Title: DOWNHOLE TOOL WITH CLOSED LOOP POWER SYSTEMS

Abstract: A tool (112) for moving within a passage (132) comprises an elongated body (207); a closed system (155) for converting a circulating flow of a fluid into movement of the tool (112) within the passage (132), and a pump-powering assembly. The closed system (155) comprises a gripper assembly (180, 182) on the body (207), a barrel surrounding and engaged with the body (207), a piston (218, 220) longitudinally fixed with respect to the body (207), a valve assembly (214), and a pump (156) configured to circulate the fluid through the closed system (155). The gripper assembly (180, 182) is configured to utilize fluid pressure to grip onto an inner surface of the passage (132). The barrel is longitudinally movable with respect to the body (207), and the gripper assembly (180, 182) is longitudinally fixed with respect to the barrel. The barrel and the body (207) define an annular space therebetween, wherein one or more interfaces between the barrel and the body (207) are sealed to substantially prevent escape of fluid from the annular space to an exterior of the barrel. The piston (218, 220) is positioned within the barrel and fluidly separates the annular space into aft and forward chambers of the barrel, wherein sizes of the aft and forward chambers of the barrel vary as the piston (218, 220) moves longitudinally within the barrel. The valve assembly (214) is configured to direct fluid to and from the gripper assembly (180, 182) and the aft and forward chambers of the barrel to produce movement of the body (207) within the passage (132). The pump-powering assembly is configured to power the pump (156) and comprises a turbine (150).
DOWNHOLE TOOL WITH CLOSED LOOP POWER SYSTEMS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to tools for conducting operations within passages, and specifically to tools for borehole intervention and/or drilling.

Description of the Related Art

U.S. Patent No. 6,003,606, entitled "Puller-Thruster Downhole Tool," discloses an innovative self-propelled tool or tractor for drilling, completion, stimulation, and intervention that pulls a drill string and simultaneously thrusts itself and its payload downhole and/or into a casing or borehole formation. The '606 patent discloses a tractor that includes one or more gripper assemblies (e.g., bladders or packerfeet) that grip onto an inner surface of a borehole or casing, and one or more propulsion assemblies that propel the tractor body forward when at least one of the gripper assemblies is gripping the borehole. A valve system directs a fluid (e.g., drilling mud, intervention fluid, hydraulic fluid) to and from the gripper assemblies and propulsion assemblies to power movement of the tractor.

The '606 patent discloses two basic types of tractor configurations — open loop and closed loop. The open loop system uses an externally provided fluid as a medium of hydraulic communication within the tractor. The open loop consists of a ground surface pump, tubing extending from the pump into a borehole, a tractor within the borehole and connected to the tubing, and an annulus between the exterior of the tractor and an inner surface of the borehole. The fluid is pumped down through the tubing to the tractor, used by the tractor to move and conduct other downhole operations, and then forced back up the borehole through the annulus. The tractor is powered by differential pressure — the difference of the pressure at the point of intake of fluid to the tractor and the pressure of fluid ejected from the tractor into the annulus. In the open loop system, a portion of the fluid is used to power the tractor's movement and another portion of the fluid flows through the tractor for various downhole purposes, such as hole cleaning, sand washing, acidizing, and
lubricating of a drill bit (in drilling operations). Both portions of the fluid return to the
ground surface through the annulus.

The '606 patent also discloses a closed loop configuration in which a hydraulic fluid
is circulated through the gripper assemblies and propulsion assemblies to power the tractor's
movement within the borehole. In particular, Fig. 19 of the '606 patent discloses a downhole
motor that powers the recirculation of the hydraulic fluid.

The '606 patent further discloses, in Fig. 24, an embodiment in which an electrical
line (referred to herein as an "E-line") is provided within the coiled tubing. The E-line can be
utilized to send electrical signals from the ground surface to the tractor to control the position
of a start/stop valve that regulates the inflow of drilling fluid into the tractor's valve
assembly, in an open loop system.

U.S. Patent Nos. 6,347,674; 6,241,031; and 6,679,341, as well as U.S. Patent
Application Publication No. 2004/0168828, disclose alternative valve systems and methods
for directing fluid to and from a downhole tractor's gripper assemblies and propulsion
assemblies for moving the tractor.

SUMMARY

In one aspect, a tool for moving within a passage is provided. The tool comprises an
elongated body; a closed system for converting a circulating flow of a fluid into movement of
the tool within the passage, and a pump-powering assembly configured to power the pump,
the pump-powering assembly comprising one of a turbine and an E-line controlled motor.
The closed system comprises a gripper assembly on the body, a barrel surrounding and
engaged with the body, a piston longitudinally fixed with respect to the body, a valve
assembly, and a pump configured to circulate the fluid through the closed system. The
gripper assembly is configured to utilize fluid pressure to grip onto an inner surface of the
passage. The barrel is longitudinally movable with respect to the body, and the gripper
assembly is longitudinally fixed with respect to the barrel. The barrel and the body define an
annular space therebetween, wherein one or more interfaces between the barrel and the body
are sealed to substantially prevent escape of fluid from the annular space to an exterior of the
barrel. The piston is positioned within the barrel and fluidly separates the annular space into
aft and forward chambers of the barrel, wherein sizes of the aft and forward chambers of the
barrel vary as the piston moves longitudinally within the barrel. The valve assembly is
configured to direct fluid to and from (1) the gripper assembly and (2) the aft and forward
chambers of the barrel to produce movement of the body within the passage.

