US 20110293450A1

(19) **United States**

(12) **Patent Application Publication**

Grimes et al.

(10) **Pub. No.: US 2011/0293450 A1**

(43) **Pub. Date: Dec. 1, 2011**

(54) **PUMP MAGNET HOUSING WITH INTEGRATED SENSOR ELEMENT**

(75) Inventors: **David J. Grimes**, Beaverton, OR (US); **Charles F. Carr**, Battle Ground, WA (US)

(73) Assignee: **Micropump, Inc.**

(21) Appl. No.: **13/151,188**

(22) Filed: **Jun. 1, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/396,715, filed on Jun. 1, 2010.

Publication Classification

(51) **Int. Cl.**
F04B 17/00 (2006.01)

(52) **U.S. Cl.** **417/420**

(57) **ABSTRACT**

An exemplary magnetically-driven fluid pump includes a magnet housing ("cup") that enables one or more sensors to be in indirect ("non-wetted") contact with the pumped fluid while avoiding the static seals normally required with sensors that are mounted to a fluid conduit or chamber and extend into the fluid pathway. Sensors may be used for monitoring the fluid or for feedback control of the pump. By coupling sensors directly to electronic circuits that control the pump, the number of wires located outside the motor housing is minimized, making the assembly more rugged. This is particularly advantageous in hazardous environments or submerged applications. Pumps and hydraulic systems disclosed exhibit fewer leaks under more aggressive pumping conditions and while providing improved pump performance, compared to conventional pumps and systems.

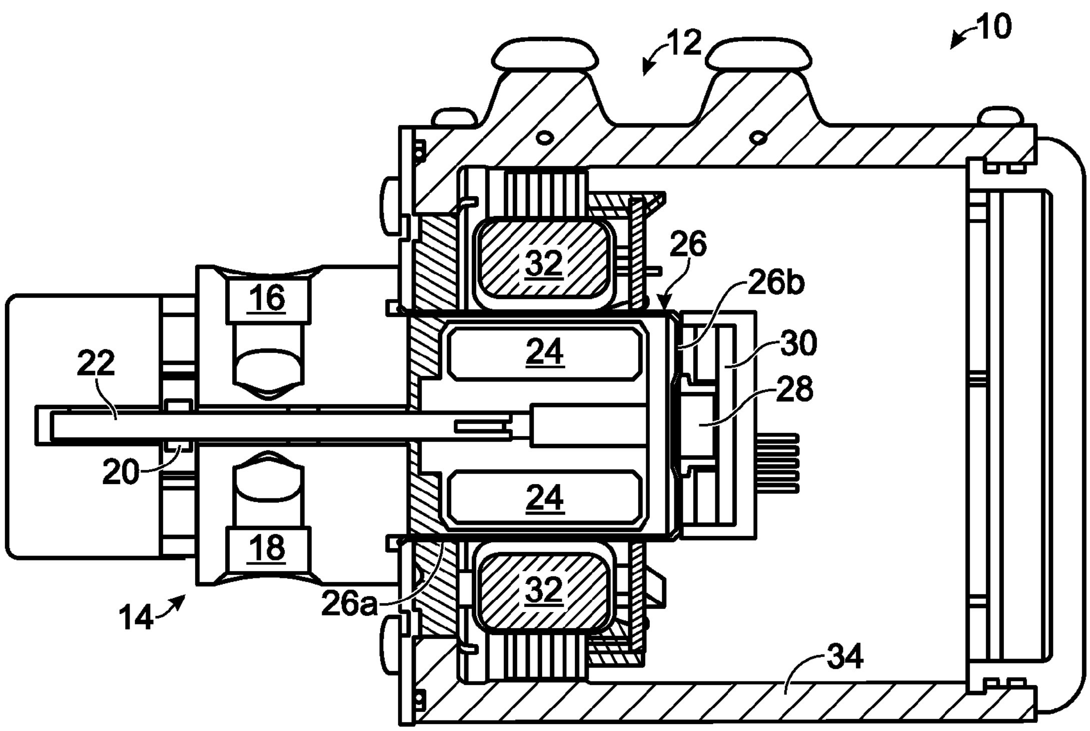

Fig. 1

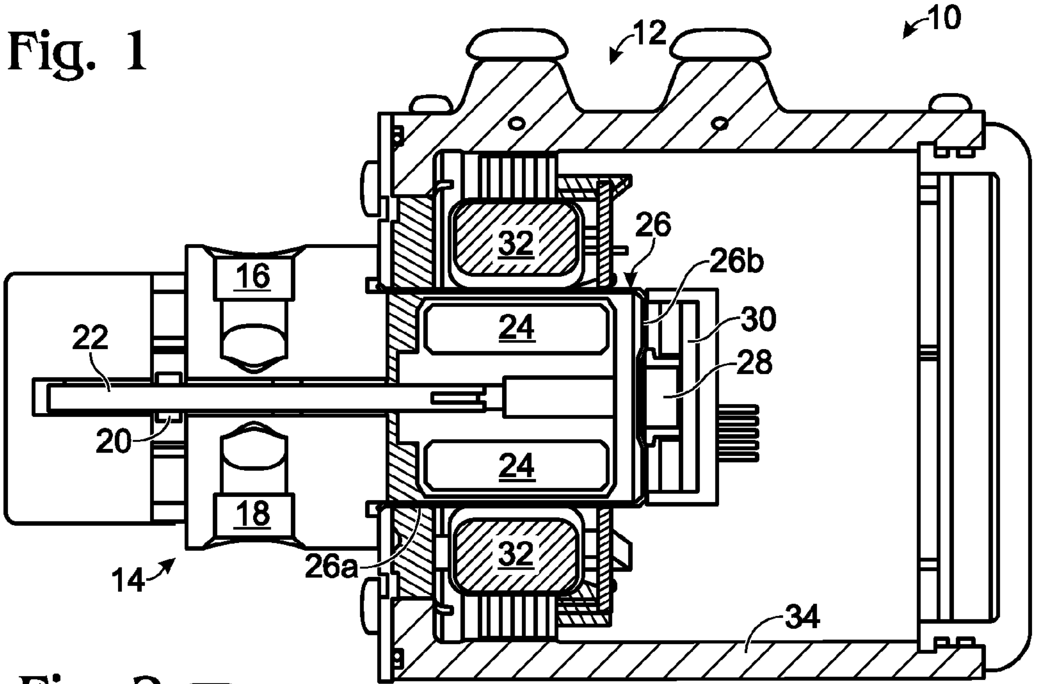
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Fig. 2

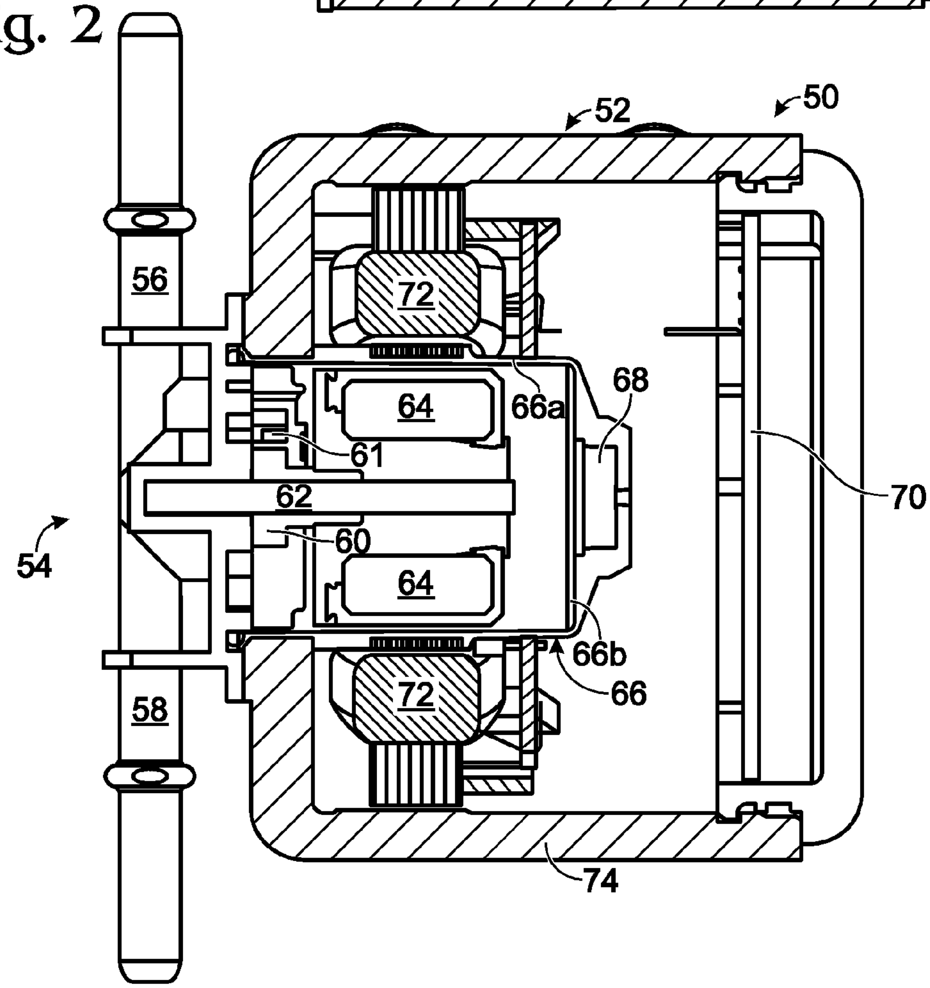
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Fig. 3

