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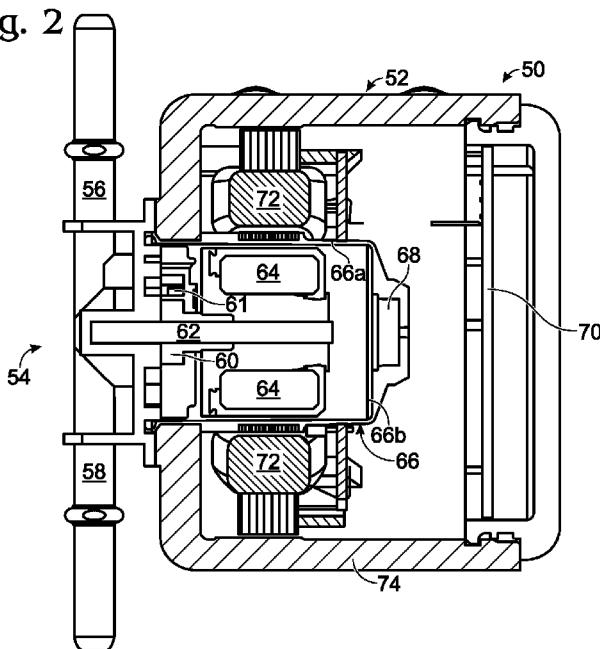
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(54) Title: PUMP MAGNET HOUSING WITH INTEGRATED SENSOR ELEMENT

Fig. 2



(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.



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**PUMP MAGNET HOUSING WITH INTEGRATED SENSOR ELEMENT****RELATED APPLICATION**

This patent application claims priority to and the benefit of U.S. Provisional Patent Application No. 61/396,715, filed on June 1, 2010, and U.S. Patent Application No. 13/151,188, filed on June 1, 2011, which are hereby incorporated by reference in its entirety.

**FIELD**

10 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.

15

**BACKGROUND**

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.

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.

5     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

10    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

15    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.

20    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

25    systems.

30    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

5        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

10        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

15        additional potential leaks by eliminating additional hydraulic connections.

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.

20        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

25        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

5     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.

In addition, the volume of space that otherwise would be occupied by

10    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

15    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

20    assembly is more rugged than conventional pump systems. This is particularly advantageous in hazardous environments or submerged applications.

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

25    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 5 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 10 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.

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 15 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.

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 20 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.

25 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 30 os 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 5 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 10 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 15 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.

Although embodiments shown herein describe sensors as being mounted to a 20 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 25 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 30 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.

5

## BRIEF DESCRIPTION OF THE DRAWINGS

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.

10 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.

15 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.

20 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.

FIG. 5 is a second perspective view of the magnetic cup shown in FIG. 4.

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

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

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

30 FIG. 9 is an exploded perspective view showing coaxial components of the magnetic cup of FIG. 4.

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

FIG. 11 is a second perspective view of the magnetic cup shown in FIG. 10.

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 5 circuit board.

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

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

10 FIG. 15 is an exploded view showing coaxial components of the magnetic cup of FIG. 13.

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

15 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.

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

20 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.

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.

25

## DETAILED DESCRIPTION

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 30 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 26a and a distal-end wall 26b that surround and are coaxial with the side walls 26a and a distal-end wall 26b that surround and are coaxial with the

driven magnet 24. The side walls 26a and distal-end wall 26b 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

5 1A 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 26a 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

10 head 14 are mounted end-to-end so that a large part of the pump head 14 extends from the driver portion 12.

Mounted to the distal-end wall 26b 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

15 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

20 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.,

25 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

30 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.

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 5 driving gear is axially affixed, a driven magnet 64, and a magnet cup 66. The magnet cup 66 has side walls 66a and a distal-end wall 66b that surround and are coaxial with the driven magnet 64. Mounted to the distal-end wall 66b 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 10 through the distal-end wall 66b. 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 66a of the magnet cup. The stator 72 is contained in an enclosure 74, which also contains the 15 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 20 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.

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 25 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 116a and a distal-end wall 116b that surround and are coaxial with the driven magnet 114. Mounted to the distal-end wall 116b is a sensor transducer 118. The 30 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 116a 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 5 into the wall of the enclosure 124, which reduces overall volume occupied by the 10 pump assembly 100.

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, 15 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 20 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.

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 25 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 30 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 5 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 10 cover.

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 15 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 20 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 25 of sensor data.

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 30 Application Publication No. US 2009-0060728 filed on August 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.

An exemplary embodiment of a magnet cup 200 made of a molded rigid 5 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 10 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.

Details of the magnet cup 200 are shown in FIGS. 11 and 12, in which a 15 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 20 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.

FIG. 16 shows an alternative embodiment of a magnetic cup 230 that 25 includes 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 30 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.

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.

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.

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.

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 5 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;
  - 5 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;
  - 10 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
  - 15 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.
- 20 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.
- 25 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;
  - 5 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
  - 15 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
  - 20 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  
5 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 10 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 15 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, 20 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.

25 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,
- 5 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;
  - 10 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.
- 15 23. A pump head, comprising:
  - a sealed pump housing;
  - a pumping member situated inside the housing;
  - 20 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:

5 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.

10 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.