For purposes of summarizing the invention and the advantages achieved over the
prior art, certain objects and advantages of the invention have been described herein above.
Of course, it is to be understood that not necessarily all such objects or advantages may be
achieved in accordance with any particular embodiment of the invention. Thus, for example,
those skilled in the art will recognize that the invention may be embodied or carried out in a
manner that achieves or optimizes one advantage or group of advantages as taught herein
without necessarily achieving other objects or advantages as may be taught or suggested
herein.

All of these embodiments are intended to be within the scope of the invention herein
disclosed. These and other embodiments of the present invention will become readily
apparent to those skilled in the art from the following detailed description of the preferred
embodiments having reference to the attached figures, the invention not being limited to any
particular preferred embodiment(s) disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a conventional coiled tubing tractor system.

Figure 2 is a schematic diagram of a turbine-powered motor for a closed loop system
for powering a downhole tractor, according to an embodiment of the invention.

Figure 3 is a more detailed schematic diagram of the closed loop system of Figure 2.

Figure 4 is a schematic diagram of an E-line powered motor for a closed loop system
for powering a downhole tractor, according to an embodiment of the invention.

Figure 5 is a more detailed schematic diagram of the closed loop system of Figure 4.

Figure 6 is a schematic diagram of a turbine-powered pump for a closed loop system
for powering a downhole tractor, according to an embodiment of the invention.

Figure 7 is a more detailed schematic diagram of the closed loop system of Figure 6.
Figure 8 is a schematic diagram of a system in which a positive displacement motor powers a pump for a closed loop system for powering a downhole tractor, according to an embodiment of the invention.

Figure 9 is a more detailed schematic diagram of the closed loop system of Figure 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates a conventional coiled tubing tractor or tool for conducting downhole operations such as intervention and drilling. The illustrated system is an open loop configuration. The coiled tubing system 100 typically includes a power supply 102 for powering ground-level equipment, a tubing reel 104, a tubing guide 106, and a tubing injector 110, which are well known in the art. The illustrated system includes a bottom hole drilling assembly 120 for drilling a borehole 132 with a drill bit 130. However, other types of bottom hole assemblies 120 can alternatively be provided, such as those for intervention operations like hole cleaning, sand washing, acidizing, and the like. As known, coiled tubing 114 is inserted into the borehole 132, and a fluid (e.g., drilling mud, intervention fluid) is typically pumped through the inner flow channel of the coiled tubing 114 towards the drill bit 130 located at the end of the drill string. Positioned between the drill bit 130 and the coiled tubing 114 is a tool or tractor 112. The illustrated bottom hole assembly 120 includes a number of elements known to those skilled in the art, such as a downhole motor 122 and a Measurement While Drilling (MWD) system 124. The tractor 112 is preferably connected to the coiled tubing 114 and the bottom hole assembly 120 by connectors 116 and 126, respectively, as known in the art. In this system, the fluid is pumped through the inner flow channel of the coiled tubing 114 and through the tractor 112 to the drill bit 130. The fluid and drilling debris return to the surface in the annulus defined between the exterior surface of the tractor 112 and the inner surface of the borehole 132, and also defined between the exterior surface of coiled tubing 114 and the inner surface of the borehole 132.

When operated, the tractor 112 is configured to move within the borehole 132. This movement allows, for example, the tractor 112 to maintain a pre-selected force on the bottom hole assembly 120 such that the rate of movement or drilling can be controlled. The tractor 112 can be used to move various types of equipment through the borehole 132. For example,
it will be understood that the tractor 112 can be connected with or include, without limitation, a downhole motor (for rotating a drill bit), steering system, instrumentation sub (an instrumented package that controls various aspects of downhole operation, including shock vibration, weight on bit, torque at bit, rate of penetration, downhole motor rpm, and differential pressure across motor), Measurement While Drilling apparatus (an apparatus for measuring gyroscopic data such as azimuth, inclination, and measured depth), drill bit, mechanical and hydraulic disconnect for intervention, jetting tools, production logging tools (including apparatus for measuring and recording, without limitation, temperature, annulus pressure, and various flow rates), drilling logging tools (for measuring and recording, without limitation, resistivity measurements, magnetic resonance (MRI), sonic neutron density, density, fluid identification, and gamma ray measurements), perforation guns, casing collar locators, and torque limiting tools (for drilling).