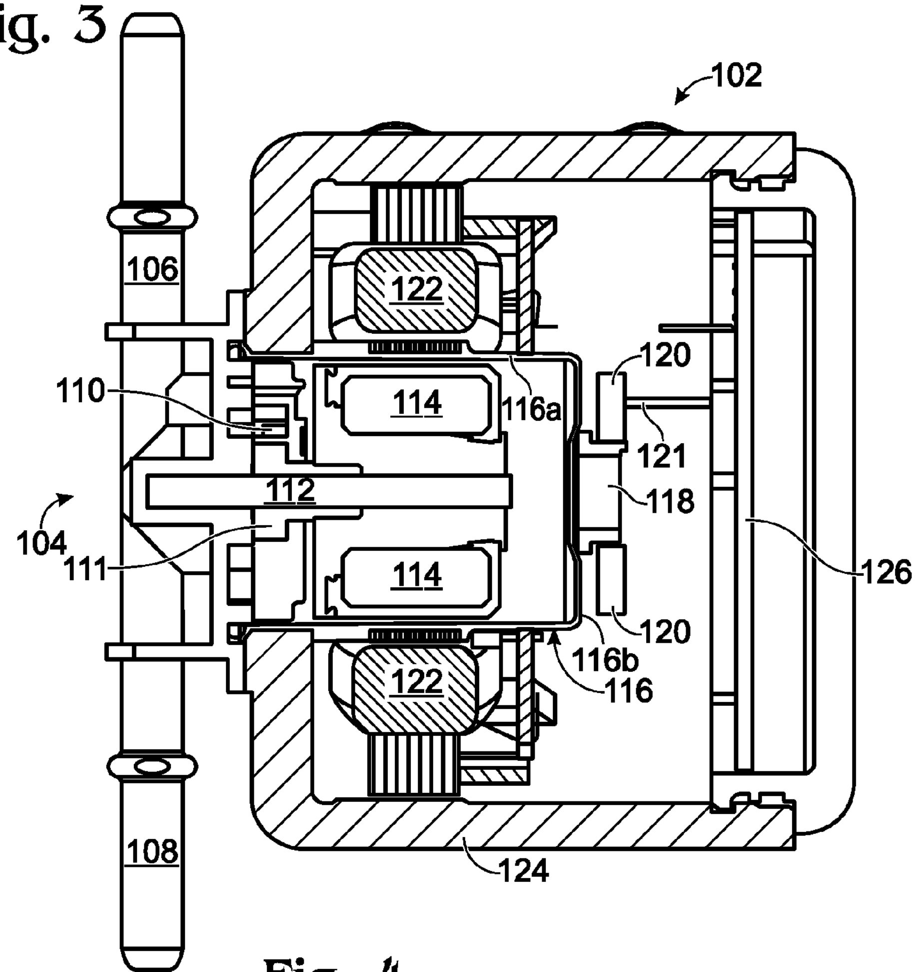
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Fig. 4

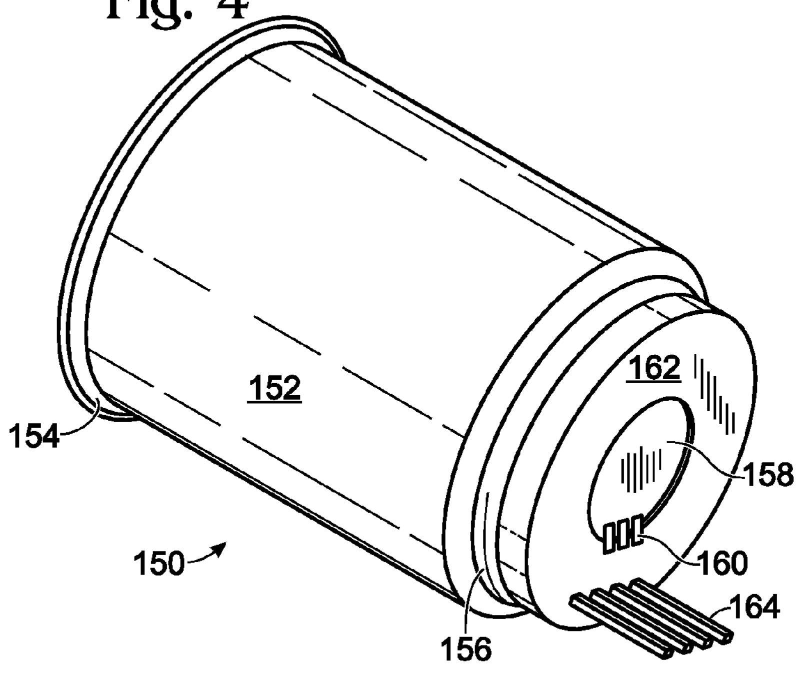
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Fig. 5

