WELLBORE ESP SYSTEM WITH IMPROVED MAGNETIC GEAR

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ABSTRACT
An electrical submersible pump system includes at least one electric motor coupled to a mechanism for hanging the pump system in a wellbore. At least one magnetic gear assembly is coupled at its input to an output of the at least one electric motor. A protector assembly is coupled at an input thereof to an output of the at least one magnetic gear assembly. A pump is functionally coupled at its input to a rotational output of the protector assembly. The protector assembly includes a tortuous path assembly having one end of each of a plurality of tortuous paths therein in fluid communication with fluid in the wellbore. The tortuous paths each have another end in fluid communication with dielectric fluid disposed within the protector, the at least one magnetic gear and the at least one electric motor.
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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND

[0003] This disclosure relates generally to the field of electrical submersible pumps (ESP) used to lift fluids out of wells drilled through permeable formations. More specifically, the disclosure relates to ESP systems having magnetic gears to provide a torque transmission connection between the motor and the pump used.

[0004] U.S. Pat. No. 7,549,467 issued to McDonald et al. describes a wellbore pump which includes a motor disposed in the wellbore. The motor is supplied by power from a source external to the wellbore. The pump includes a magnetic gear member rotationally coupled at an input thereof to an output of the motor, and a pump coupled at its input to an output of the magnetic gear member.

[0005] Electrical connection to the ESP system, transfer of torque from the motor to the pump and sealing the pump against wellbore fluid pressure while maintaining dielectric fluid in the motor and gear assembly are all considerations in the design of an ESP system. Accordingly, there is a need for improved ESP systems taking into account such considerations.

SUMMARY

[0006] An electrical submersible pump system includes at least one electric motor coupled to a mechanism for hanging the pump system in a wellbore. At least one magnetic gear assembly is coupled at its input to an output of the motor. A protector assembly is coupled at an input thereof to an output of the at least one magnetic gear assembly. A pump is functionally coupled at its input to a rotational output of the protector assembly. The protector assembly includes a tortuous path assembly having one end of each of a plurality of tortuous paths therein in fluid communication with fluid in the wellbore. The tortuous paths each have another end in fluid communication with dielectric fluid disposed within the protector, the at least one magnetic gear and the at least one electric motor.

[0007] Other aspects and advantages of the invention will be apparent from the description and claims which follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is an overview of an example ESP system.

[0009] FIG. 2A shows an example implementation of the ESP system of FIG. 1 wherein data transmission from the ESP system and control thereof may be remotely performed over a network, such as the Internet.

[0010] FIG. 2B shows an example wellbore hanger/outlet.

[0011] FIG. 2C shows an example of coiled tubing conveyance of an ESP system.

[0012] FIG. 3 shows an example upper portion of the ESP system of FIG. 1.

[0013] FIG. 4 shows an example electric motor of the example ESP system.

[0014] FIG. 5 shows an example connection between a magnetic gear and a flow section including pressure compensation.

[0015] FIG. 6 shows the example connection in more detail.

[0016] FIGS. 7 and 8 show cut away views of an electrical contact (starpoint) sub.

[0017] FIG. 9 shows an example of a flexible shaft assembly.

[0018] FIG. 10 shows an example of a torque through connector.

[0019] FIG. 11 shows internal details of an example protector with a tortuous path assembly.

[0020] FIG. 12 shows an example segment of the tortuous path assembly in more detail.

DETAILED DESCRIPTION

[0021] An example ESP system 10 that may be conveyed into a well using jointed tubing, wireline, slickline or coiled tubing, for example, is shown generally in FIG. 1. The ESP system 10 may include an upper or "top" sub 12 that is configured to make connection to an end of one of the foregoing conveyance devices for movement into and out of the wellbore. A lower end of the ESP system 10 may include a "muleshoe" sub 28. The muleshoe sub 28 may be added below a pump 26 to provide protection while running into the wellbore during deployment, and to provide a mounting location for a pump intake memory gauge. In addition, the muleshoe sub 28 may provide a suitable location for inner bore sealing as part of a well barrier control mechanism. Both a single-shot sealing option, and a pressure responsive valve with multiple stable positions may be considered as suitable example options for wellbore sealing below the muleshoe sub 28. For purposes of this disclosure, the term "up" is intended to mean in a direction toward the outlet of a wellbore, while "down" is intended to mean in the opposite direction. Corresponding terms may include "upper end" and "lower end" with reference to various modules or sections that make up the ESP system 10.