A closed loop configuration has relevant differences from an open loop system that operates on differential pressure (the difference in pressure between the bore of the tractor and the exterior of the tractor). With an open system, a restriction in the system is required to produce a pressure difference (decrease) between the interior and exterior of the tractor. Typically, the restriction is an orifice such as a fixed diameter nozzle, and is not capable of being adjusted from the surface. For typical coiled tubing rig operations, the effective means of control is to control the surface pump output flow rate. However, the differential pressure available at the tractor is a quadratic (non-linear) function of the surface pump output flow rate. Thus, doubling the surface pump output flow rate will increase the differential pressure through an in-series fixed orifice by a factor of four. This makes power control of the tractor more difficult as normal operational changes can have non-linear impact on tractor power, requiring additional features to be incorporated into the open loop powered tractor to restrict the amount of pressure delivered to the gripper assemblies, for example. Further, this has a disadvantage in that the normal operating range of the surface pump output flow rate required for various operations may have to be restricted, thus reducing cleaning efficiency during the operation.

Described below are four embodiments of closed loop power systems for powering a tractor: (1) a turbine-powered motor, (2) an E-line powered motor, (3) a turbine-powered
pump; and (4) a pump powered by a positive displacement motor. Any one of these configurations can be used for circulating a given tractor’s closed system fluid (e.g., hydraulic fluid) through the tractor’s valve system, gripper assemblies, and propulsion assemblies. The difference between these configurations is how power is delivered to the downhole pump that circulates the fluid.

**Turbine-Powered Motor**

Figure 2 is a schematic illustration of a turbine-powered motor for circulating hydraulic fluid in a closed loop for powering a downhole tool or tractor, according to an embodiment of the present invention. In this configuration, a first fluid (typically drilling/intervention fluid) that is externally pumped into the coiled tubing usually at the ground surface flows through the tractor and passes through a turbine 150 on its way to the remaining bottom hole assembly (typically secured to the distal end of the tractor). The turbine 150 drives a generator 152 that produces electricity, as known in the art of turbine power generation. The electricity produced by the generator 152 powers an electric motor 154 that in turn powers a pump 156. The pump 156 circulates a second fluid (typically hydraulic fluid) in a closed system loop 155. Box 158 represents a valve system, gripper assemblies, and propulsion assemblies as known in the art. For example, the valve system, gripper assemblies, and propulsion assemblies can be substantially as shown and described in U.S. Patent Nos. 6,003,606; 6,347,674; 6,241,031; and 6,679,341, as well as U.S. Patent Application Publication No. 2004/0168828. Also, the gripper assemblies can be substantially as shown and described in U.S. Patent Nos. 6,464,003 and 6,715,559; U.S. Patent Application Publication No. 2005/0247488; and U.S. Provisional App. No. 60/781,885. The second fluid provides hydraulic force for operation of the gripper assemblies and propulsion assemblies, and in some cases the valves.

Commercially available turbine-generators are sold by Spring Electronics of Worcestershire, United Kingdom. One turbine-generator sold by Spring Electronics comprises a three-phase alternator, rectifier, and switch mode power supply producing about 70 Watts at 50 volts. Larger versions of turbine-generators are commercially available.
Figure 3 is a more detailed schematic illustration of the closed loop system of Figure 2 adapted for use with a variation of the Puller-Thruster Downhole Tool (also referred to as "Puller Thruster Assembly" or "PTA") described in U.S. Patent No. 6,003,606. As the first fluid is pumped through the turbine 150, the turbine powers the motor 154 and in turn the pump 156 that circulates the second fluid through the illustrated valve assembly. The second fluid flows from a supply line 228 through a start/stop valve 160 (also known as an "idler valve") into the valve system. A six-way control valve 162 shuttles back and forth to direct the fluid to and from an aft gripper assembly 180 (illustrated as a deflated packerfoot) and a forward gripper assembly 182 (illustrated as an inflated packerfoot), and also to and from an aft propulsion assembly 184 and a forward propulsion assembly 186 (each propulsion assembly comprising barrels and internal pistons, as taught in the '606 patent). Valves 164 and 166 (also known as "directional control valves") control the shuttling and position of the six-way control valve 162. Packerfeet valves 168 and 170 regulate the flow of fluid into the packerfeet 180 and 182. A reverser valve 172 controls the direction of tractor movement (i.e., upright or downhole). The operation of these valves is understood from the teachings of the aforementioned patents incorporated by reference. A sump 157 is preferably provided to store a reservoir of the second fluid. The circulating second fluid returns to the sump 157 via a return line 230.

Figure 3 shows an embodiment of a tool 200 (illustrated as a Puller-Thruster Assembly) positioned within a drilled hole 205 inside a rock formation 212. The tool 200 includes an elongated body formed of central coaxial cylinders 207. The aft gripper assembly 180, aft propulsion assembly 184, forward gripper assembly 182, and forward propulsion assembly 186 are engaged on the central coaxial cylinders 207. The aft propulsion assembly 184 includes annular pistons 218 secured to the cylinders 207. Similarly, the forward propulsion assembly 186 includes annular pistons 220 secured to the cylinders 207. The number of pistons can vary (e.g., up to 20 pistons) and depends on the desired thrust and pull loads.

