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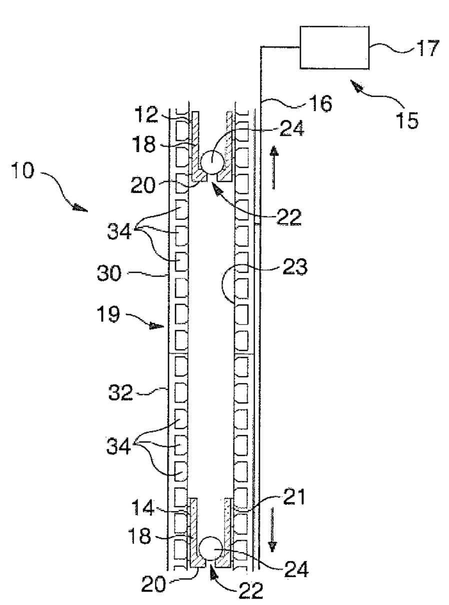

FIG. 1

(57) Abstract: The invention relates to a pump for lifting fluid from a wellbore. The pump comprises a first piston and a second piston, each piston being configured for linear reciprocal movement generated by magnetic fields. A control system is operable to control the magnetic fields to generate substantially concurrent opposed movement of the first and second pistons so as to provide a substantially continuous flow of fluid from the wellbore. The control system may comprise one or two power cables connected to Variable Speed Drives (VSDs).

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Improved Pump for Lifting Fluid from a Wellbore

Field of the Invention

This invention relates to an improved pump for lifting fluid from a wellbore. Such pumps are commonly referred to as either electrical submersible pumps (ESPs) or hydraulic submersible pumps (HSPs) depending upon the nature of the drive mechanism. In particular embodiments, the invention relates to a pump having dual pistons configured for deployment downhole to pump hydrocarbons and/or water from a well.

Background to the Invention

It is known to use artificial lift to boost production and increase the recovery of oil and/or gas from a well when the reservoir pressure alone is not sufficient to flow fluids to the surface. In addition, water can build up in a well and this can hamper the production of hydrocarbons.

By placing a submersible pump in a wellbore, it is possible to lift fluids (typically oil or water) to the wellhead. This effectively lowers the pressure in the wellbore making production flow viable and/or increasing the production rate.

Such artificial lift is typically performed by a centrifugal pump which is placed in the well during completion. Due to their length and the need for high rotational speed, centrifugal pumps need to be placed in a relatively long and straight section of the well. In practice, this is difficult to achieve due to well curvature. If the well is curved, the pump shaft will bend every time it rotates and this will result in vibration and wear which will lead to a short operational lifetime.

As described in US 7,857,065 it is known to use electromagnetism to drive a well tool, which may, for example, be configured as a pump. However, such pumps produce pulsating flow which includes periods of backflow each time the piston is lowered to begin a new stroke. Accordingly, such pumps are not particularly efficient and, like the above, they require a relatively straight well section in which to operate so as to avoid undue stresses and limited lifetime.

US 6,926,504 discloses an ESP for use in a wellbore, which comprises a stator, an armature that linearly reciprocates relative to the stator, a travelling valve that reciprocates with the armature, a standing valve connected to the stator housing and multiple fishing necks to allow for the travelling valve and standing valve to be separately retrievable from the wellbore. Accordingly, these pumps also produce pulsating flow and periods of backflow each time the armature is lowered to begin a new stroke.

It is therefore an aim of the present invention to provide an improved pump for lifting fluid from a wellbore, which addresses at least some of the afore-mentioned problems.

Summary of the Invention

According to a first aspect of the present invention there is provided a pump for lifting fluid from a wellbore, the pump comprising: a first piston and a second piston, each piston being configured for linear reciprocal movement generated by magnetic fields; and a control system operable to control said magnetic fields to generate substantially concurrent opposed movement of the first and second pistons so as to provide a substantially continuous flow of fluid from the wellbore.