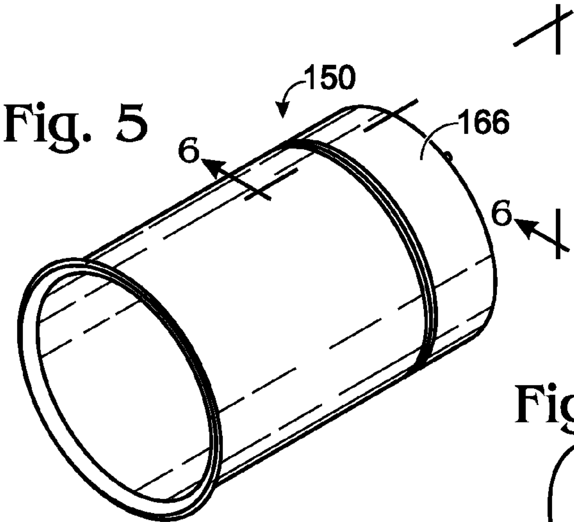


Fig. 6

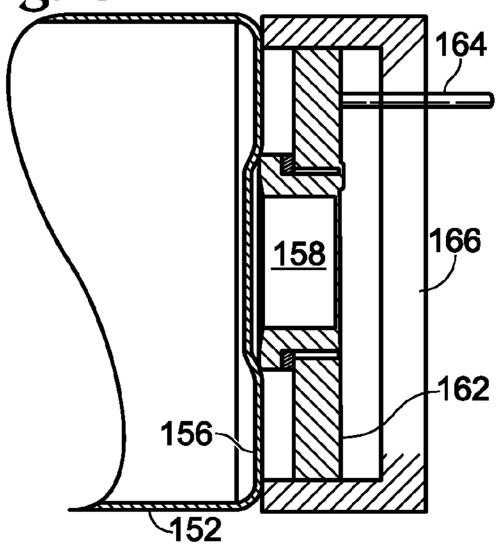


Fig. 7

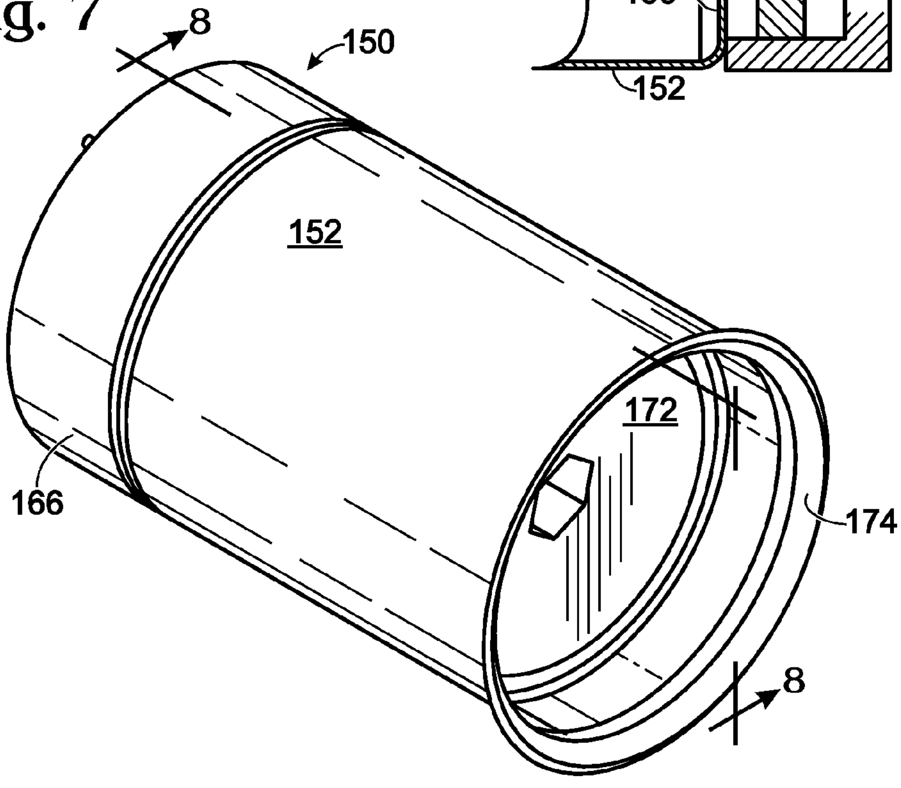


Fig. 8

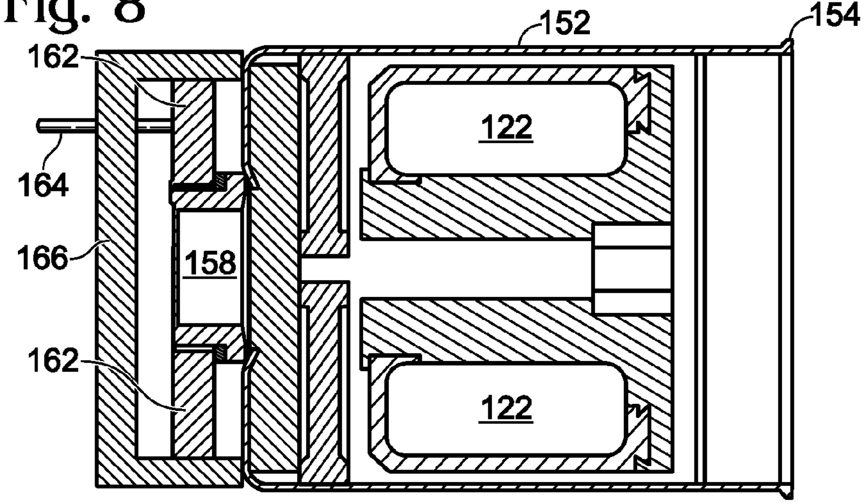


Fig. 9

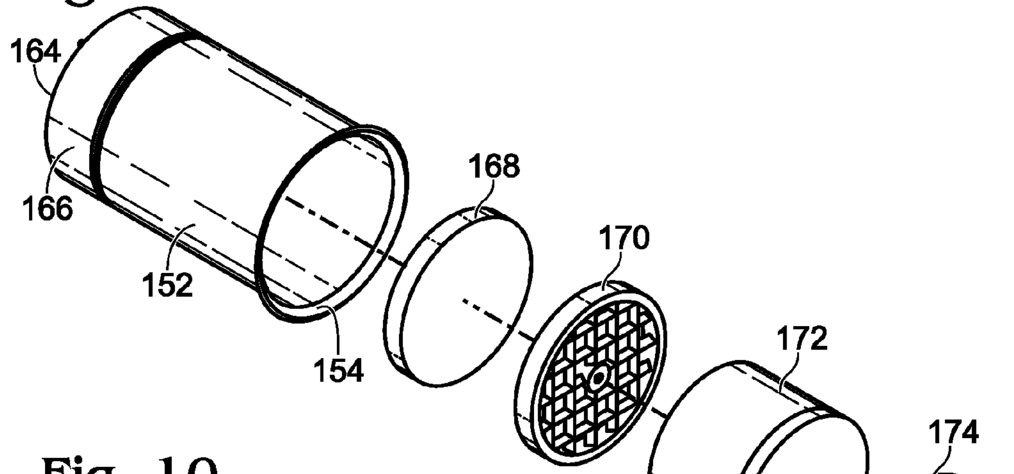


Fig. 10

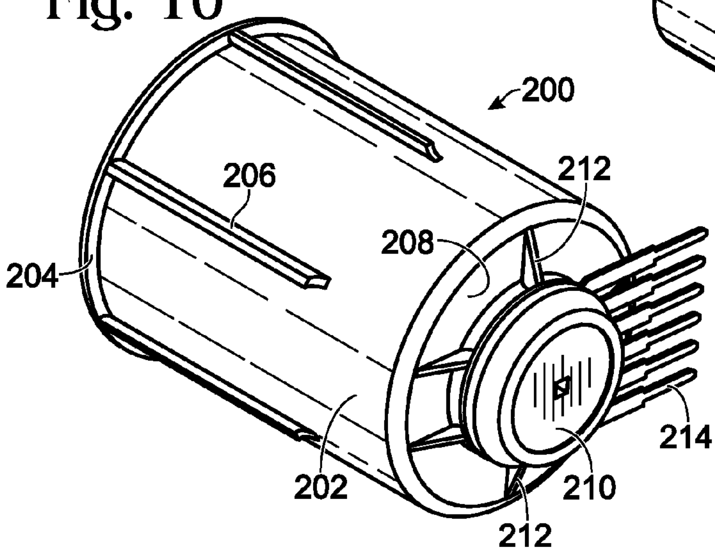


Fig. 11

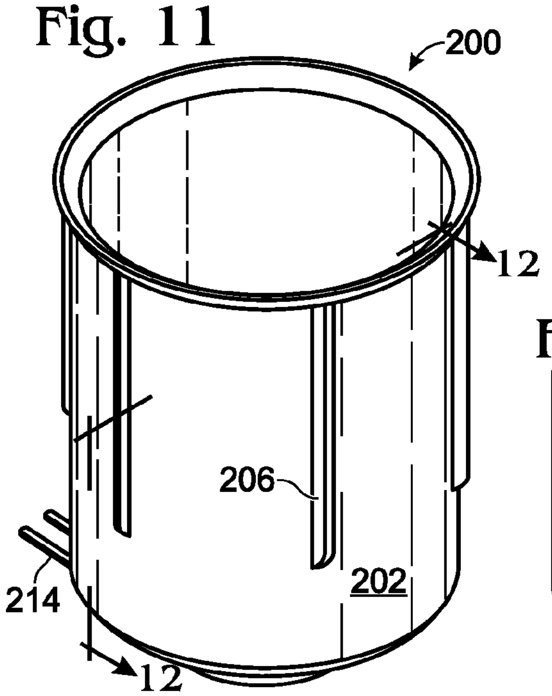