The tool body defines an internal mud flow passage 224 inside the cylinders 207. The aft end of the tool body has an inlet 201 connected to coiled tubing 114 via a coiled tubing connector 206 (connection can be threaded or snapped together). While Figure 3 shows
coiled tubing 114, the tool 200 can also be used with rotary drill rigs instead (and the same is also true for the embodiments of Figures 4-9). The forward end of the tool body is connected to a bottom hole assembly (BHA) 204. The illustrated tool includes a female coiled tubing connector 208 and stabilizers 210. The valve control pack 214 is positioned between the forward and aft gripper assemblies and also between the forward and aft propulsion assemblies. Splines 216 can optionally be incorporated between the central coaxial cylinders 207 and the gripper assemblies to prevent the transmission of torque from the BHA 204 to the coiled tubing 114.

In use, drilling/intervention fluid flows from the coiled tubing 114 into the inlet 201 of the tool body, and downhole (toward the bottom of the hole) through the mud flow passage 224. The fluid flows through the turbine 150, turning the motor 154. The fluid continues through the passage 224 into the BHA 204, exiting the BHA 204 through an outlet 203. The inlet 201 and outlet 203 are also shown in relation to the turbine 150 on the bottom right hand side of Figure 3. The drilling/intervention fluid that exits via the outlet 203 then flows uphole to the ground surface through an annulus defined between the tool 200 and the drilled hole 205.

The upper right hand side of Figure 3 includes a cross-sectional view of the inflated packerfoot 182, taken along line A-A. The illustrated packerfoot 182 includes three inflated sections. Three mud flow return paths 222 are defined between the three inflated sections of the packerfoot. These return paths 222 allow drilling fluid that exits via the outlet 203 to flow back uphole past the inflated packerfoot. It will be understood that the aft packerfoot 180 can be substantially identical to the forward packerfoot 182. The illustrated packerfoot cross section shows the packerfoot inflated radially beyond the outside diameter 226 of the tool 200.

An advantage of the system using a turbine-powered motor as illustrated is that the system is flow-based, meaning that the downhole tractor can be more easily controlled by the surface pump that pumps fluid down into the coiled tubing toward the turbine. With a flow-based system, any change in the surface pump output volume flow rate linearly changes the power available to the tractor. Since the surface pump output flow rate can be relatively easily adjusted dynamically during tractor operation, the resulting adjustment of the power to
the tractor provides enhanced control over the tractor's speed and pulling force. This enhanced control is available over a substantial operating range of surface pump output flow rates. This is convenient for some types of operations. For example, during sand washing it is desirable to provide a maximum amount of fluid into the borehole while the tractor continues its forward movement, usually at near-maximum pulling capacity.

While the illustrated turbine-powered motor system disclosed in Figures 2 and 3 offers enhanced control over prior systems, one limitation of the system is a loss of efficiency. With each energy conversion, the overall machine efficiency is reduced. For example, the conversion from fluid flow of the drilling/intervention fluid in the coiled tubing into mechanical rotation of the turbine results in some energy loss. Similarly, the conversion of mechanical rotation of the turbine into electrical power from the generator also results in some energy loss.

Another limitation of the turbine-powered pump system is that the turbine requires relatively high flow rates to generate significant amounts of electrical power. For some tractor operations, such as delivering perforation guns, it may be desirable to limit the amount of flow that gets delivered to the bottom hole assembly, for environmental protection reasons. For these types of applications, a turbine-powered motor system may be less preferable than other embodiments disclosed herein.

**E-Line Powered Motor**

Figure 4 is a schematic illustration of an E-line powered motor for circulating hydraulic fluid in a closed loop for powering a downhole tool or tractor, according to an embodiment of the present invention. In this configuration, an E-line 190 preferably extends from the tractor upward to a control box 191, typically located at the ground surface. As used herein, "control box" is a broad term and incorporates a wide variety of controls, including controls in a very small housing and those including wireless features. The illustrated E-line 190 extends to the downhole electric motor 154 that in turn powers the pump 156, it being understood that the motor 154 and pump 156 are preferably housed within or on the tractor. Compared to the embodiment of Figures 2 and 3, this embodiment does not include a turbine. The control box 151 preferably includes at least a portion of an electronic control system.
adapted to send electrical control signals through the E-line 190 for powering and controlling the motor 154. The pump 156 circulates a fluid (typically hydraulic fluid) in a closed system loop 155. Box 158 represents a valve system, gripper assemblies, and propulsion assemblies as known in the art and preferably as described above.

In one embodiment, the E-line 190 is provided within coiled tubing that also delivers a fluid to the tractor in an open system loop. For example, in drilling operations it is typically desirable to deliver fluid to the drill bit to lubricate the bit and carry drill cuttings back up to the ground surface through the annulus between the borehole inner surface and the exterior of the tractor. In other operations, it may be desirable to deliver an intervention fluid to the bottom hole assembly (e.g., sand washing, acidizing, hole cleaning, etc.). The drilling or intervention fluid preferably passes through an internal passage of the tractor to the bottom hole assembly, and then flows up through the annulus.

In an alternative embodiment, the E-line 190 is provided within a wireline that does not include a lumen for the delivery of fluid. In other words, there is no coiled tubing. In this embodiment, the tractor is completely electrically powered and controlled. This configuration is useful for operations that do not require the delivery of fluid into the borehole, for example logging operations.