Thus, embodiments of the present invention provide a pump which can be used to generate artificial lift (e.g. of hydrocarbons or water) and which, due to the opposite direction of movement of the two pistons during each pump stroke means that there is substantially always one piston performing an upstroke so as to provide smooth, near continuous flow from a well. Furthermore, the fact that the pump comprises two separate pistons allows each piston to be shorter in length than a single piston configured to generate the same flow rate and also allows each piston to move over a shorter distance, therefore requiring shorter straight well sections for the pistons to move back and forth in. Consequently, each piston is subjected to less physical stress and therefore the lifetime of the pump should increase accordingly. The pump may be configured for lifting one type of fluid or two or more different types of fluid (at the same or at different times). Thus, the pump may be configured for lifting a mixture of fluids.

The present pump is also believed to be more reliable than a centrifugal pump since the only moving parts in the pump are the two pistons.

In addition, the power consumption (meaning the power drawn from the grid) by the present pump will be relatively constant since there will substantially always be one piston travelling upwardly while the other travels downwardly. This is advantageous over a single piston design whereby the power will fluctuate between high and low for each successive upwards and downwards stroke.

Embodiments of the present invention are particularly suited to use in wellbore applications, both on-shore and off-shore, including subsea wells. As artificial lift is especially desirable in deep water applications and those involving heavy oil, the present pump may be configured for these applications. Moreover, the present pump could be configured for topside circulation or arranged on or adjacent the seabed so as to pump several wells together.

The control system may comprise a single power cable which is configured to generate the substantially concurrent opposed movement of the first and second pistons. In which case, the control system may be limited to providing synchronous movement of the first and second pistons. Note, with this arrangement, the two pistons will reach the end of their strokes at the same time and there will be a momentary stop while each piston changes direction. Thus, although there will be no periods of backflow, the upwards flow may pause momentarily at the ends of each stroke.

Alternatively, the control system may comprise two power cables, each one being configured to control a single one of the first and second pistons. The two cable arrangement would additionally allow for individual control of each piston (e.g. resulting in asynchronous, non-concurrent or non-opposing movement). In which case, the control system can be configured to ensure that the pistons do not stop and change direction at the same time to eliminate any momentary pauses in upwards flow. This can be achieved by controlling the pistons so that there is always at least one piston travelling in the direction of desired fluid flow (e.g. in an upstroke direction). More specifically, this can be achieved by maintaining the piston travelling in the upstroke direction for at least the duration of the time taken for the other piston to change direction, travel in a downstroke direction and change direction again. Thus, the pistons can be controlled to move in the same (e.g. upstroke) direction for a short period of time at the end of each stroke.

The pump may comprise a first linear motor stator and a second linear motor stator disposed in-line so as to respectively generate the linear reciprocal movement of the first and second pistons. The linear motor stators may each comprise a set of electrically conductive coils (windings) configured to generate the magnetic fields required to move the pistons. More specifically, the linear motor stators may be configured as three-phase electric motors.

The control system may comprise at least one variable-speed drive (VSD) (also known as a variable-frequency drive, an adjustable-frequency drive, an AC drive, a micro drive or an inverter drive and which is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage). The control system may further comprise at least one three-corded power cable configured to provide three-phase electrical power to at least one stator. As such, the at least one power cable may comprise three conductors (A, B, C) arranged to carry three alternating currents of the same frequency but which have a phase difference such that they reach their peak instantaneous values at three different times. More specifically, the current in each conductor may have a phase difference of one third (120 degrees) of one cycle of the electric current to provide constant power transfer over each cycle thereby helping to reduce motor vibrations. Another advantage of using a three-phase motor is that the instantaneous currents may sum to zero to provide a balanced load. Each coil in the at least one stator may be connected to one of the three-phase conductors of the at least one power cable. It is therefore easy to control the direction of motion generated by the linear three-phase motor by the order in which the coils associated with the three-phase conductors (A, B, C) are arranged along the direction of motion.