Fig. 12

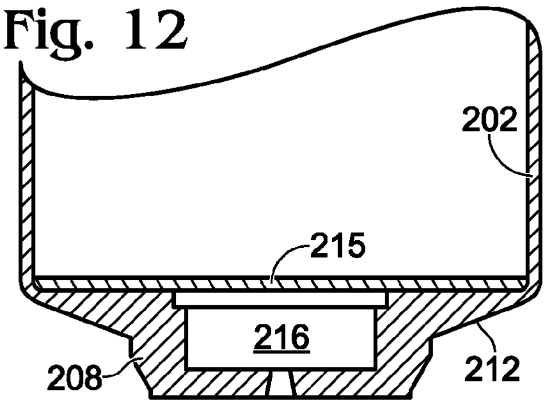


Fig. 13

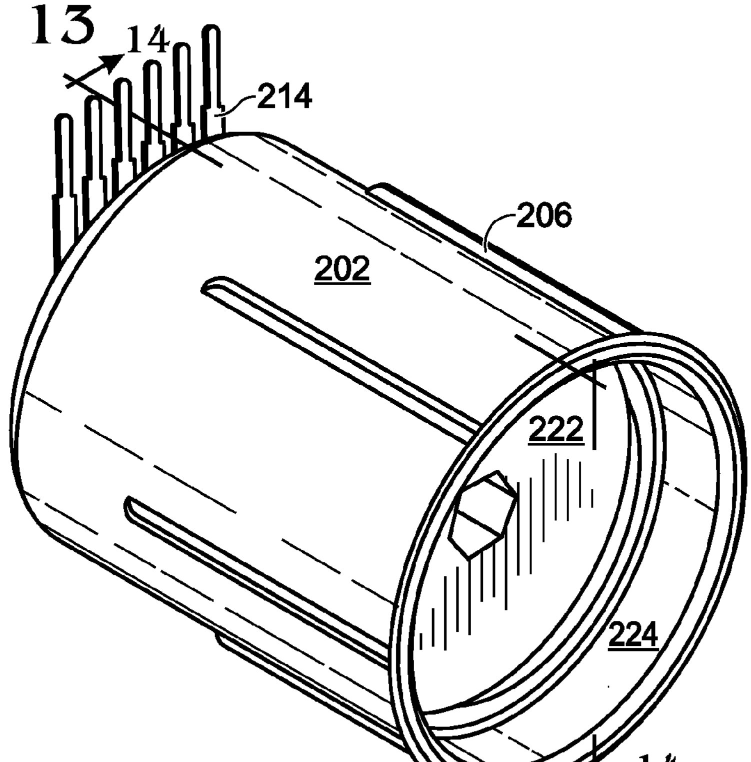


Fig. 14

Fig. 15

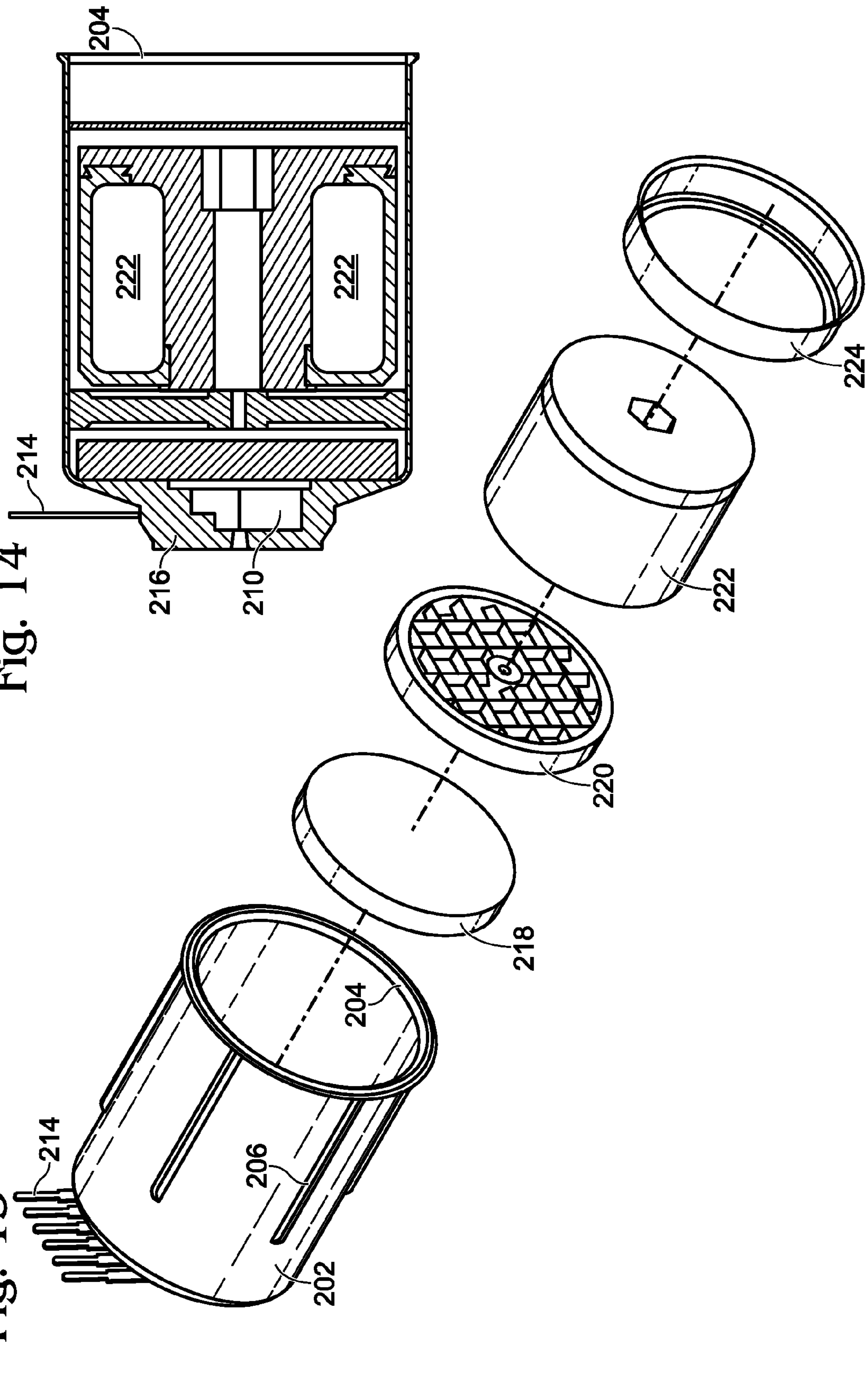


Fig. 16

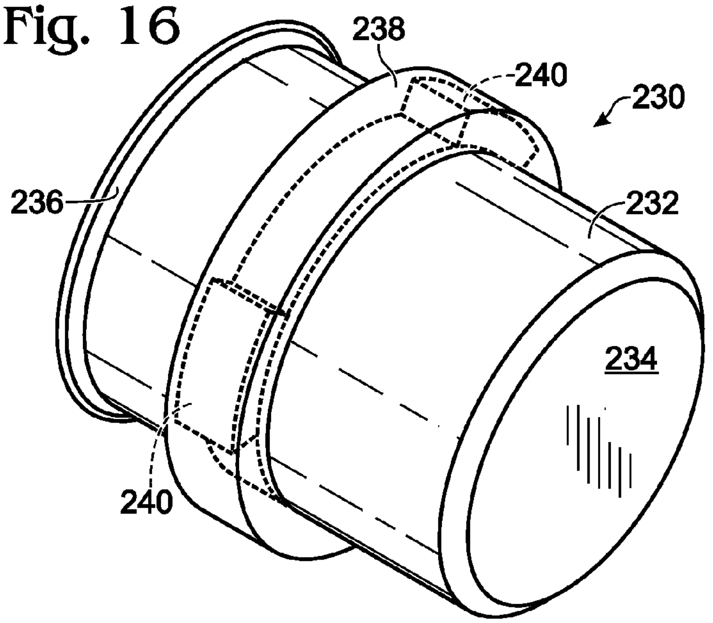


Fig. 17

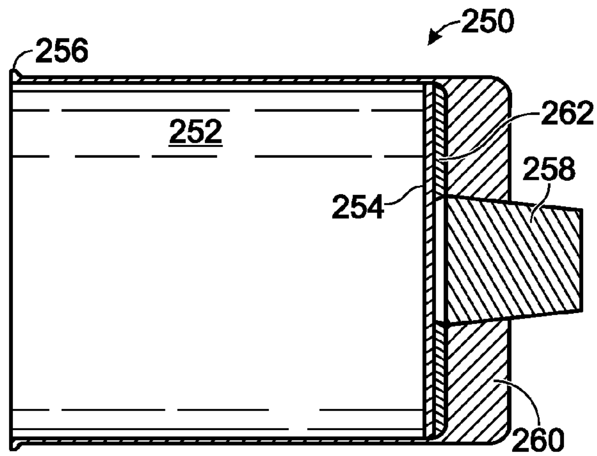
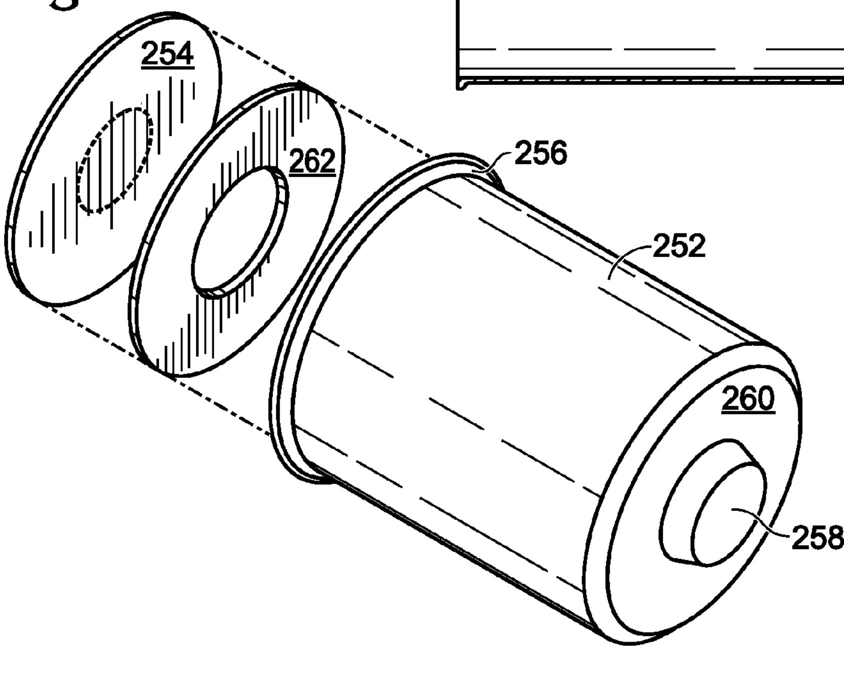
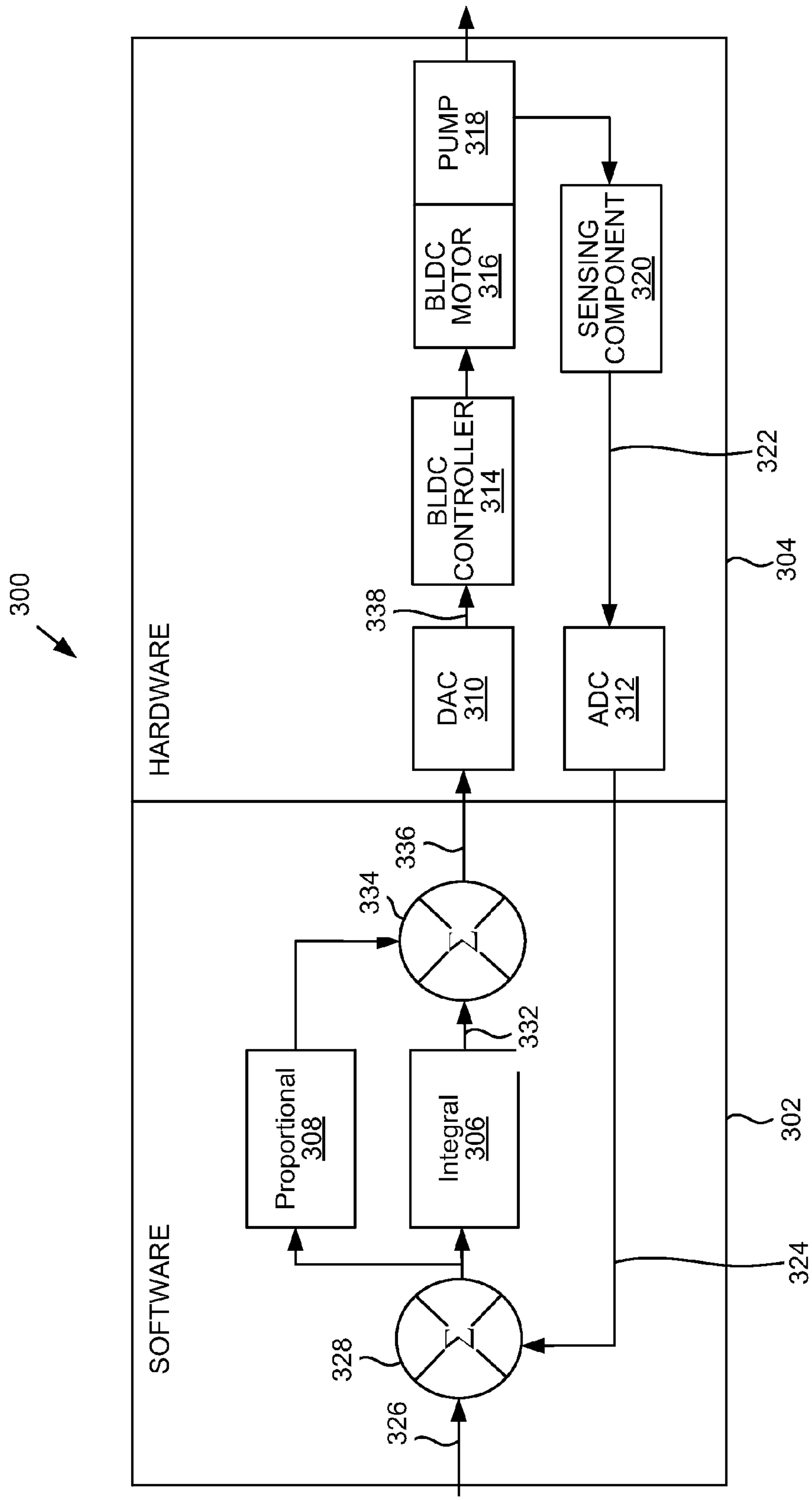