Figure 5 is a more detailed schematic illustration of the closed loop system of Figure 4 adapted for use with the variation of the Puller-Thruster Downhole Tool shown in Figure 3. The E-line 190 provides power and electrical control for the motor 154, which in turn powers the pump 156 that circulates a fluid (typically hydraulic fluid) in a closed loop through the illustrated valve assembly. The E-line 190 extends along with the coiled tubing 114 for delivering drilling/intervention fluid to a BHA 204. As noted below, other embodiments omit the coiled tubing 114 and only provide a wireline. In use, drilling/intervention fluid flows from the coiled tubing 114 into the inlet 201 of the tool body, and downhole (toward the bottom of the hole) through the mud flow passage 224. The fluid flows into the BHA 204 and ultimately exits the BHA 204 through the outlet 203. The drilling/intervention fluid that exits via the outlet 203 then flows uphole to the ground surface through an annulus defined between the tool 200 and the drilled hole 205.
An advantage of an E-line powered motor as described herein is that the tractor's performance is independent of any fluid flow pumped down to the tractor from a ground surface pump. In the illustrated embodiment, the power to operate the tractor comes from surface electricity. Hence, the tractor is completely controllable with electrical power transmission and control equipment. The power can be delivered to the motor via an E-line or wireline, without using any coiled tubing. Advantageously, for operations that do not require an intervention or drilling fluid (e.g., logging), the tractor can be operated with wireline equipment alone. This makes the system easily transportable because the costs and time associated with assembly and disassembly of coiled tubing equipment are completely circumvented. Thus an advantage of the disclosed embodiment is the ability to be rapidly deployed.

The disclosed system is useful for a variety of operations. For example, the disclosed configuration is useful if multiple tractors are employed in series, as may be necessary to traverse a "washout" in the borehole. A washout is a portion of the borehole having a relatively larger diameter than the rest of the borehole. The washout diameter may be larger than the expansion capability of the tractor's gripper assemblies, making it impossible to grip the borehole wall within the washout. However, the washout can be traversed if two tractors are employed in series and both tractors employ a closed loop hydraulic fluid circuit powered by an E-line and electric motor as disclosed above. In particular, the first tractor's motor can be electrically powered until the first tractor encounters the washout, at which point its gripper assemblies are unable to contact the borehole wall. When this condition is detected, power to the first tractor's motor can be turned off and power to the second tractor's motor can be turned on. The second tractor will then move until it encounters the washout, at which point the second tractor can be turned off and the first tractor again turned on to resume movement in a portion of the borehole having a contactable hole diameter. It will be understood that the separation between the tractors typically controls the maximum length washout that can be traversed. Separate E-lines can be provided for each tractor. Alternatively, a single E-line and a downhole control system can be provided to control which tractor receives the electrical power. In some operations, it may be desirable to simultaneously power both tractors.
Even in embodiments in which the E-line is provided within coiled tubing, skilled artisans will recognize that the fluid delivery through the coiled tubing can be selectively provided or shut off (simply by turning on or off the surface pumps) depending upon the type of operation conducted by the tractor. For operations that require tractor movement but do not require fluid for other purposes (e.g., logging), tractor control becomes easier and less expensive due to the ability to shut off the fluid delivery through the coiled tubing.

Another advantage of the E-line powered motor system, compared to the turbine-powered motor system of Figures 2 and 3, is that there is no efficiency loss associated with converting turbine rotation into electricity with a generator, or in converting a fluid flow into motor rotation. The motor is controlled entirely electrically. Still another advantage of the E-line powered motor system, compared to the turbine-powered motor system, is that it is possible to generate significant amounts of electrical power without any fluid input to the tractor, let alone an undesirably high rate of fluid input. As mentioned above, in certain tractor operations, such as delivering perforation guns, it is desirable to limit fluid flow to the bottom hole assembly. In these applications, an E-line powered motor system may be preferable.

While the illustrated E-line powered motor system may be more efficient in some cases than the turbine-powered motor system described above, the E-line system nonetheless still involves some energy losses associated with the transmission of electrical power through the E-line, as well as efficiency loses in the electric motor and the downhole pump.

In one embodiment, the control box 191 comprises a power supply, switches, connectors, displays (e.g., LED, other types of lights), a NEMA (National Electrical Manufacturers Association) box, and electrical wires. In this embodiment, the control box 191 is designed for simple on/off toggling for the delivery of power to the motor 154. In addition, various types of power regulation devices may be included, such as a rheostat to adjust power to the tractor and hence tractor speed.

In another embodiment, in addition to using the E-line 190 to deliver power and control signals to the motor 154, the control box 191 delivers power and control signals through the E-line 190 to other components of the tractor. The control box 191 can also receive signals from such other components and use the received signals to make control
decisions. In this embodiment, the control box 191 preferably comprises a power supply, electrical switches, electrical connectors, power converters, a computer server or personal computer with CPU board, display panel, data storage capability, user interface (preferably graphical), software operating system, high speed mouse, and keyboard. Software for running the control box 191 can be custom-developed. Alternatively, the software can be a modification of a commercially available program (such as "Lab View" made by National Instruments of Austin, TX).