[0022] The top sub 12 may be followed successively by a "star point sub" 13 and a motor 14, which in the present example may be an electric motor. The star point sub 13 may include one or more sensors and control devices related to operation of the ESP system and the motor 14. The star point sub 13 may also be used to make electrical connection between a cable (see FIG. 2). The motor 14 may be coupled at its lower end to a magnetic gear assembly 16. In the present example, the magnetic gear assembly 16 accepts as rotational input from the motor 14 high rotational speed and low torque, and converts such rotation therein into low rotational speed at correspondingly (inversely) proportional high torque. A protector 18 may be similar in operating principle to the protector ordinarily used in ESP systems and may be configured to exclude wellbore fluid at existing wellbore pressure and temperature from entering the magnetic gear assembly 16 and the motor 14. The protector 18 may also axially decouple the magnetic gear assembly 16 and the motor 14 from axial and lateral loading generated by the pump 26. Not shown in FIG. 1 for clarity is a flow shroud that diverts wellbore fluid flow from the pump outlet (122 in FIG. 11) so that it can travel in an annular space outside the ESP system 10 and be sealingly diverted into a tubing or coiled tubing and thence flow upwardly in the wellbore.
The present example of ESP system 10 may be of modular design, and enable first lowering the pump 26, including the muleshoe sub 28, a flex sub 27 to enable relative axial deflection between the upper components (terminating at field coupling sub coupled to the upper end of a pump discharge sub 20, and thence coupled to a lower end of the protector 18 and the components described above. The pump 26, flex sub 27, pump discharge sub 20 and a field coupling sub 22 may be inserted into the well first, to be followed by the foregoing described components beginning with the field coupling sub 22. The entire ESP system 10 may also be lowered into the wellbore as an assembled unit. The pump 26, flex sub 27, protector 18, magnetic gear assembly 16, motor 14 and star point sub may each be enclosed in a respective pressure resistant housing and may be coupled by threads, locking rings or any other device known in the art for joining housing segments together, end to end.

FIG. 2A shows the example ESP assembly 10 of FIG. 1 as it may be deployed in an example wellbore. The pump 10 assembly may be deployed at the end of threaded, jointed tubing 42, extending from the pump 10 to a wellhead 40. Selective length adjustments of the jointed tubing to ensure proper axial positioning of the ESP system 10 may be made using one or more selected short length "pump" joints 48 of threaded tubing. Electrical and/or optical signal cable 46 may extend from top sub (12 in FIG. 1) along the exterior of the jointed tubing 42, retained thereon by bands 44 up to a dual orifice hanger disposed in the wellhead 40. An example of such a hanger is shown in cross section at 41 in FIG. 2B. Tubing and fluid flow exit from the wellhead 40 may extend to a flow tee 38 and to fluid processing devices (not shown) proximate the surface. Electrical connections from the wellhead 40 may extend to a junction box 36 wherein a power supply (not shown) may be provided to supply electrical power to operate the motor (14 in FIG. 1) and to strip off sensor signals from the cable 46 and conduct them to a signal communication subsystem 34 so that data signals from the ESP assembly 10 and control signals communicated thereto may be transferred to and from a remote control station 30 such as may communicate over a secure network such as a secure server 32 connected to the Internet.

In other examples, the pump system 10 may be inserted into and removed from the wellbore using a coiled tubing unit. An example of the foregoing is shown in FIG. 2C and may include a storage reel 150, a coiled tubing 152 therein, a roller assembly 154 and a tubing injector 156 coupled to the wellhead 40. The cable (46 in FIG. 2B) may be disposed inside the coiled tubing 154 in such examples. See, as a non-limiting example, U.S. Pat. No. 5,285,008 issued to Sas-Jaworsky.

FIG. 3 shows an example connection between the star point sub 13 and the motor 14. The star point sub 13 may include various forms of sensors 54, for example pressure, temperature and flow sensors. The star point sub 13 may include electrical feedthroughs 130 to enable external electrical connection to the cable (46 in FIG. 2A) to be transposed to internal electrical connections between the various "subs" or components of the ESP system. In FIG. 3, connection 56 to the motor (14 in FIG. 1) is shown wherein the feedthroughs 130 are visible. In some examples, the feedthroughs 130 may not extend past the motor. FIG. 3 also shows an example connection between the star point sub (14 in FIG. 1) and the top sub (12 in FIG. 1). The motor housing and star point sub housing may be coupled by threads 8 as shown in FIG. 3.