Fig. 18

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BLDC
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FIG. 19

PUMP MAGNET HOUSING WITH INTEGRATED SENSOR ELEMENT

RELATED APPLICATION

[0001] This patent application claims priority to and the benefit of U.S. Provisional Patent Application No. 61/396,715, filed on Jun. 1, 2010, which is hereby incorporated by reference in its entirety.

FIELD

[0002] This disclosure pertains to, inter alia, various types of pumps that are magnetically driven. More specifically it pertains to such pumps in which a rotary or rotary-reciprocating element, such as a pump gear, is connected to a driven magnet housed in a magnet housing ("magnet cup") in which the magnet is wetted by the fluid being pumped by the pump.

BACKGROUND

[0003] Conventional hydraulic systems often include one or more pumps for urging fluid flow. Many such systems also include sensors or indicators of any of various parameters such as pressure, temperature, conductivity, etc., of the fluid flowing in the system. Conventional indicators include Bourdon gauges, ball-flowmeters, analog thermometers, and the like that directly indicate the respective parameter. A "sensor" usually includes a transducer or the like that converts the parameter being sensed (e.g., pressure or temperature) into a corresponding signal (e.g., an electronic or optical signal). The sensor usually also includes an electronic circuit that receives data directly from the transducer and processes the data for use by other electronics as required for, e.g., providing a measure of the parameter or for use in control circuits. The measurement can be used, for example, for a display of the parameter (e.g., LED display). An example control circuit includes a controller connected and configured to perform feedback control or other control of a motor or other actuator powering a pump.

[0004] In hydraulic systems including a pump, the pump is typically a discrete stand-alone component, by which is meant that the pump is manufactured and sold separately, from other components, to original equipment manufacturers (OEMs) for incorporation into the OEM's own system, along with other components, fluid conduits, and the like. Similarly, sensors and indicators are also usually discrete components, configured and sold for use by OEMs in any of various applications. This arrangement works fine for most hydraulic circuits, particularly those in which space is not a constraining factor. However, connecting a conventional discrete component into a hydraulic circuit typically requires some kind of static seal. For permanent applications, the components can be welded into place. While usually providing an effective static seal, a component welded into place is extremely difficult or impossible to remove. For many if not most applications, static seal(s) are configured to allow a component to be removed from the system from time to time. An exemplary static seal for this purpose is an elastomeric O-ring, ring seal, gasket, or the like. Unfortunately, these and analogous types of static seals exhibit an increased probability of leaks. Leakage risk can be a serious problem in submersible systems, systems handling hazardous fluids, and systems that must operate under severe conditions or that must operate trouble-free for extremely long periods of time.

[0005] Certain applications of hydraulic circuits have demanded that components thereof, such as pumps, indicators, sensors, conduits, and the like, be miniaturized as much as possible. Other applications have demanded that components be ruggedized to a high degree. Sometimes both miniaturization and ruggedness must be achieved simultaneously. Unfortunately, increased miniaturization often works against achieving simultaneously better ruggedization. This is not only true for hydraulic systems in general but also for pumps and other components used in such systems.

[0006] Striving to reduce size of and/or to ruggedize a hydraulic system can substantially increase the difficulty of using certain discrete components such as pumps and sensors. One challenge involves the difficulty of establishing and maintaining adequate seals, such as static seals isolating the interior of a pump housing from the exterior environment or sealing around a sensor extending from outside into the hydraulic flow path. Another challenge arises from placing and connecting the components much closer together in the system. For example, placing a conventional stand-alone pressure sensor at the inlet or outlet of a miniaturized pump can result in a contorted arrangement that occupies too much space and in which the component is essentially shoe-horned into its location. These arrangements can excessively stress the components and/or their respective housings, compromise seals, and reduce the overall reliability and/or operational life of the components. In fact, requirements of small size and critical sealing can actually preclude the use of conventional fluidic sensors in a hydraulic system.

SUMMARY

[0007] Pump systems described herein were developed in the course of researching possible improvements in gear pumps used for specific applications requiring miniaturization and improved ruggedness. Specifically, including one or more sensors as part of the physical pressure barrier ("housing") of the pump provides much smaller pump-sensor combinations while mitigating the effects of any additional potential leaks by eliminating additional hydraulic connections.

[0008] For magnetically actuating a rotary pumping member (such as a combination of a driving gear and a driven gear in a gear pump), the rotary pumping member is coupled to a driven magnet configured to rotate on a longitudinal axis when driven by a magnet driver. The driven magnet is sealingly housed in a magnet housing ("magnet cup") that allows the magnet to be bathed by the pumped fluid and isolated from the external environment as the magnet is being driven. This maintains the location of driven parts of the pump within the fluid path and avoids having to use a leak-prone dynamic seal. The ability to isolate the rotor environment from the stator environment is a primary advantage of magnetically-driven pumps.

[0009] Adding sensors to a magnetically-driven pump generally poses a challenge regarding how to deal with electrical connections between the sensor and the electronics that either control operation of the pump (for a feedback control-type sensor), or that store and/or communicate data (for a fluid monitoring-type sensor). Some fluidic sensors that use wired electrical connections are designed so that the wires must pass through a hole ("through-hole") in the fluid containment wall, thus requiring a seal to prevent fluid from contacting and possibly damaging the electronics. Addition of through-holes and seals tends to make a pump less robust because each wire that enters a motor housing adds a potential leak point where moisture or environmental contaminants can gain access to the motor electronics. The incorporation of one or more sensor transducers in the magnet cup eliminates the need to use discrete component(s) to provide the sensor function(s), thereby eliminating static seal(s) that otherwise would be required. Certain embodiments of magnet cups disclosed herein enable one or more sensors to be in indirect contact with the pumped fluid while avoiding the static seals normally required with sensors that are mounted to a fluid conduit or chamber and extend into the fluid pathway.

[0010] In addition, the volume of space that otherwise would be occupied by housing(s) of the stand-alone component(s) is reduced, resulting in a substantially more compact assembly. By incorporating sensor electronics on a printed circuit board mounted to the outside of the distal-end wall of the magnet cup, for example (with the sensor transducer being mounted to the circuit board and sensing its respective parameter through the wall of the magnet cup), the assemblies are made more compact and more reliable. In this way, the sensor electronics can be coupled directly, with minimal or no external wiring, to motor-control electronics located, for example, on a printed circuit board situated inside a housing containing a magnet-driving stator. By incorporating the sensor(s) in the wall of the magnet cup, because fewer wires are located outside the motor housing, the entire pump assembly is more rugged than conventional pump systems. This is particularly advantageous in hazardous environments or submerged applications.

[0011] Although the exemplary embodiments shown herein are gear pumps, pumping systems consistent with the disclosed sensing devices are not limited to gear pumps. Rather, they include any of various types of pumps having at least one movable pump element contained in a housing and coupled to a permanent magnet that is driven by magnetic forces that originate outside the housing and are directed at the magnet through walls of the housing. The magnet is normally contained in a portion of the housing called a magnet housing or magnet cup. In pumps in which the movable element is a rotary element, the magnet and magnet cup are configured so that the magnet, when placed in a rotating magnetic field, rotates in the magnet cup about a longitudinal magnet axis. To such end the driven magnet usually has a substantially cylindrical shape and the magnet cup has a substantially hollow cylindrical (can-like) configuration that contains the driven magnet. The driven magnet can be driven by a driving magnet coupled to the armature of a motor, or by a driving stator located outside the magnet cup. Lines of magnetic force produced by the driving magnet or by the stator pass through the wall of the magnet cup and inductively couple to the driven magnet. During running of the pump, these lines of magnetic force are directed so as to urge rotation of the driven magnet about its axis, which causes rotation of the rotary pump element. In a gear pump, the rotary pump element is termed a "driving gear" that is interdigitated with a corresponding driven gear. As the driving gear rotates, it causes corresponding contra-rotation of the driven gear. The combined gear rotations produce a pumping force. The gear pump can be, for example, what is conventionally known as a "cavity style" or can include, for example, a "suction shoe," or can be a hybrid of these.