In this embodiment, the control box 191 can deliver electrical power and control signals through the E-line 190 to various instruments, tools, and apparatuses on the tractor. The control box 191 can also be configured to present and store data collected from such instruments, tools, and apparatuses. For example, for intervention and completion operations, the tractor can include logging tools (e.g., pressure sensors, flow rate sensors, and temperature sensors), casing collar collectors, and/or gyroscopic-based positioning instruments electrically connected to the control box 191 through the E-line 190. As another example, for drilling operations, the tractor can include a Measurement While Drilling apparatus (e.g., for measuring inclination, azimuth, and depth), tension compression sub, instrumented downhole drilling motor, and/or Logging While Drilling apparatus (e.g., drilling logging tools for detecting resistivity, magnetic resonance (MRI), sonic, neutron density, density, fluid identification, gamma ray measurements) electrically connected to the control box 191 through the E-line 190. Furthermore, sensors such as speedometers, temperature sensors, pressure sensors and the like can be included within the tractor and in electrical communication with the control box 191 through the E-line 190.

**Turbine-Powered Pump**

Figure 6 is a schematic illustration of a turbine-powered pump for circulating hydraulic fluid in a closed loop for powering a downhole tool or tractor, according to an embodiment of the present invention. In this configuration, a first fluid (typically drilling/intervention fluid) that is externally pumped into the coiled tubing at the ground surface flows through the tractor and passes through a turbine 150 on its way to the remaining bottom hole assembly (typically secured to the distal end of the tractor). The flow through
the turbine 150 produces rotation of the turbine's output shaft, which drives the pump 156 through a gearbox 192. The pump 156 circulates a second fluid (typically hydraulic fluid) in a closed system loop 155. Box 158 represents a valve system, gripper assemblies, and propulsion assemblies as known in the art and preferably as described above.

Figure 7 is a more detailed schematic illustration of the closed loop system of Figure 6 adapted for use with the variation of the Puller-Thruster Downhole Tool shown in Figure 3. As the first fluid is pumped through the turbine 150, the turbine output shaft rotates to power the pump 156 via the gearbox 192 (not shown), and the pump 156 in turn circulates the second fluid through the illustrated valve assembly. In use, drilling/intervention fluid flows from the coiled tubing 114 into the inlet 201 of the tool body, and downhole (toward the bottom of the hole) through the mud flow passage 224. The fluid flows through the turbine 150, powering the pump 156. The fluid continues through the passage 224 into the BHA 204, exiting the BHA 204 through the outlet 203. The inlet 201 and outlet 203 are also shown in relation to the turbine 150 on the bottom right hand side of Figure 7. The drilling/intervention fluid that exits via the outlet 203 then flows uphole to the ground surface through an annulus defined between the tool 200 and the drilled hole 205.

A relevant advantage of using a turbine-powered pump as illustrated is that the system is flow-based, as described above. In other words, the downhole tractor can be more easily controlled by the surface pump that pumps fluid down into the coiled tubing toward the turbine. With a flow-based system, any change in the surface pump output volume flow rate linearly changes the power available to the tractor. Since the surface pump output flow rate can be relatively easily adjusted dynamically during tractor operation, the resulting adjustment of the power to the tractor provides enhanced control over the tractor's speed and pulling force. This enhanced control is available over a substantial operating range of surface pump output flow rates.

Another relevant advantage of the turbine-powered pump system is that the downhole pump is desirably directly powered by the rotating output of the turbine/gearbox combination, without any intermediate steps (e.g., electrical power generation from the turbine output, and use of such electrical power to drive an electric motor that drives the pump). As explained above, the provision of such intermediate steps can introduce a risk of a loss of efficiency in
converting the kinetic energy of the first fluid pumped into the turbine into power for driving the operation of the downhole pump. While the turbine-powered pump system still involves some efficiency losses associated with converting the first fluid's flow into mechanical rotation of the turbine, the disclosed turbine/gearbox combination advantageously provides a highly efficient conversion of the first fluid's kinetic energy.

**Pump Powered by Positive Displacement Motor**

Figure 8 is a schematic illustration of a pump powered by a positive displacement motor (PDM) for circulating hydraulic fluid in a closed loop for powering a downhole tool or tractor, according to one embodiment of the present invention. In this configuration, a first fluid (typically drilling/intervention fluid) that is externally pumped into the coiled tubing typically at the ground surface flows through the tractor and passes through a positive displacement motor 250 (sometimes referred to as a "mud motor") on its way to the remaining bottom hole assembly (typically secured to the distal end of the tractor). The flow through the positive displacement motor 250 produces rotation of the motor's output shaft 251, which drives the pump 156, typically through a gearbox 252. The pump 156 circulates a second fluid (typically a different type of fluid than the first fluid, such as, for example, hydraulic fluid) in a closed system loop 155. Box 158 represents a valve system, gripper assemblies, and propulsion assemblies as known in the art and preferably as described above.