15 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;

20 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

25 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;

5

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

10

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

15

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

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Fig. 1

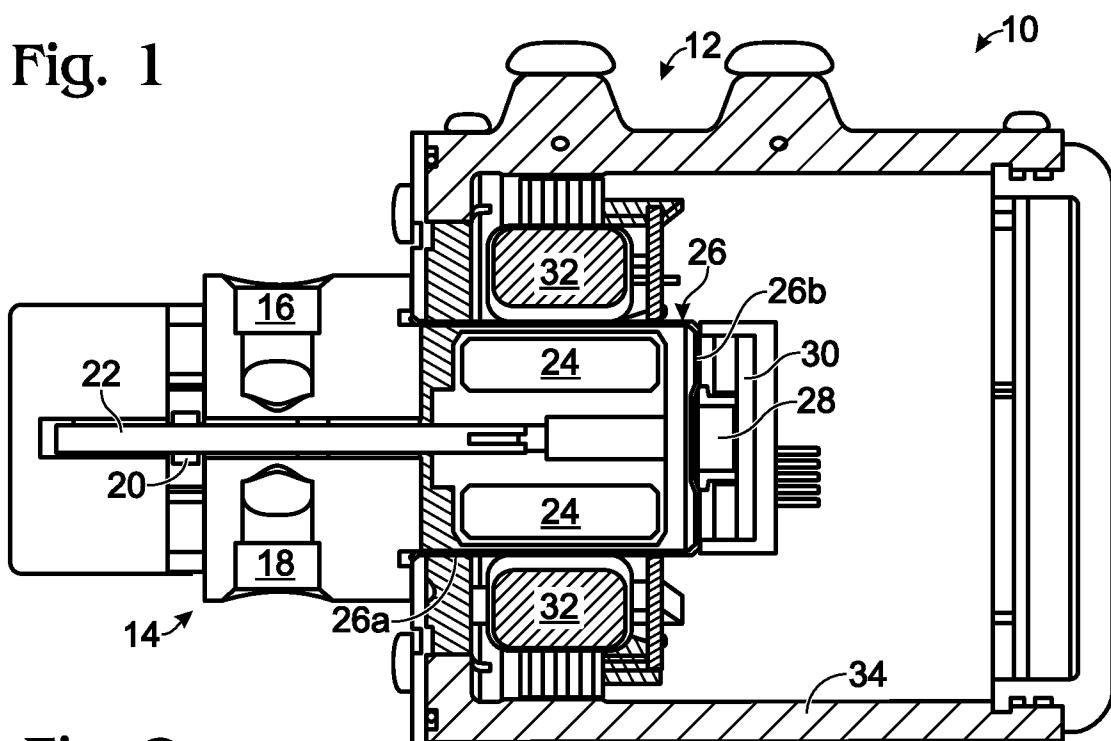


Fig. 2

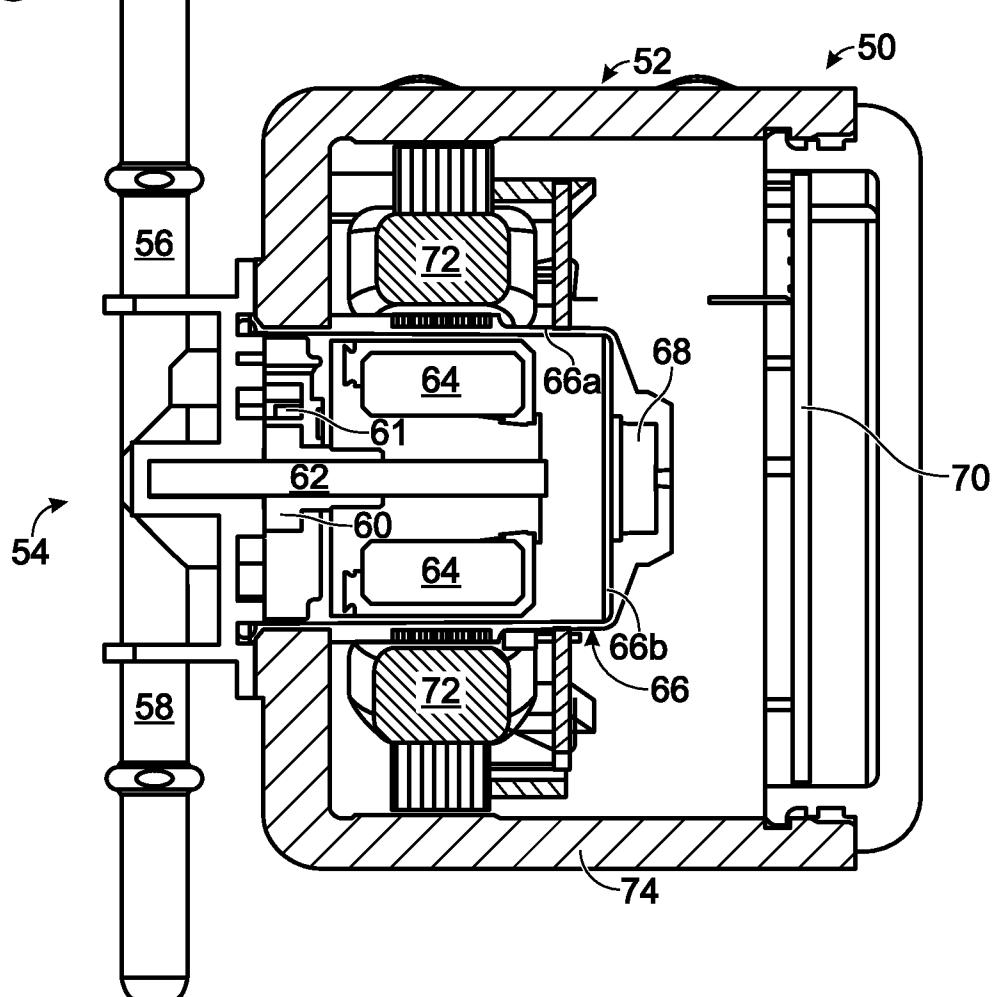


Fig. 3

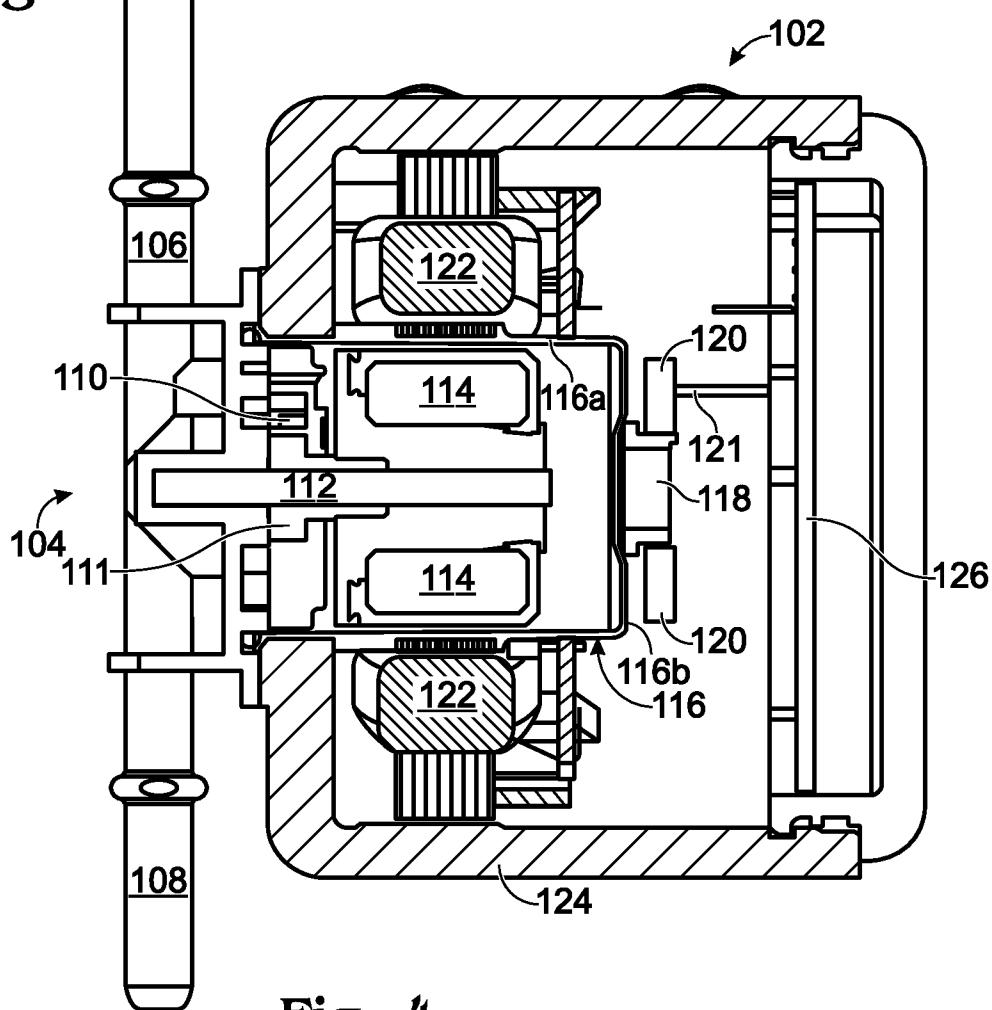
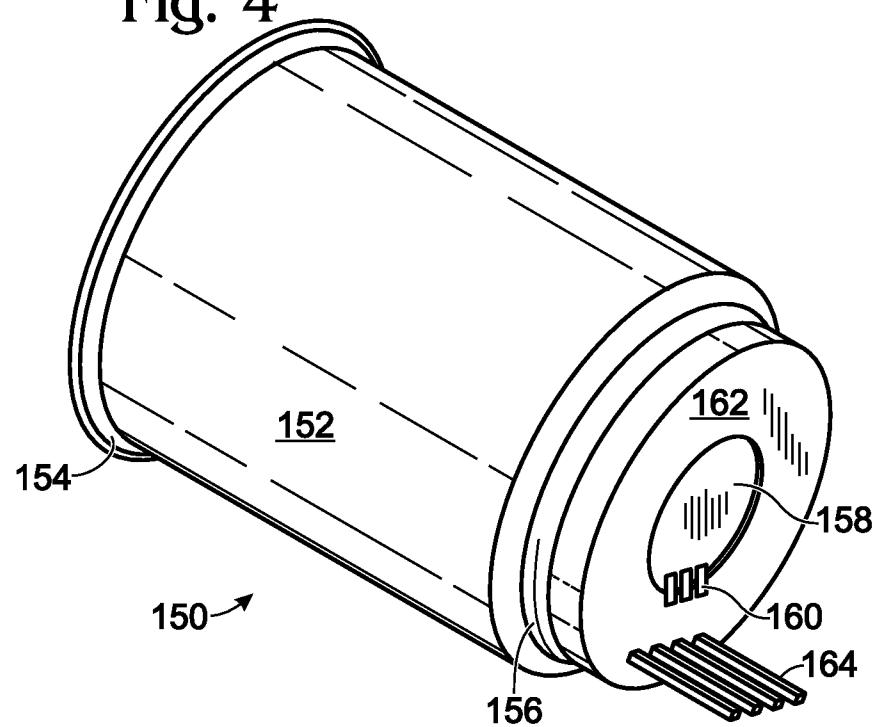
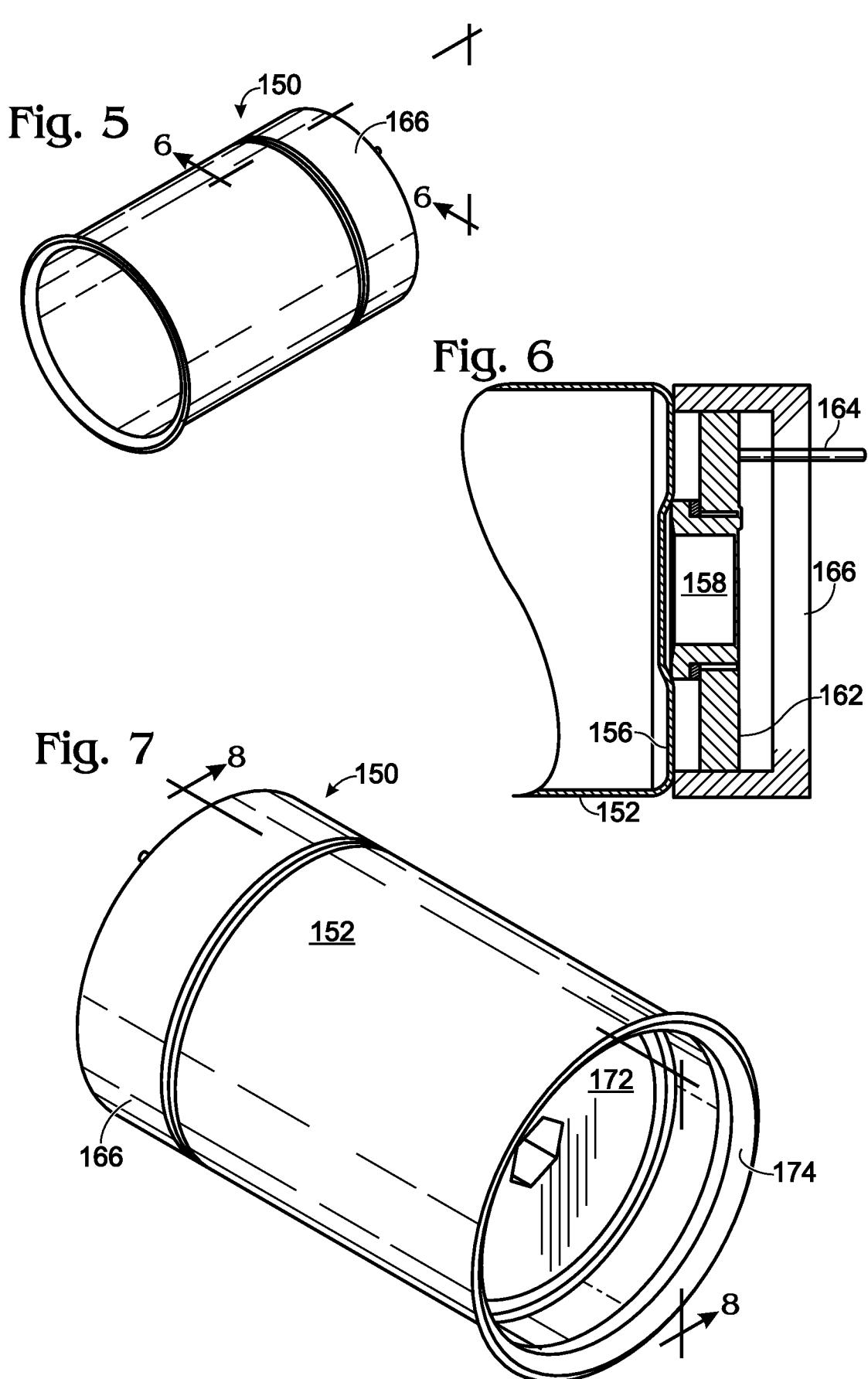