The stators may be permanently disposed on the production tubing. For example, the stators may be provided on one or more pre-configured sections of production tubing, which are in turn connected in series with other standard sections of production tubing. The stators may be mounted on the exterior of the production tubing or integrated within the thickness of the production tubing itself. This is advantageous in that the stators need not be accommodated within the inner diameter of the production tubing to form an obstruction therein and therefore the full bore of the production tubing can be utilized for fluid flow. For example, each set of electrically conductive coils (windings) may be wound around (or in the thickness of) the production tubing.

In an embodiment where the two pistons are controlled by one VSD through one three-phase power cable, the order of the coils provided for the first stator may be different to the order of the coils provided for the second stator in order to effect the opposed movement of the first and second pistons. For example, the first stator may comprise coils A, B and C, which are respectively connected to the three-phase conductors of the power cable (which are correspondingly denoted A, B and C), and the coils may be arranged around the first stator in the order A above B above C such that, upon start-up the first piston is urged in a downwards direction. By contrast, the second stator may comprise coils A, B and C, which are also respectively connected to the three-phase conductors of the power cable (denoted A, B and C), and the coils may be arranged around the second stator in the order A above C above B such that, upon start-up the second piston is urged in an upwards direction. It will be understood that switching the order of any two of the coils (i.e. phases) in the second stator compared to the first stator will have the effect of changing the direction of motion of the corresponding piston in a similar manner as is commonly employed for changing the direction of rotation of a three-phase rotary motor. More generally, each stator may comprise coils ordered in opposite directions (i.e. top to bottom, ABC, and bottom to top, CBA) so as to make the pistons move in opposite directions (i.e. towards and away from each other) when a magnetic field is generated by the coils by operation of the control system.

In an embodiment where the two pistons are controlled by two VSDs through two separate three-phase power cables, the pistons can be controlled independently from each other. Accordingly, this solution requires communication and/or coordination between the two VSDs in order to effect the substantially concurrent opposed movement of the first and second pistons, but gives a higher degree of system flexibility. The communication and/or coordination may be achieved by the use of position sensors, configured to relay positional information through, for example, a fibre optic cable or each VSD may estimate the position of each piston. One VSD can be configured to operate as a master and the other VSD can be configured to operate as a slave. Alternatively, the VSDs may employ two-way communication. It is also possible for this system to control different stroke lengths for each piston.

In either of the above embodiments, each stator may comprise multiple sets of coils (e.g. ABCABC and ACBACB) so as to generate the required force and distance of travel of each piston. Each set of coils may be connected in series or in parallel. It should be noted that whether the coils are connected in series or in parallel does not affect the operation of the pump but the configuration can be determined so as to provide a desired power output or other characteristic. For example, high voltage linear motors are generally connected in series but coils connected in parallel may be useful in the event of a fault developing in one coil since it may not prevent the other coils from operating.

The control system may be operable from a topside or subsea location to send appropriate signals through the power cable to operate the pump as desired. For example, the control system may be configured to alter the speed of operation of the pump by adjusting the frequency of an applied voltage and current.

A position indicator may be provided to relay signals to the control system to confirm that the pistons are operating as intended. The position indicator may be constituted by a series of relatively small magnets provided along the length of each piston or stator for generating feedback through the at least one power cable, on a frequency other than that which is driving the pistons. The magnets may be arranged to generate a distinctive signal in the stator coils (e.g. including a notch at a position corresponding to a missing magnet at the centre of the piston as it moves along the stator).

One or more stops may be provided to limit the movement of each piston. For example, a stop may be provided at each end of each stator. The stops may be electrically activated, for example, by providing coils arranged to generate a force opposite to the movement of the piston to stop the piston before it is moved in the opposite direction. Such stops may also be employed to ensure that the pistons are at a desired position before the stators are energised and the pumping begins. Alternatively, the stops may be passive and may be constituted by permanent magnets or mechanical stops provided at one or more ends of each stator. Such permanent magnets or mechanical stops may be employed to hold the pistons in the wellbore when the pump is not activated (i.e. when the coils are not powered). A combination of electrically activated and passive stops may also be used.