FIG. 4 shows an example connection 56 between the motor 14 and the magnetic gear assembly (16 in FIG. 1). The motor 14 output shaft may be rotationally connected by splines or other connection to an input shaft of the magnetic gear assembly (16 in FIG. 1). The motor housing and the magnetic gear housing may be directly connected, such as by threads, or may include a double-male threaded coupling 8A threadedly coupled to female threads at adjacent longitudinal ends of the motor housing and the magnetic gear assembly housing.

FIG. 5 shows connection between the lower end of the magnetic gear assembly 16 and an upper portion of the protector 18. The protector 18 may consist of a thrust section, a pressure compensation section and a tortuous path section, shown in FIG. 5 at 62, 64, and 68, respectively. A drive shaft 99 may be rotationally coupled to the output of the magnetic gear assembly 16 using splines or any other torque transmitting fitting. The tortuous path section 68 will be further explained with reference to FIGS. 11 and 12.

The thrust section 62 is shown in more detailed view in FIG. 6. The thrust section 62 may include bearings 62A to isolate thrust loading and lateral loading in the drive shaft 99 from the magnetic gear assembly (16 in FIG. 1), while freely transmitting rotation therethrough. The pressure compensation section 63 may include a flexible bladder or reservoir 64 to maintain pressure of hydraulic or other dielectric fluid filling the interior of the protector 18 at pump discharge pressure so that no wellbore fluid will enter the interior of such components and may compensate the system volume for temperature changes. The components located above the protector 18 may include provision for communication of hydraulic pressure from the bladder or reservoir 64 to the interior of such components so that wellbore fluid will be less likely to enter any or all of them by reason of differential fluid pressure.

FIG. 7 shows a cut away view of an example star point sub 13A. The star point sub 13 may include a pressure resistant, high strength housing 13A that may be connected at one end to the top sub (12 in FIG. 1). O-rings 13J may sealingly engage the lower end of the star point sub 13 to the motor (14 in FIG. 1) housing, in an end section 13B sized to fit within a corresponding opening in the motor housing. A suitable opening 13C may be provided in the housing 13A wall to enable passage of an electrical contact (see FIG. 3) between contact pins and the motor (14 in FIG. 1).

Electrical connection to one of the electrical conductors in the cable (46 in FIG. 2A) may be made to a bus bar ring 13F disposed in an annular space in the upper part of the housing 13A. The bus bar ring 13F may be supported at the end of a conductor pin 13E insulatingly supported in an appropriately sized annular space to limit movement of the conductor pin 13E. A lower electrical contact 13D makes mechanical and electrical contact with conductor pins (see FIG. 3) to provide an electrical conductor path to the motor (14 in FIG. 1). The conductor pin 13E in FIG. 7 may be the "neutral" conductor in a two pole, single phase electrical power system, or may be one of three conductors in a three phase, delta connected system. Conductor pin 13E may also be the neutral conductor in a four-wire, wye connected three-phase power system. In the present example, the conductor pin 13E may be shorter than the other conductor pins in the starpoint sub 13. In the present example, the conductor pin 13E may terminate at its upper end in a bus bar ring 13F. FIG. 8 shows a similar cut away view of the starpoint sub 13,
wherein a long conductor pin 13G may make electrical contact with a cable conductor other than the neutral conductor. The bus bar ring 13F may have an opening for each long conductor pin 13G to enable passage therethrough. The long electrical conductor pin 13G may make electrical contact with the electrical cable (46 in FIG. 1) through a surface cable contact 131.

Fig. 9 shows a cut away view of the lower end of the protector 18 coupled to the flex sub 27. The upper end of a flex shaft 104 may be coupled to one end of a torque through connector 102. The torque through connector 102 may be connected at its other end to the driveshaft (99 in FIG. 5). The flex shaft 104 may be sufficiently flexible to absorb any bending loads occurring between the turbine through connector 102 and the pump rotor 26B, which is connected at its upper end to the bottom of the flex shaft 104.

Fig. 10 shows an example of the torque through coupling 102. An opening may be formed in the bottom of the drive shaft 99 to slidingly receive an input mandrel 102A. When the mandrel 102B is inserted into the opening in the drive shaft 99, it may be locked in place with a locking pin 102C. An output mandrel 102A may be rotationally and axially locked into the input mandrel 102B by rotating the output mandrel 102A one quarter turn so that a keyed coupling 102C, 102D is engaged. The flex shaft (104 in FIG. 9) may be coupled to the output mandrel 102B by a threaded connection 102A.