Fig. 4



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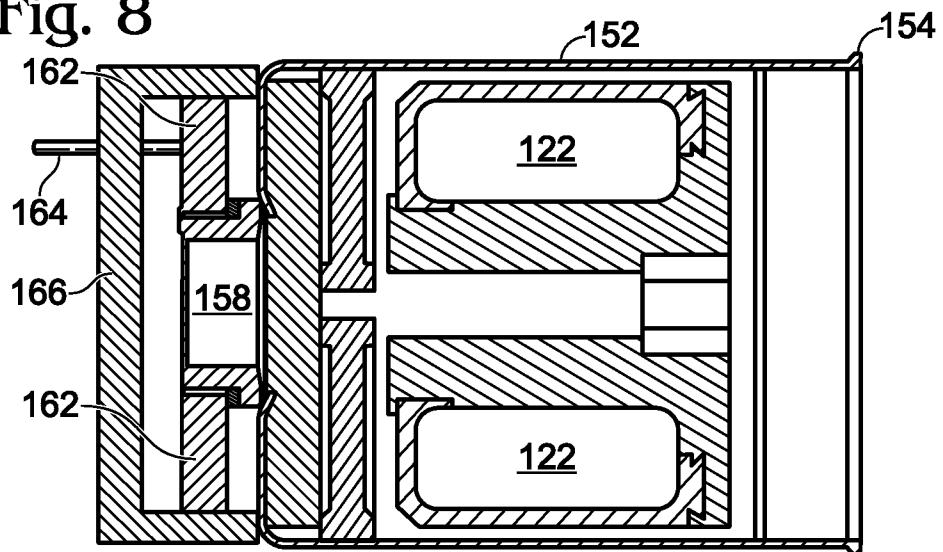
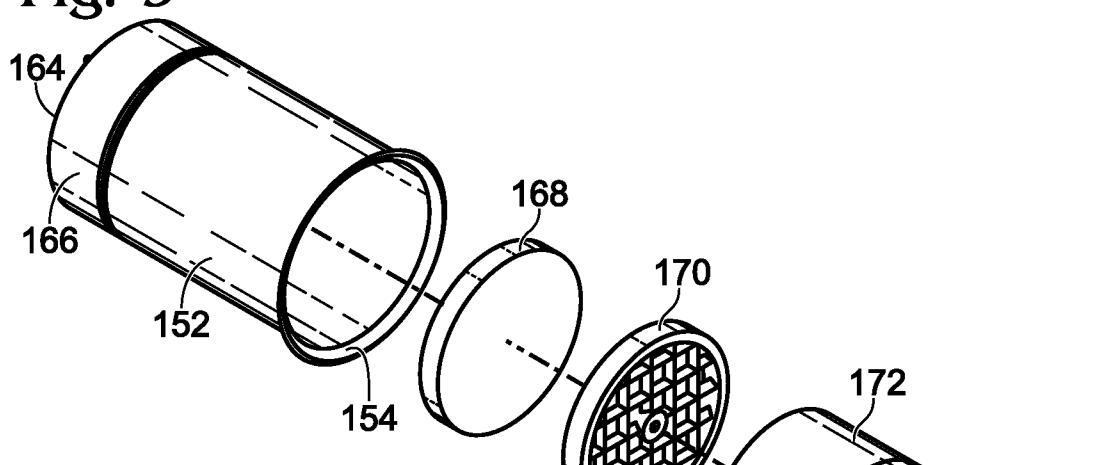
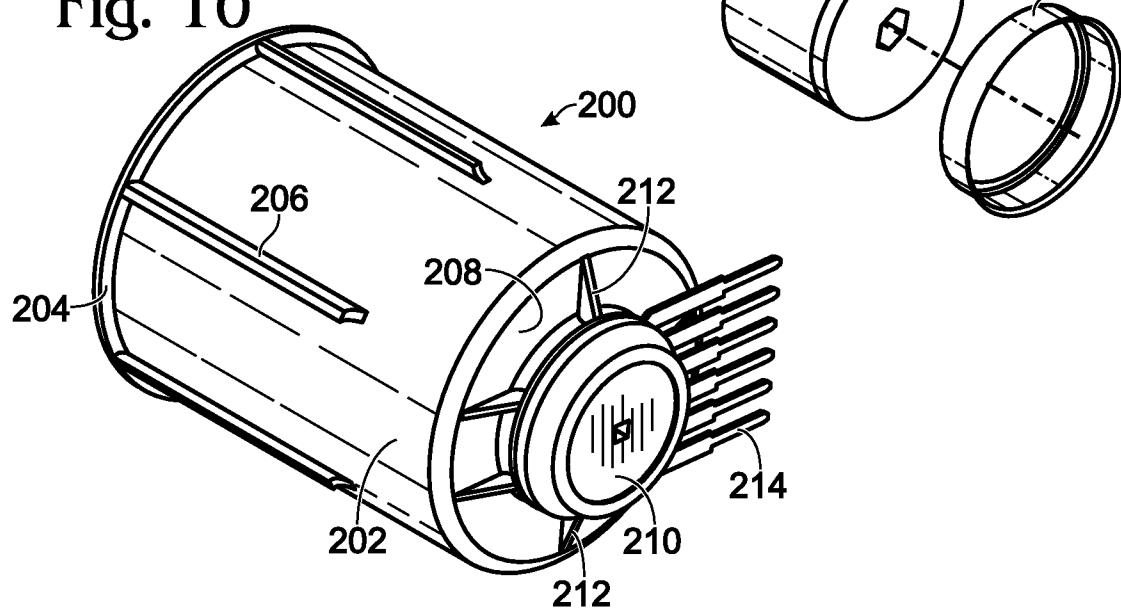
**Fig. 8****Fig. 9****Fig. 10**