One or more switching elements may be provided for increased control. For example, switching elements could be provided to control the movement of each piston independently using a single three-phase power cable. The switching elements may be controllable using different frequencies on the three-phase power cable to those employed to operate the pump (e.g. a superimposed high frequency signal).

The switching elements may be configured to turn each piston on and off and/or to turn each coil or set of coils on and off. Furthermore, switching elements may be provided to enable the pistons to move in the same (as opposed to opposite) directions. In particular embodiments, switching elements may be employed to ensure that the movement of the first and second pistons is phased so that both pistons do not stop and turn at exactly the same time (i.e. so a continuous upwards force is provided). It will be understood that such operation is consistent with the pistons having substantially concurrent opposed movement since, for the majority of each stroke the pistons will be moving in opposite directions.

The switching elements may be configured for use in high temperature environments such as may be experienced downhole in a wellbore. For example, the switching elements may comprise silicon carbide transistors.

The switching elements may comprise solid state switches and/or reed switches. In certain embodiments, reed switches (activated by a magnetic field) may be used to control solid state switches. In some embodiments, a fibre optic cable may be provided to activate the switching elements.

The power cable or cables may be disposed between the production tubing and a casing of the well. In one embodiment, the power cable or cables may be attached to or integrated into the outer surface of the production tubing.

Each piston may be configured such that it can be retrieved and replaced without requiring extraction of the production tubing. For example, each piston may be provided with an attachment element (e.g. in the form of a lifting lug) for attaching to a wireline intervention tool.

Each piston may comprise a magnetic element which may be constituted by a permanent magnet or an electromagnet. Alternatively, the first or second piston may comprise a squirrel cage rotor (also known as a short-circuited rotor piston) comprising permanently short-circuited windings, usually un-insulated, around the periphery of the piston and which are joined by continuous end rings. In a particular embodiment, each piston may comprise one or more ring magnets. In certain embodiments, the magnets may be arranged in a Halbach array. Each magnetic element may have a high critical point temperature (for example, of between 150 and 350 degrees Celsius, typically 200 degrees Celsius). Where the magnetic element is constructed as an electromagnet, the power for the electromagnet may be provided by inductive coupling.

It will be noted that, where the control system comprises one VSD and one power cable it is possible to effect the opposed motion of the pistons by changing the direction of the magnetic field generated by the coils for the first and second stators either by switching two of the three-phase conductors of the power cable between the first and second stators or by re-ordering the coils themselves.

Each piston may include a non-return valve allowing fluid to flow through the piston in an upwards (production) direction and preventing fluid from flowing through the piston in a downwards direction. In other embodiments, a valve may be provided which is independent of at least one piston.

It will be understood that, in operation, the pump will be capable of isolating upstream fluid from downstream fluid. This may be achieved by the pistons being configured to seal against the production tubing so that fluid is only permitted to flow through the pistons themselves. In other embodiments, a seal may be provided which is independent of at least one piston.

An advantage of embodiments of the present invention is that, even if the pump is not operating (either because it is not required or because it is broken), it is still possible for fluids to flow through the pump to the surface so that production can continue as long as the fluid has sufficient force to open the valves.

It may be desirable to place the pistons in a (temporary) container configured to prevent the pistons from sticking to the production tubing by magnetic forces during an intervention (e.g. when it is necessary to deploy and/or retrieve the pistons by wireline). The container may be lowered when an intervention tool is deployed, at least one piston moved into the container and the container retrieved from the wellbore. Advantageously, the container may be configured to eliminate or reduce magnetic fields on the outside of the container and/or penetrating the container. It may also be desirable to place the pistons in a cylinder made of non-magnetic materials to prevent the pistons from attaching to a drilling deck or other equipment during handling.

Although an advantage of using a single power cable is that it is not necessary to synchronise the movement of the pistons during use, if one or more pistons need to be removed and replaced, it may be necessary to perform an initial synchronisation of the pistons. This may be performed using switching elements to bring each piston into a desired start position. In embodiments where two power cables and two VSDs are employed, synchronisation can be performed without using switching elements as the VSDs can be controlled to bring each piston to a desired position.