Figs. 11 and 12 show, respectively, a seal section and a tortuous path assembly disposed in the seal section. The tortuous path in the seal assembly for the ESP system communicates ambient pressure to dielectric fluid filling the motor, while sealing wellbore fluids from the motor. The tortuous path includes a series of tubes and chambers circumferentially surrounding the pump drive shaft (99 in FIG. 10). Communication tubes, upper and lower seal shafts provide additional defense from wellbore fluid ingress into the seal section. One communication tube has an end in fluid communication with the wellbore fluid and another has an end in fluid communication with the motor dielectric fluid. The communication tubes extend into the seal section from opposite directions and each has an opening opposite from where the respective tube enters the chamber. A port is provided in the intake tube, most remote from the upper shaft seal, and a port in the discharge tube is provided to the upper shaft seal. Thus a tortuous path is provided between the lower and upper shaft seal's thereby minimizing pressure differential, leading to deterioration in seal shaft integrity.

Fig. 11 shows the relevant section of the protector 18 and the location of the tortuous path assembly therein. An upper portion of the protector may include a shaft seal 110 and a thrust bearing assembly 114 (also shown in FIG. 6 at 62). Thermal expansion of the dielectric fluid for the motor may be compensated by a compensating reservoir 116 (also shown in FIG. 6 at 64). Another shaft seal 118 may be disposed at a selected position along the drive shaft 99, generally at the upper end of the tortuous path section 112. The tortuous path section 112 may have a lower shaft seal 120 at its lower end. The pump discharge 122 is shown just below the tortuous path section.

Fig. 12 shows an example of a segment of the tortuous path assembly 112. Wellbore fluid may be applied to an intake tube 112B at one end of the assembly 112. A discharge tube 112A may be disposed at the same end of the assembly 112 as the intake tube 112B inlet. Wellbore fluid pressure may be forced to return through the discharge tube 112A by suitable arrangement of another, similarly configured segment disposed above the one shown in FIG. 12. By having fluid flow through such tubes and have the flow direction reversed in each section, a sufficiently tortuous path may be provided such that intrusion of wellbore fluid into the dielectric fluid may be minimized, while maintaining a U-tube effect in all inclinations.

While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. An electrical submersible pump system, comprising:
   - at least one electric motor coupled to a mechanism for hanging the pump system in a wellbore;
   - at least one magnetic gear assembly coupled at its input to an output of the motor;
   - a protector assembly coupled at an input thereof to an output of the at least one magnetic gear assembly; and
   - a pump functionally coupled at its input to a rotational output of the protector assembly;
   wherein the protector assembly comprises a tortuous path assembly having one end of each of a plurality of tortuous paths therein in fluid communication with fluid in the wellbore, the tortuous paths each having another end in fluid communication with dielectric fluid disposed within the protector, the at least one magnetic gear and the at least one electric motor.

2. The pump system of claim 1 wherein the pump comprises a progressive cavity pump.

3. The pump system of claim 1 further comprising a flexible torque transmission shaft disposed between a rotational output of the protector assembly and a rotational input of the pump.

4. The pump system of claim 3 wherein the protector assembly comprises a jointed coupling engaged at one end with the bottom of a drive shaft extending through a housing disposed below the magnetic gear assembly, the jointed coupling engaged at its other end to the flexible torque transmission shaft.

5. The pump system of claim 4 wherein the drive shaft is rotatably supported in its housing at both its longitudinal ends by bearings, at least one of the bearings configured to accept thrust loading from the drive shaft to isolate the thrust loading from the at least one magnetic gear assembly.

6. The pump system of claim 5 wherein the tortuous path assembly is disposed at a lower end of the drive shaft housing.

7. The pump system of claim 1 wherein the hanger mechanism comprises a coupling to join to a lower end of a coiled tubing, and wherein an electrical cable coupled to the pump system is disposed within the coiled tubing.

8. The pump system of claim 1 further comprising an electrical connector sub including a connector ring in contact with a first contact pin extending from the at least one electric motor and at least one contact slot in contact with at least a second, longer contact pin extending from the motor.

9. The pump system of claim 1 wherein synchronization is mechanically maintained between each of a plurality of magnetic gear assemblies, and of each of a plurality of electric motors.
10. The pump system of claim 1 further comprising a variable volume reservoir disposed within the protector assembly and in fluid communication with the dielectric fluid end of the tortuous path assembly.

11. The pump system of claim 1 wherein the pump is the furthest downhole rotating part of the pump system.

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