[0012] Another type of pump involving a movable pump element coupled to a driven magnet is a piston pump. In some configurations of piston pumps, the piston undergoes both rotary and linearly reciprocating motion as driven magnetically. Other exemplary types of pumps include centrifugal pumps, lobe pumps, or pumps that have a pressure-compliant member inside the housing.

[0013] As noted above, the pump housing constitutes the physical pressure barrier of the pump, i.e., the physical barrier separating the inside of the pump from its external environment (and vice versa). Escape of fluid from inside the pump housing across the physical barrier constitutes a leak. The pumps and hydraulic systems described herein exhibit fewer leaks under more aggressive pumping conditions, while providing improved pump performance over longer periods of time, compared to conventional pumps and systems.

[0014] Since the magnet cup constitutes a portion of the pump housing, in many embodiments of the invention at least one sensor is integrated into a wall of the magnetic cup so as not to be wetted by the pumped fluid. Such an "integral sensor" is associated with the magnetic cup in such a way that it functions essentially as a part of the cup instead of as a separate, discrete component. The integrated sensor is any of various sensors that can quantitatively react to their respective parameters as sensed across a wall or portion of a wall of the magnet cup, or a cross a wall or other fluid barrier coupled to a wall of the magnet cup. The sensor(s) can be one or more of pressure sensors, temperature sensors, or other sensors such as, for example, conductivity sensors, resistivity sensors, turbidity sensors, flow-rate (viscosity) sensors, pH sensors, dissolved gas sensors, or sensors of other fluidic variables such as turbidity, dissolved ions, and optical absorption, or sensors that detect rotation of elements of the pump motor. A conductivity sensor can be used, for example, to shut a pump down in the event of a "running dry" condition. A rotation sensor can be used, for example, if a motor controller is sensorless, to sense rotation direction or whether rotation of a pumping element is occurring at all. An example rotation sensor is based on the Hall effect. A dissolved gas sensor can be used to control a degassing system. Exemplary sensor types include strain gauge sensors, capacitive sensors, resistive sensors, piezoelectric sensors, and electrodes such as ion-specific electrodes. The sensors can be connected to other electronics by conventional conductors (wires, pins, and the like) or, if permitted by the type and general configuration of the sensor, by wireless connections. Other Hall-effect sensors detect mechanical motion of one or more internal magnetic elements. Inductive sensors include, for example, a voice coil for measuring acoustic signals and/or fine-positioned displacements. Another exemplary inductive sensor receives and/or transmits RF signals.

[0015] Although embodiments shown herein describe sensors as being mounted to a distal-end wall of the magnet cup, the location of sensors is not limited to a particular wall of the magnet cup, or even to a magnet cup at all. For example, sensor(s) can be located at either the pump-inlet region of the magnet cup (for sensing, e.g., inlet pressure) or the pump-outlet region of the magnet cup (for sensing, e.g., outlet pressure). Exemplary mounting arrangements of the sensor to a wall of the magnet cup or other region of the pump housing, thus producing an integral sensor, include direct welded, separate membrane welded, over-molded, adhesive-mounted, statically sealed in place, clamped, mechanically joined, and integrated directly into the wall by molding or casting. Many types of sensors do not actually contact the fluid in the pump. For example, a strain-gauge based pressure sensor is capable of sensing pressure through the wall of a thin-walled magnet cup or through a localized thinner region of a magnet cup. Such a sensor transducer can be coupled directly to an “unpierced” wall of the magnet cup. A desirable method for mounting a capacitive sensor is resistance welding to a wall (e.g., the distal end wall) of a non-magnetic metal or injection-molded polymeric magnet cup.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a coronal section of an embodiment of a magnetically-driven pump comprising a pump head and a housing. A sensor transducer is integrated into a wall of the magnet cup and directly connected to a circuit board.

[0017] FIG. **2** is a coronal section of an embodiment of a compact magnetically-driven pump, comprising a pump head and a housing. A sensor transducer is disposed in a dry cavity within the wall of the magnet cup so as not to be wetted by the fluid being pumped. The integral sensor transducer may be wired directly to a nearby circuit board or it may communicate wirelessly with nearby electrical components.

[0018] FIG. **3** is a coronal section of an embodiment of a compact magnetically-driven pump comprising a pump head and a housing. A sensor transducer is integrated into a wall of the magnet cup, and a dry sidewall portion of the sensor transducer is directly connected to a circuit board.

[0019] FIG. **4** is a first perspective view of an exemplary embodiment of a magnetic cup, as used for example in the embodiment shown in FIG. **3**, in which the integral sensor transducer is directly connected to an annular circuit board.

[0020] FIG. **5** is a second perspective view of the magnetic cup shown in FIG. **4**.

[0021] FIG. **6** is a first cross-sectional view showing components at the distal end of the magnetic cup shown of FIG. **4**.

[0022] FIG. **7** is a third perspective view of the magnetic cup shown in FIG. **4**, also showing the driven magnet in situ.

[0023] FIG. **8** is a second cross-sectional view of the magnetic cup shown in FIG. **4**, also showing the driven magnet in situ.

[0024] FIG. **9** is an exploded perspective view showing coaxial components of the magnetic cup of FIG. **4**.

[0025] FIG. **10** is a first perspective view of an alternative embodiment of the magnetic cup shown in FIG. **2**.

[0026] FIG. **11** is a second perspective view of the magnetic cup shown in FIG. **10**.

[0027] FIG. **12** is a first cross-sectional view of the distal end of the magnetic cup shown in FIG. **10**, in which a sensor transducer can be disposed within a dry cavity in the distal end wall of the magnetic cup and conveniently wired to a nearby printed circuit board.

[0028] FIG. **13** is a third perspective view of the magnetic cup shown in FIG. **10**, showing the driven magnet in situ.

[0029] FIG. **14** is a second cross-sectional view of the magnetic cup shown in FIG. **10**, including a sectional view of the driven magnet.

[0030] FIG. **15** is an exploded view showing coaxial components of the magnetic cup of FIG. **13**.

[0031] FIG. **16** is a perspective view of an embodiment of the magnet cup in which sensor(s) are integrated into the side wall.

[0032] FIG. **17** is a side elevation view of an embodiment of the magnet cup in which a sensor is integrated into the distal end of the magnet cup using a static seal.

[0033] FIG. **18** is an exploded view of the magnet cup and sealed-sensor embodiment shown in FIG. **17**.

[0034] FIG. **19** is a block diagram showing hardware and software components of an exemplary feedback-control system that may be used to monitor and control a fluid pump.

[0035] The foregoing and additional objects, features, and advantages of the invention will become more apparent from the following detailed description, which proceeds with reference to the accompanying figures.

DETAILED DESCRIPTION

[0036] FIG. **1** depicts an embodiment of a pump assembly **10** including a driver portion **12** and a pump head **14**. The pump head **14** includes an inlet port **16**, an outlet port **18**, a driving gear **20**, a shaft **22**, a driven magnet **24**, and a magnet cup **26**. The magnet cup **26** is internal to the driver portion **12**. The magnet cup **26** has side walls **26*a*** and a distal-end wall **26*b*** that surround and are coaxial with the driven magnet **24**. The side walls **26*a*** and distal-end wall **26*b*** serve to isolate the driven magnet **24** (which, along with the pump head **14**, is generally bathed in the fluid being pumped) from electrical parts of the assembly that are kept “dry,” i.e., not wetted by the fluid being pumped. The fluid-wetted interiors of the pump head **1**A and magnet cup **26** comprise a “pump housing.” Coaxially surrounding the magnet cup **26** is a stator **32**, located outside the pump housing, that is magnetically coupled to the driven magnet **24** across the side walls **26*a*** of the magnet cup. The stator **32** is contained in an enclosure **34**. The enclosure **34**, being outside the pump housing, is “dry.” In the embodiment shown in FIG. **1**, the enclosure **34** and pump head **14** are mounted end-to-end so that a large part of the pump head **14** extends from the driver portion **12**.

[0037] Mounted to the distal-end wall **26*b*** is a sensor transducer **28**, comprising a parameter-sensitive surface (i.e., a surface that responds in a measurable way to the parameter to which the sensor is sensitive). In this embodiment, the sensor transducer **28** is sealingly mounted with its parameter-sensitive surface facing the driven magnet **24**. The phrase “sealingly mounted” means that the sensor transducer **28** is held in a position so as to maintain contact with at least a portion of the mounting surface at one or more contact points at which a barrier prevents fluid from passing through or across the surface. The barrier may take the form of, for example, the surface itself, an o-ring, an absorbent material, an adhesive material, or the like. As a purchased component, the sensor transducer **28** may be a type capable of being operated while in contact with (wetted by) fluid. But, in the various embodiments discussed herein, the sensor transducer desirably also is capable of being operated (or is configured specifically for operation) in a dry condition, i.e., without being wetted by the pumped fluid. At least the parameter-sensitive surface can be incorporated into a wall of the magnet cup. The sensor transducer **28** in this embodiment is electrically connected directly to a printed circuit board **34** situated outside the magnet cup **28**. The printed circuit board **30** contains an electronic circuit that, for example, receives transducer signals from the sensor transducer **28** and conditions the transducer signals for use by other electronics (not shown), such as driver electronics for the stator **32**. For example, the transducer signals can be used for feedback control of the driver electronics for the stator **32**.