Fig. 11

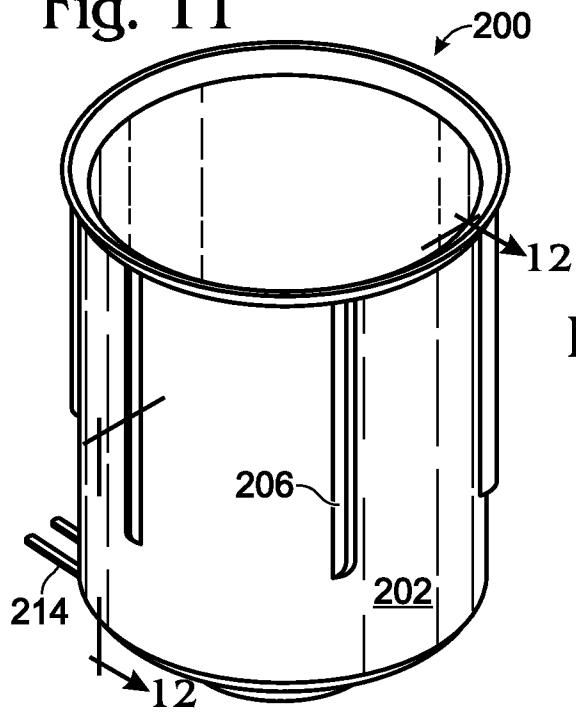


Fig. 12

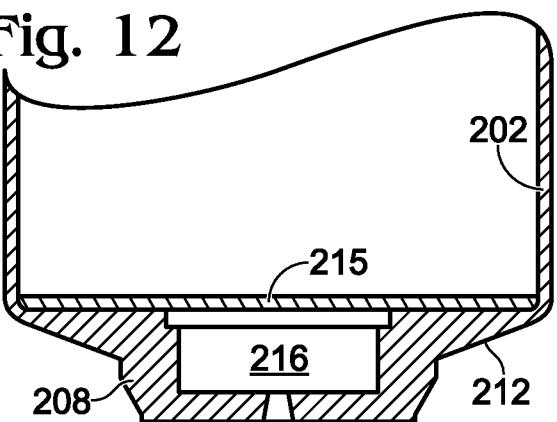
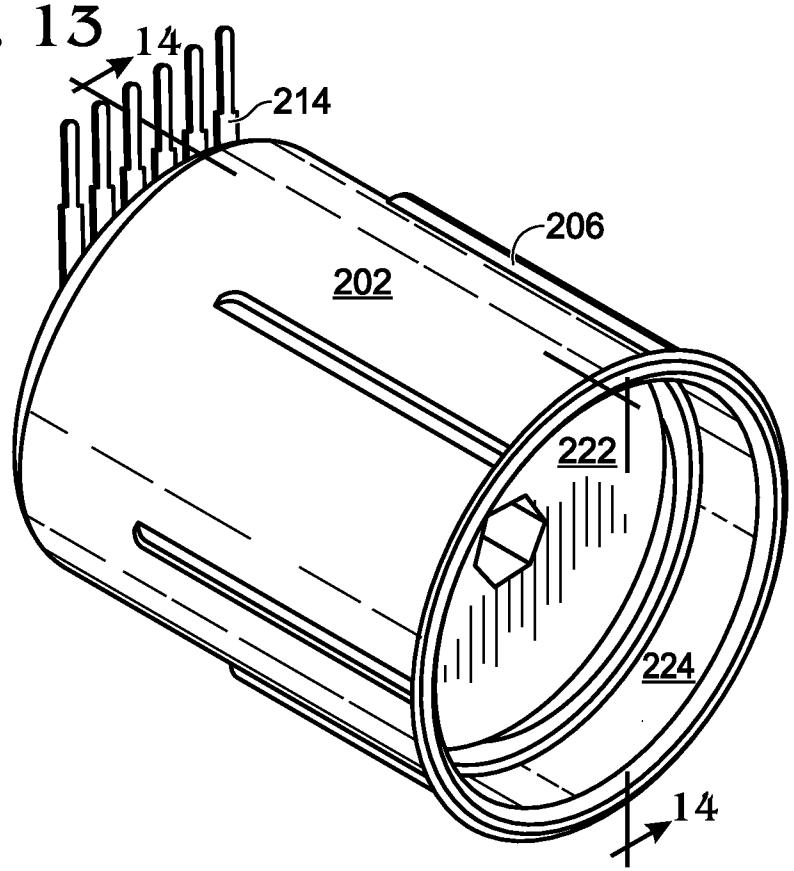
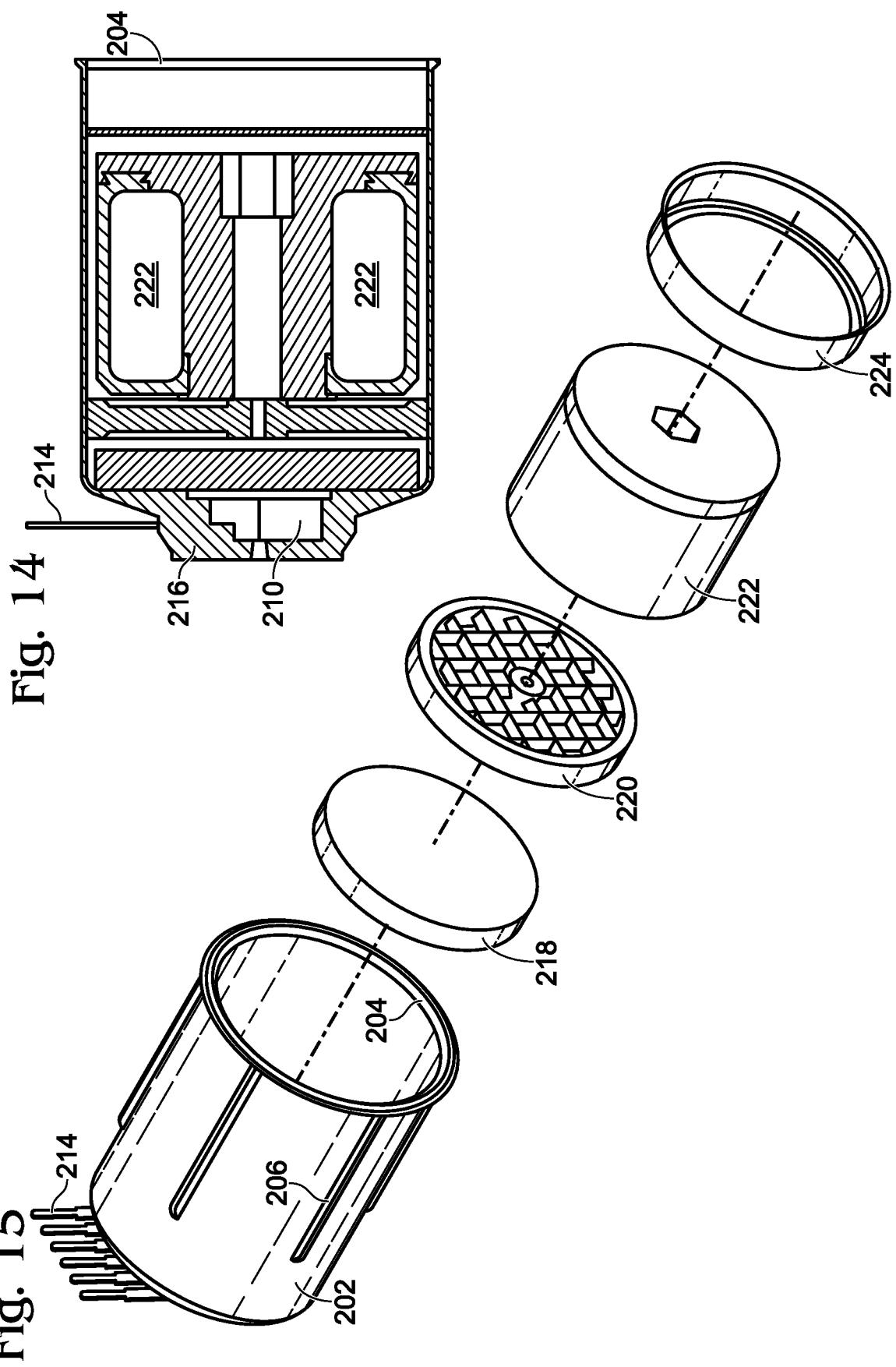


