherein at least two of the rotors of the pump modules are supported by a common shaft.

28. The pump of claim 27, wherein the shaft is a rotatable shaft.

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