[0038] FIG. **2** depicts another embodiment of a pump assembly **50** configured to occupy less space than the embodiment shown in FIG. **1**. The pump assembly **50** comprises a driver **52** and a pump head **54**. The pump head **54** includes an inlet port **56**, an outlet port **58**, a driving gear **60**, a driven gear **61**, a shaft **62** to which the driving gear is axially affixed, a driven magnet **64**, and a magnet cup **66**. The magnet cup **66** has side walls **66***a* and a distal-end wall **66***b* that surround and are coaxial with the driven magnet **64**. Mounted to the distal-end wall **66***b* is a sensor transducer **68**. The sensor transducer **68** is mounted such that its parameter-sensitive surface faces the interior of the magnet cup so as to sense its respective parameter through the distal-end wall **66***b*. Other portions of the sensor transducer **68** extend from the magnet cup **66**. The sensor transducer **68** is electrically connected to a printed circuit board **70**. Coaxially surrounding the magnet cup **66** is a stator **72** that is magnetically coupled to the driven magnet **64** across the side walls **66***a* of the magnet cup. The stator **72** is contained in an enclosure **74**, which also contains the printed circuit board **70**. The sensor transducer **68** can be connected to the PCB **70** by wiring (not shown). Alternatively, the sensor transducer **68** can be coupled to the PCB **70** wirelessly using, for example, radio frequency (RF) or infrared (IR) signals for delivering data to the PCB **70**. The printed circuit board **70** desirably has not only electronics that receive and condition transducer signals from the sensor transducer **68** but also driver electronics for the stator **72**. In this embodiment, a portion of the pump housing is located inside a thick wall of the enclosure **74**, which reduces the relative volume occupied by the pump assembly **50**.

[0039] FIG. **3** depicts another embodiment of a pump assembly **100** also configured to occupy reduced volume. The pump assembly **100** comprises a driver **102** and a pump head **104**. The pump head **104** includes an inlet port **106**, an outlet port **108**, a driven gear **110**, a driving gear **111**, a shaft **112** axially coupled to the driving gear **111**, a driven magnet **114**, and a magnet cup **116**. The magnet cup **116** has side walls **116***a* and a distal-end wall **116***b* that surround and are coaxial with the driven magnet **114**. Mounted to the distal-end wall **116***b* is a sensor transducer **118**. The sensor transducer **118** is mounted such that its parameter-sensitive surface faces the driven magnet **114** without being wetted by the pumped fluid normally in the magnet cup. Other portions of the sensor transducer **118** extend from the magnet cup to a first printed circuit board **120**. Coaxially surrounding the magnet cup **116** is a stator **122** that is magnetically coupled to the driven magnet **114** across the side walls **116***a* of the magnet cup. The stator **122** is situated within an enclosure **124**, which also contains the first printed circuit board **120** to which the sensor transducer **118** is mounted. The first printed circuit board **120** is connected to a second printed circuit board **126** by conductive pins **121**. The first printed circuit board **120** contains electronics that receive and condition transducer signals from the sensor transducer **118**, and the second printed circuit board **126** contains driver electronics for the stator **122**. In this embodiment the pump head **104** extends at least partially into the wall of the enclosure **124**, which reduces overall volume occupied by the pump assembly **100**.

[0040] The magnet cup **116** can be made of any of various rigid materials that are not magnetic. For example, the magnet cup **116** can be made of a non-magnetic metal or metal alloy, in which event the magnet cup can be formed by machining, deep-drawing, casting, or the like. As another example, the magnet cup can be made of a polymeric or copolymeric material formed by machining or molding, for example. The polymeric or copolymeric material can be reinforced using fibers, particles, or other suitable non-magnetic material. A polymeric magnet cup may be transparent or translucent to selected wavelengths of electromagnetic radiation so as to enable a non-wetted sensor to detect, across the wall of the magnet cup, optical properties or variation in such properties of the fluid being pumped.

[0041] An exemplary embodiment of a magnet cup **150** made of metal is shown in FIG. **4**, in which the depicted cup includes a cylindrical body **152**. The body **152** includes a proximal mounting flange **154** for mounting the cup to a pump head (see FIG. **3**). The body **152** also includes a distal-end plate **156** to which a sensor transducer **158** is bonded such that the parameter-sensitive surface of the transducer faces the interior of the magnet cup. The opposing (outward facing) surface of the sensor transducer **158** is visible in the drawing, connected by pins **160** to an annular circuit board **162**. The circuit board **162** includes male connector pins **164** by which the circuit board is electrically connected to other electronics located on a separate circuit board (not shown). The magnet cup **150** of FIG. **4**, also shown in a different perspective view in FIG. **5**, is similar to the magnet cup **26** shown in FIG. **1** and the magnet cup **116** shown in FIG. **3**. A cross-sectional view along cut lines shown in FIG. **5** provides some additional detail, for example purposes, as shown in FIG. **6**. Depicted in FIG. **6** are the cylindrical body **152**, the distal-end plate **156** of the magnet cup **150**, the sensor transducer **158**, the printed circuit board **162**, and connecting pins **164**. Also shown in the figure is a cover **166** configured to fit over the sensor transducer **158** and circuit board **162**, with provision for the pins **164** to extend through the cover **166**. Note that the cup **150** shown in FIG. **4** is similar to the cup of FIG. **6**, but lacks the cover **166** shown in FIG. **6**. Similarly, the cup **26** shown in FIG. **1** includes a cover, while the cup **116** shown in FIG. **3** lacks the cover.

[0042] In the embodiment of FIG. **6**, the sensor transducer **158** is sealingly integrated into the distal-end plate **156**, such that the sensor transducer **158** remains in contact with, and surrounded by, the annular printed circuit board **162**. This allows electrical signals from the sensor transducer **158** to be directly connected to hardware components on the circuit board **162** via the pins **160** (see FIG. **4**) without the need for separate connecting wires and associated through-holes. The sensor transducer **158** is integrated with the dry side of a thin plate **156**, which forms a barrier between wet and dry environments, while still allowing the sensor transducer **158** to detect one or more fluidic parameters of interest. Placing the sensor transducer **158** adjacent a wet surface prevents direct contact with pumped fluid such that the sensor transducer **158** operates as a "non-wetted" sensor. The integration of the sensor transducer **158** with the plate **156**, and the direct connection of the sensor transducer to the circuit board **162** form a mechanically rigid unit that is more likely to ensure the integrity of electrical continuity for reliable transmission of sensor data.

[0043] FIG. **7** is another perspective view of the magnet cup **150**, including the cover **166**. A cross section of the magnet cup **150** and driven magnet **122** is shown in FIG. **8**. FIG. **9** is an exploded view of the magnet cup **150** showing features used for making the interior of the magnet cup **150** pressure-compliant. See U.S. Patent Application Publication No. US 2009-0060728 filed on Aug. 29, 2008, incorporated herein by reference, particularly the embodiments of pressure-absorbing members shown in FIGS. 1E, 2, 3, 4A, 4B, and 5, and the accompanying discussion in paragraphs 42-48 and 53-60 of that reference. These features include a plug 168 (made of, e.g., fluorosilicone foam) and retainer 170. Also shown are the driven magnet 172 and a retainer shoe 174.

[0044] An exemplary embodiment of a magnet cup **200** made of a molded rigid polymer material is shown in FIG. **10**, in which the depicted cup includes a cylindrical body **202**. The body **202** includes a proximal mounting flange **204** for mounting the cup to a pump head (not shown). The body **202** also includes stiffening ribs **206** and a distal-end wall **208** in which a sensor transducer **210** is bonded such that a parameter-sensitive surface of the transducer faces the interior of the magnet cup. The distal-end wall **208** also includes stiffening ribs **212**. The sensor transducer **210** comprises pins **214** by which the sensor transducer is electrically connected to a circuit board (not shown). The magnet cup **200** of FIG. **10** is otherwise similar to the magnet cup **66** shown in FIG. **2**.

[0045] Details of the magnet cup **200** are shown in FIGS. **11** and **12**, in which a portion of the body **202** is shown along with the distal-end wall **208**. The distal-end wall **208** defines a cavity **216** in which the sensor transducer **210** is sealingly mounted (e.g., by use of adhesive) so that the sensor transducer **210** operates as a non-wetted sensor. FIG. **13** shows another perspective view of the magnet cup **200**, and a cross section of the magnet cup **200** is shown in FIG. **14**. Further details are provided in FIG. **15**, including certain features used for making the interior of the magnet cup **200** pressure-compliant. These features include a plug **218** (made of, e.g., fluorosilicone foam) and retainer **220**. Also shown are the driven magnet **222** and a retainer shoe **224**.