Positive displacement motors are well known. A positive displacement motor typically comprises a stator that defines a fluid flow enclosure, a rotor that revolves within the stator, and an output shaft that rotates with the rotor. The rotor typically includes a plurality of lobes, i.e., curved or rounded projections that absorb the kinetic energy of fluid flowing through the stator, causing the rotor to revolve within the stator. Numerous suppliers sell positive displacement motors in a wide variety of sizes and performance capabilities. For example, Weatherford's [www.weatherford.com](http://www.weatherford.com) "High Performance PDM" and a "MacDrill High Temperature PDM" are suitable, as is the "Navi-Drill Ultra Series" motors sold by Baker Hughes [www.bakerhughes.com](http://www.bakerhughes.com). Positive displacement motors are also sold by numerous smaller suppliers, and are commercially available in small diameter sizes that produce significant torque at acceptable RPM levels.
Figure 9 is a more detailed schematic illustration of the closed loop system of Figure 8 adapted for use with the variation of the Puller-Thruster Downhole Tool shown in Figure 3. As the first fluid is pumped through the positive displacement motor 250, the motor's output shaft 251 rotates to power the pump 156 via the gearbox 252, and the pump 156 in turn circulates the second fluid through the illustrated valve assembly. In use, drilling/intervention fluid flows from the coiled tubing 114 into the inlet 201 of the tool body, and downhole (toward the bottom of the hole) through the mud flow passage 224. The fluid flows through the positive displacement motor 250, which drives the pump 156 through the gearbox 252. The fluid continues through the passage 224 into the BHA 204, exiting the BHA 204 through the outlet 203. The inlet 201 and outlet 203 are also shown in relation to the positive displacement motor 250 on the bottom right hand side of Figure 9. The drilling/intervention fluid that exits via the outlet 203 then flows uphole to the ground surface through an annulus defined between the tool 200 and the drilled hole 205.

A relevant advantage of using a pump 156 powered by a positive displacement motor 250 as illustrated is that the system is flow-based, as described above. In other words, the downhole tractor can be more easily controlled by the surface pump that pumps fluid down into the coiled tubing 114 toward the motor 250. With a flow-based system, any change in the surface pump output volume flow rate linearly changes the power available to the tractor. Since the surface pump output flow rate can be relatively easily adjusted dynamically during tractor operation, the resulting adjustment of the power to the tractor provides enhanced control over the tractor's speed and pulling force. This enhanced control is available over a substantial operating range of surface pump output flow rates. The pump 156 powered by a positive displacement motor 250 also allows an operator to more quickly and easily shut off the tractor simply by stopping the pumping of the open system fluid down through the coiled tubing 114 to the motor 250, or by reducing the fluid's flow rate to a level that is less than a level required to maintain operation of the pump 156.

Another advantage of a positive displacement motor 250 is that several design aspects of the motor can be varied to allow some tuning of the expected operational torque and RPM delivered to the gearbox 252. Design aspects that can be varied include the rotor pitch angle, the number of stages, and the number of lobes of the rotor. This makes it easier to optimize
the range of operation of the pump 156. Still another advantage is that positive displacement motors are a proven, reliable, and relatively inexpensive technology for utilizing the kinetic energy of a fluid.

Yet another advantage of this system is that the pump 156 can be directly powered by the rotating output shaft 251 of the motor/gearbox combination, without any intermediate steps (e.g., electrical power generation from the motor output, and use of such electrical power to drive an electric motor that drives the pump). The provision of such intermediate steps would introduce a risk of a loss of efficiency in converting the kinetic energy of the first fluid pumped through the positive displacement motor 250 into power for driving the operation of the pump 156. The disclosed motor/gearbox combination advantageously provides a highly efficient conversion of the first fluid’s kinetic energy.

Although this invention has been disclosed in the context of certain preferred embodiments and examples, it will be understood by those skilled in the art that the present invention extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses of the invention and obvious modifications thereof. Thus, it is intended that the scope of the present invention herein disclosed should not be limited by the particular disclosed embodiments described above.
WHAT IS CLAIMED IS:

1. A tool for moving within a passage, comprising:
   an elongated body;
   a closed system for converting a circulating flow of a fluid into movement of the tool within the passage, the closed system comprising:
   a gripper assembly on the body, the gripper assembly configured to utilize fluid pressure to grip onto an inner surface of the passage;
   a barrel surrounding and engaged with the body, the barrel being longitudinally movable with respect to the body, the gripper assembly being longitudinally fixed with respect to the barrel, the barrel and the body defining an annular space therebetween, wherein one or more interfaces between the barrel and the body are sealed to substantially prevent escape of fluid from the annular space to an exterior of the barrel;
   a piston longitudinally fixed with respect to the body, the piston positioned within the barrel, the piston fluidly separating the annular space into aft and forward chambers of the barrel, wherein sizes of the aft and forward chambers of the barrel vary as the piston moves longitudinally within the barrel;
   a valve assembly configured to direct fluid to and from (1) the gripper assembly and (2) the aft and forward chambers of the barrel to produce movement of the body within the passage; and
   a pump configured to circulate the fluid through the closed system; and
   a pump-powering assembly configured to power the pump, the pump-powering assembly comprising a turbine.