Fig. 13





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Fig. 16

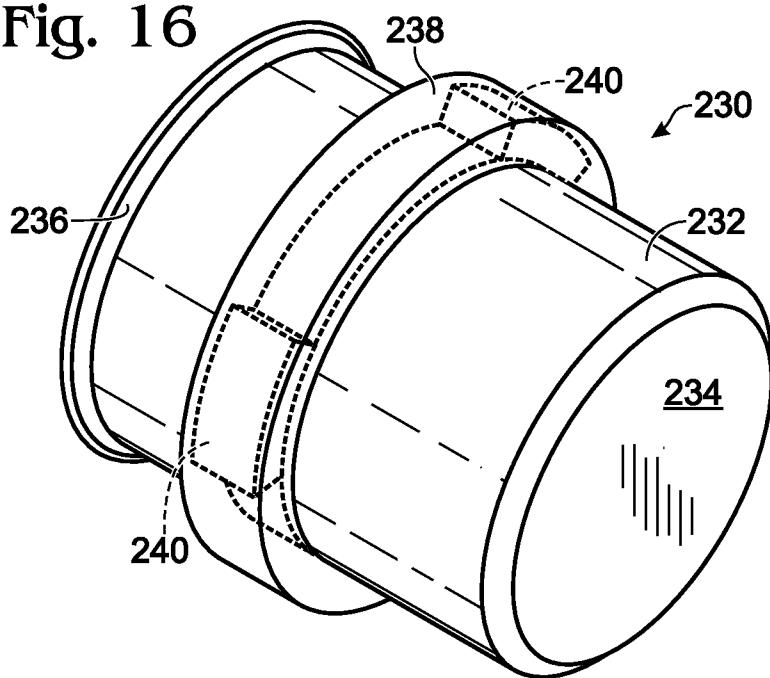


Fig. 17

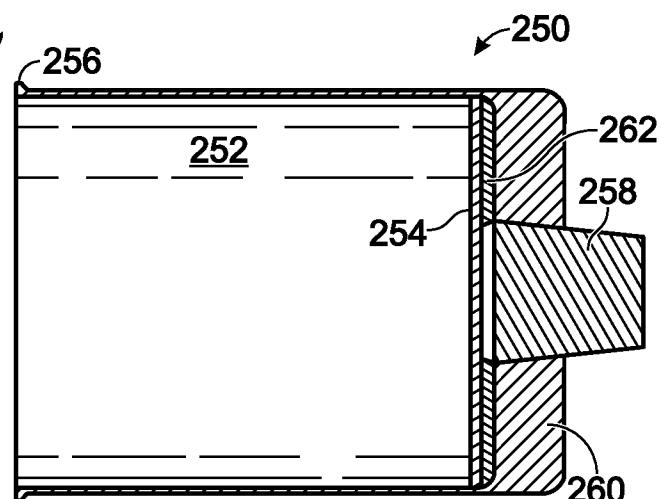
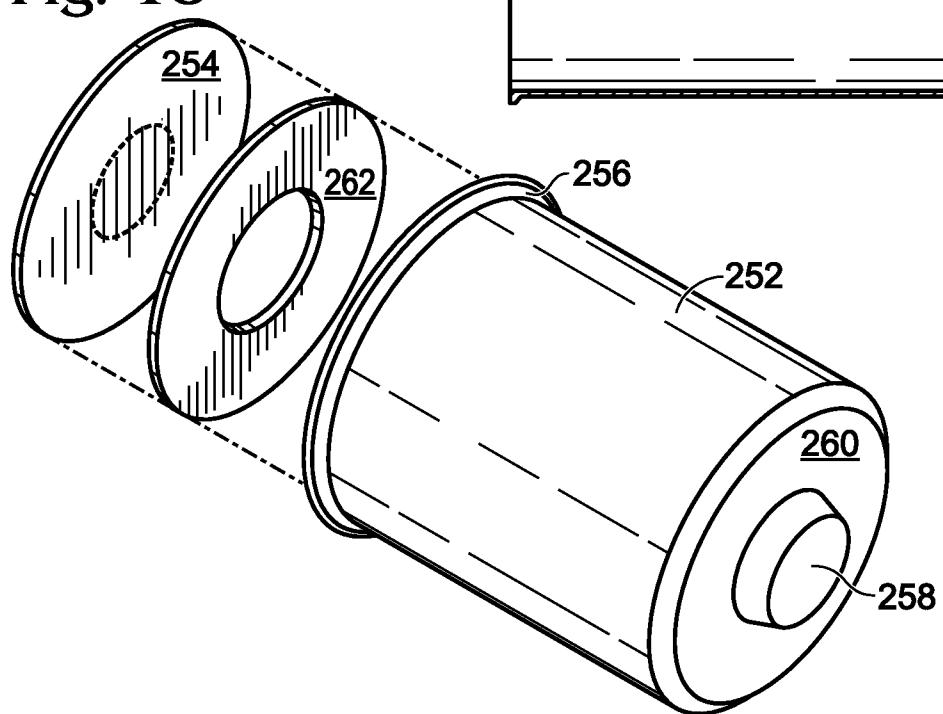