[0046] FIG. **16** shows an alternative embodiment of a magnetic cup **230** that includes a a side wall **232**, a distal-end wall **234**, a proximal mounting flange **236**, and an assembly **238** of one or more non-wetted sensors **240**. In this embodiment, the sensor assembly **238** is integrated into the side wall **232** instead of being integrated into the distal-end wall **234**. Individual sensors **240** may be disposed in a ring around the circumference of the magnetic cup **230** such that they protrude above the surface of the cup **230**. Alternatively, the sensors **240** may be configured as mini- or micro-mechanical sensors disposed within or on the surface of the body **232**. The sensor assembly **238** may be configured as a narrow ring as shown, a wide ring, or an outer cylinder that is coaxial with side wall **232**.

[0047] FIGS. **17** and **18** show an alternative embodiment of a magnetic cup **250**, that includes a side wall **252**, a distal-end wall **254** that may be thicker than the side wall **252**, a proximal mounting flange **256**, and a non-wetted sensor **258**. In this embodiment, the sensor **258** may be inset into the distal-end wall **254** and held in place by a cover **260** and a seal **262**. The seal **262** may be an adhesive, a gasket, an o-ring, or the like.

[0048] FIG. **19** shows an exemplary feedback control system **300** for a self-modulating pump assembly that includes one or more sensing components as described above. For example, the feedback control system **300** may be used to maintain a prescribed temperature or pressure associated with the pump assembly. As discussed above, all components of the control system can be located in the pump assembly without the need for additional housings, wiring, or seals. Shown are software and hardware portions, **302** and **304**, respectively. The exemplary software portion **302** includes an integral controller **306** and a proportional controller **308** typically used in feedback-control systems. The exemplary hardware portion **304** includes a digital-to-analog converter (DAC) **310**, an analog-to-digital converter (ADC) **312**, a motor controller (BLDC) **314** for driving the motor stator (BLDC motor) **316**, and thus the pump **318**, and at least one sensing component **320**.

[0049] To provide feedback control to the pump **318** based on measurements obtained by the sensing component **320**, a measured feedback signal **322** from the sensing component **320** is converted by the ADC **312** into a first digital feedback signal **324** that can be processed by the software portion **302**. Additional data may be combined with the first digital feedback signal **324** from an external source by a second digital feedback signal **326**. A first multiplexer **328** combines the digital feedback signals **324**, **326** for processing by the controllers **306**, **308**. A proportional control signal **330** and an integral control signal **332** may then be combined by a second multiplexer **334** to form a composite control signal **336**. The composite control signal **336** may then be transmitted to the DAC **310** for conversion into an analog control signal **338**. The analog control signal **338** may then be processed by the BLDC controller **314**, and subsequently delivered at an appropriate time to the motor **316** for controlling the performance of the pump **318**.

[0050] In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope and spirit of these claims.

We claim:

1. A pump assembly, comprising:

a pump head including a sealed pump housing;

a movable pumping member situated inside the pump housing;

a driven magnet connected to the pumping member so that induced motion of the driven magnet causes corresponding induced motion of the pumping member;

a magnet housing being a respective portion of the pump housing and containing the driven magnet so that the induced motion of the driven magnet occurs in the magnet housing, the driven magnet and interior of the magnet housing being wetted by fluid being pumped by induced motion of the pumping member;

at least one sensor element sealingly mounted with respect to a wall of the magnet housing such that the sensor is not wetted by the fluid; and

a magnet-driver situated outside the magnet housing and being magnetically coupled to the driven magnet such that a changing magnetic field produced by the magnet-driver induces motion of the driven magnet and hence of the pumping member in the housing.

2. The pump assembly of claim **1**, wherein the sensor element is integral to the wall of the magnet housing.

3. The pump assembly of claim **1**, wherein the sensor element is sealingly mounted in the wall.

4. The pump assembly of claim **1**, wherein the sensor element is sealingly mounted to the wall.

5. The pump assembly of claim **1**, wherein the sensor element is sealingly mounted within the wall.

6. The pump assembly of claim **1**, wherein the sensor element comprises a transducer.

7. The pump assembly of claim **1**, wherein:

the wall of the magnet housing comprises a wet surface and a dry surface;

the wet surface contacts the fluid in the interior of the magnet housing; and the sensor does not contact the fluid in the interior of the magnet housing.

8. The pump assembly of claim **1**, wherein the sensor is situated within a cavity in a wall of the magnet housing.

9. The pump assembly of claim **1**, further comprising an electrical connection to the sensor.

10. The pump assembly of claim **1**, further comprising a wireless electrical connection to the integral sensor.

11. The pump assembly of claim **1**, wherein:

the pumping member comprises a driving gear and a driven gear interdigitated with the driving gear; and

the driving gear is coupled to the driven magnet.

12. The pump assembly of claim **1**, wherein:

the magnet housing comprises a body and a distal-end wall;

the sensor is integrated into the distal-end wall; and

the sensor is surrounded by a circuit board, comprising a rigid electrical connection to the sensor.

13. The pump assembly of claim **1**, further comprising a printed circuit board electrically connected to the sensor element.

14. The pump assembly of claim **1**, wherein the magnet driver comprises a stator.

15. The pump assembly of claim **12**, further comprising:

a motor housing containing the stator; and

stator-driver electronics situated in the motor housing and electrically connected to the stator.

16. The pump assembly of claim **1**, wherein the sensor element comprises at least one transducer selected from the group consisting of pressure transducers, temperature transducers, flow-rate transducers, conductivity transducers, rotation-sensing transducers, dissolved gas transducers, pH transducers, turbidity-sensing transducers, ion-specific-sensing transducers, optical-absorption transducers, and combinations thereof.

17. The pump assembly of claim **1**, wherein the sensor element is selected from the group consisting of strain-gauges, capacitive transducers, resistive transducers, inductive transducers, piezoelectric transducers, magnetically-coupled transducers, Hall effect transducers, and electrodes.

18. The pump assembly of claim **1**, wherein the sensor element is sealingly mounted into a wall of the magnet housing, by a procedure selected from the group consisting of direct welding, laser welding, separate membrane welding, brazing, over-molding, adhesive bonding, statically sealing in place, clamping, mechanically joining, molding, and casting.

19. The pump assembly of claim **1**, wherein the pumping member is selected from the group consisting of pump gears, centrifugal members, lobed members, and pistons.

20. The pump assembly of claim **1**, further comprising a pressure-compliant member situated inside the pump housing.

21. The pump assembly of claim **1**, wherein:

the sensor element is a pressure transducer; and

the sensor element is located at either a pump-inlet region of the magnet housing, for sensing inlet pressure, or a pump-outlet region of the magnet housing, for sensing outlet pressure.

22. The pump assembly of claim **1**, further comprising:

a sensor electronic circuit located outside the pump housing and electrically connected to the sensor element;

a driver circuit located outside the pump housing and electrically connected to the magnet driver; and

a controller electrically connected to the sensor electronic circuit and to the driver circuit, the controller being configured to control operation of the magnet driver, and hence of the pumping member, based on data provided to the controller by the sensor electronic circuit.

23. A pump head, comprising:

a sealed pump housing;

a pumping member situated inside the housing;

a driven magnet situated in the housing and connected to the pumping member so that induced motion of the driven magnet causes corresponding induced motion of the pumping member;

a magnet housing being a respective portion of the pump housing and containing the driven magnet so that the induced motion of the driven magnet occurs in the magnet housing, the driven magnet and interior of the magnet housing being wetted by the fluid being pumped by induced motion of the pumping member; and

at least one sensor element integrally mounted to a wall of the magnet housing such that the sensor element is sensitive to at least one parameter of the fluid being pumped by the pumping member.

24. The pump head of claim **23**, wherein:

the sensor element includes a parameter-sensitive surface that is capable of measuring properties of the fluid being pumped; and

the sensor element is integrally mounted to a wall of the magnet housing such that the parameter-sensitive surface faces the interior of the magnet cup.

25. The pump head of claim **23**, wherein the sensor element is integrally mounted in a wall of the magnet housing such that the sensor is adjacent to a wet surface in contact with the fluid in the interior of the magnet cup.

26. A method for controlling a magnetically-driven hydraulic pump, in which a pumped fluid is separated from pump-driving electronic components by a pump housing including a magnet housing, the method comprising:

providing a sensor, mounted relative to a wall of the magnet housing, such that the sensor is not wetted by the fluid;

using the sensor, measuring at least one parameter of the fluid to produce a measurement signal;

supplying the measurement signal as a control signal to the electronic components, the control signal having at least one characteristic based on the measurement of the parameter and being a signal to which the electronic components are operationally responsive; and

based on the control signal, inducing the electronic components to produce a corresponding change in driving of the pump.

27. A fluid pump, comprising:

pump-element means magnetically coupled to driven magnet means;

pump housing means for containing the pump-element means separate from an external environment and in contact with a fluid to be pumped, the pump housing means comprising housing means for said driven magnet means;

magnet-drive means, located external to said housing means for said driven magnet means, for inducing motion of said driven magnet means, and thus of said pump-element means in said housing means;

parameter sensing means associated with said housing means for measuring at least one property of the fluid without contacting the fluid;

pump control means coupled to said parameter sensing means for receiving data associated with said measured at least one property and for producing a corresponding pump-control signal; and

means for adjusting operation of the pump in response to the corresponding pump-control signal.

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