2. The tool of Claim 1, wherein the body has an internal fluid chamber, the body configured to be secured to a fluid conduit so that an open-system fluid flowing through the conduit flows into the internal fluid chamber of the body, the turbine configured to receive the open-system fluid flow through the internal fluid chamber of the body, the turbine having an output shaft configured to rotate as the open-system fluid flows through the turbine, wherein rotation of the output shaft powers the pump.
3. The tool of Claim 2, wherein the pump-powering assembly further comprises:
   a generator operatively connected to the output shaft of the turbine so that
   rotation of the output shaft causes the generator to produce electricity; and
   a motor configured to be powered by electricity generated by the generator, the
   motor operatively connected to power the pump.
4. The tool of Claim 2, wherein the pump-powering assembly further comprises
   a gearbox operatively connected between the pump and the output shaft of the turbine.
5. The tool of Claim 2, wherein the fluid conduit is coiled tubing.
6. A method comprising:
   providing an elongated body within a passage;
   providing a closed system comprising:
      a gripper assembly longitudinally movably engaged with the body and
      configured to utilize fluid pressure to grip onto an inner surface of the passage;
      a propulsion assembly configured to utilize fluid pressure to propel the
      body within the passage when the gripper assembly grips the inner surface of
      the passage; and
      a valve assembly configured to direct fluid to and from the gripper
      assembly and the propulsion assembly to produce movement of the body
      within the passage;
   providing a flexible conduit extending from the body and in fluid
   communication with an internal chamber of the body;
   pumping a first fluid through the flexible conduit and the internal chamber of
   the body; and
   converting kinetic energy of the first fluid into power for powering a pump,
   the pump in turn powering a flow of a second fluid within the closed system, the
   second fluid flow powering movement of the body within the passage;
   wherein power provided by the second fluid to power movement of the body
   within the passage is substantially linearly proportional to a flow rate of the first fluid
   through the flexible conduit.
7. The method of Claim 6, wherein converting kinetic energy of the first fluid into power for powering the pump comprises:
   - conveying the first fluid through a turbine downstream of the flexible conduit,
   - the turbine driving a generator that produces electrical power; and
   - powering the pump with the electrical power produced by the generator.

8. The method of Claim 6, wherein converting kinetic energy of the first fluid into power for powering the pump comprises:
   - conveying the first fluid through a turbine downstream of the flexible conduit,
   - thereby producing rotation of an output shaft of the turbine; and
   - utilizing the rotating output shaft to power the pump.

9. The method of Claim 8, wherein utilizing the rotating output shaft to power the pump comprises using a gear reduction operatively connected between the output shaft and the pump.

10. An apparatus, comprising:
    - an elongated body having an internal chamber and being configured to be positioned within a passage;
    - a flexible fluid conduit with a distal end connected to the body in fluid communication with the internal chamber;
    - a first pump connected in fluid communication with a proximal end of the flexible conduit, the first pump configured to pump a first fluid into the flexible conduit;
    - a closed system for converting a circulating flow of a second fluid into movement of the body within the passage, the closed system comprising:
        - a gripper assembly on the body, the gripper assembly configured to utilize fluid pressure to grip onto an inner surface of the passage;
        - a barrel surrounding and engaged with the body, the barrel being longitudinally movable with respect to the body, the gripper assembly being longitudinally fixed with respect to the barrel, the barrel and the body defining an annular space therebetween, wherein one or more interfaces between the
barrel and the body are sealed to substantially prevent escape of fluid from the annular space to an exterior of the barrel;

a piston longitudinally fixed with respect to the body, the piston positioned within the barrel, the piston fluidly separating the annular space into aft and forward chambers of the barrel, wherein sizes of the aft and forward chambers of the barrel vary as the piston moves longitudinally with respect to the barrel;

a valve assembly configured to direct fluid to and from (1) the gripper assembly and (2) the aft and forward chambers of the barrel to produce movement of the body within the passage; and

a second pump configured to circulate the second fluid through the closed system to thereby power movement of the body within the passage; and

a pump-powering assembly downstream of the flexible conduit, the pump-powering assembly configured to convert a flow of the first fluid into power for the second pump, such that the power for the second pump is substantially linearly proportional to an output flow rate of the first fluid from the first pump.

11. The apparatus of Claim 10, wherein the pump-powering apparatus comprises a turbine through which the first fluid flows.

12. The apparatus of Claim 11, wherein the pump-powering apparatus further comprises a generator driven by the turbine to produce electrical power, the second pump configured to be powered by the electrical power produced by the generator.

13. The apparatus of Claim 11, wherein the turbine includes an output shaft that rotates as the first fluid flows through the turbine, the output shaft powering the second pump.

14. The apparatus of Claim 13, wherein the pump-powering apparatus further comprises a gearbox operatively connected between the output shaft and the second pump.
VALVE SYSTEM, GRIFFER ASSEMBLIES AND PROPULSION ASSEMBLIES

CLOSED LOOP OF HYDRAULIC FLUID FLOW

FIG. 4
A. CLASSIFICATION OF SUBJECT MATTER

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)
E21B

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C

See patent family annex

Date of the actual completion of the international search
23 January 2008

Date of mailing of the international search report
31/01/2008

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Authorized officer
van Berlo, Andre
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