Fig. 18



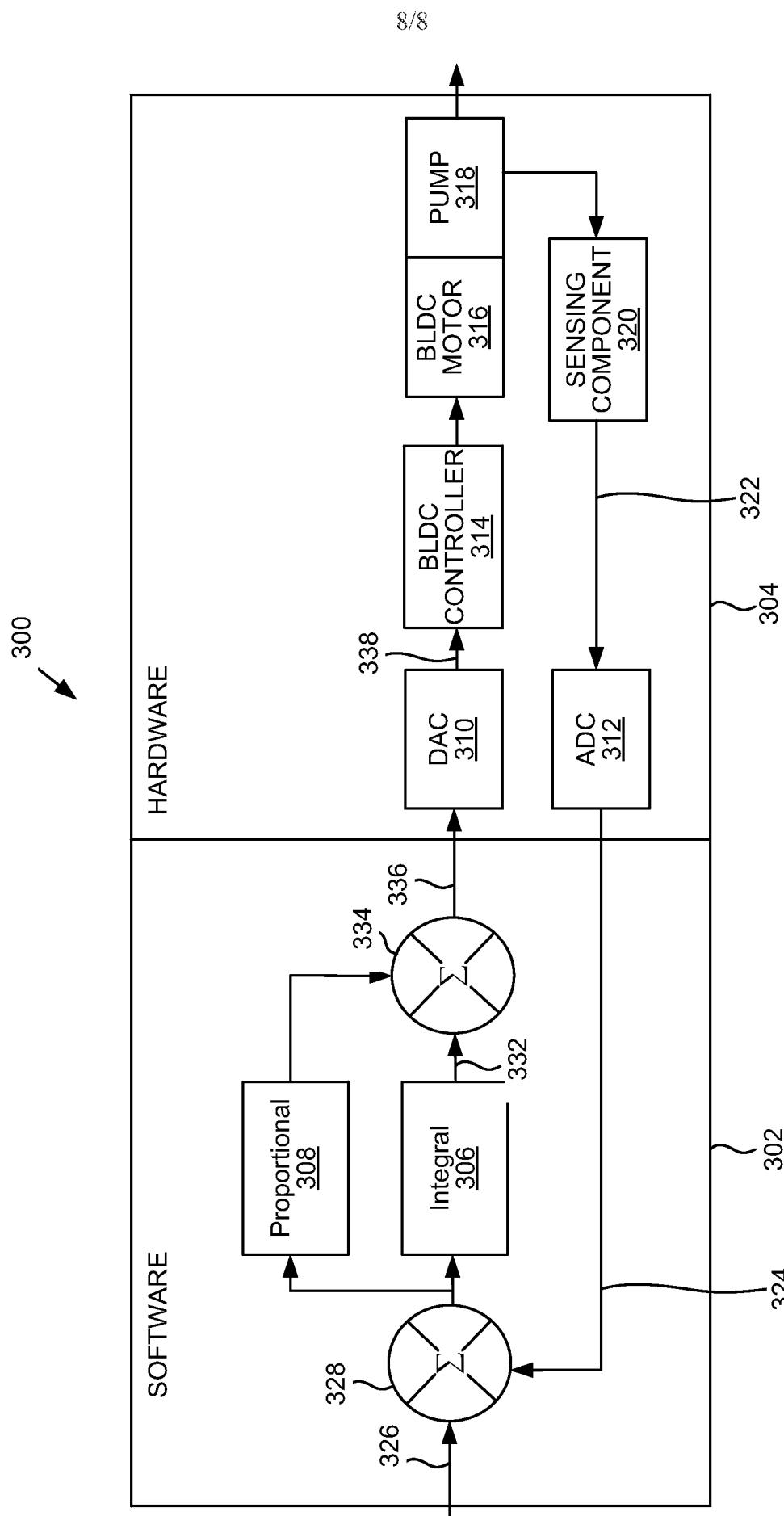


FIG. 19

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/US2011/038952

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(8) - F04B 17/00 (2011.01)

USPC - 417/420

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - F04B 17/00, 17/03; F04D 13/02; H02K 29/08 (2011.01)

USPC - 417/420, 423.7, 423.11, 423.14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Google Patent

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,096,390 A (SEVRAIN) 17 March 1992 (17.03.1992) entire document	1, 7, 9, 11, 13, 14, 17, 19
Y		2-6, 8, 10, 12, 15, 16, 18, 20-27
Y	US 6,527,517 B1 (WALLRAFEN et al) 04 March 2003 (04.03.2003) entire document	2-6, 8, 16, 18, 23-25, 27
Y	US 2010/0006044 A1 (DULEY) 14 January 2010 (14.01.2010) entire document	10, 22, 26
Y	US 7,411,326 B2 (ACHOR et al) 12 August 2008 (12.08.2008) entire document	12, 15
Y	US 2009/0060728 A1 (GRIMES et al) 05 March 2009 (05.03.2009) entire document	20
Y	US 2004/0146417 A1 (DUNN) 29 July 2004 (29.07.2004) entire document	21

Further documents are listed in the continuation of Box C.

\* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 October 2011	17 OCT 2011
Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 -Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774