The stators may have an inner liner comprising non-conductive material. Furthermore, the first and second pistons may have at least one external scraper ring configured to prevent material from attaching to the inner liner.

Although not required, in some embodiments, sensors may be provided for measurement and/or additional control.

Each piston may be configured to provide a pump stroke which is the same order of length as the length of the piston. For example, each piston may be 4m long and may be configured to travel 4m in each direction during operation.

The pump length is not limited but may, for example, be at least 10m long and in some embodiments may be 20m, 30m or 50m long. For comparison, a typical section of production tubing may be 12m long.

It will be understood that, the dual piston nature of the pump allows for the pump to be configured around bends or kinks in the wellbore since one piston and stator may be provided above a bend and the other piston and stator may be provided below the bend.

Accordingly to a second aspect of the invention, a system of two or more pumps according to the first aspect may be provided to lift fluids from a wellbore.

Brief Description of the Drawings

Specific embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a schematic cross-sectional view of a pump in accordance with a first embodiment of the present invention in which the control system comprises one VSD and one three-phase power cable, in an outward stroke configuration;

Figure 2 shows a schematic view of the three separate conductors of the three-phase power cable configured to operate the pistons shown in Figure 1;

Figure 3 shows a schematic cross-sectional view of a pump in accordance with a second embodiment of the present invention in which the control system comprises two VSDs and two three-phase power cables, in an outward stroke configuration;

Figure 4 shows a schematic view of the three separate conductors of each three-phase power cable configured to operate the pistons shown in Figure 3;

Figure 5 shows a side perspective view of a portion of a piston for a pump in accordance with a third embodiment of the present invention, which comprises a squirrel cage rotor; and

Figure 6 shows a schematic part cross-sectional view of a portion of a pump in accordance with a fourth embodiment of the present invention, in which the piston shown includes a magnetic position indicator.

Detailed Description of Certain Embodiments

With reference to Figure 1, there is illustrated a pump 10 for lifting fluid from a wellbore in accordance with a first embodiment of the present invention. The pump 10 comprises a first piston 12 and a second piston 14. Each piston 12, 14 is configured for linear reciprocal movement generated by magnetic fields. A control system 15 is operable to control the magnetic fields to generate substantially concurrent opposed movement of the first and second pistons 12, 14 so as to provide a substantially continuous flow of fluid from the wellbore. The control system 15 comprises a single three-phase power cable 16 and a variable speed drive (VSD) 17 arranged to generate the substantially concurrent opposed movement of the first and second pistons 12, 14, as will be described in more detail below.

When employed downhole, the power cable 16 is disposed between the production tubing 19 and the production casing (not shown), or integrated in the production tubing. For example, the power cable 16 may be attached to the outside of the production tubing 19, attached to the inside of the production casing or somewhere in-between. It will be understood that in permanent installations the power cable 16 has to be outside of the production tubing 19 or integrated into the production tubing 19 in order to be able to install the pump 10 in the cased well and to avoid the need for the cable to take up valuable space within the production tubing 19 itself.

Each piston 12, 14 comprises a hollow cylindrical body 18 provided on a substantially planar base 20. The base 20 defines a central fluid inlet 22 into the body 18. A non-return valve 24 is arranged to selectively open and close the inlet 22 depending on the direction of fluid flow. As illustrated, the valve 24 will open to allow flow in an upwards direction (e.g. to pump fluids from a well) but will close to prevent fluid flow in a downwards direction. The body 18 of each piston 12, 14 is configured to seal against the production tubing 19 so that fluid is only permitted to flow through the valves 24. The body 18 is further equipped with scraper rings 21 to prevent, e.g. scale, sand or wax, from attaching to an inner liner 23 provided on an inner surface of the production tubing 19, at least in the vicinity of the pistons 12, 14. The inner liner 23 is preferably made from a hard material to ensure that all wear is on the retrievable pistons 12, 14. The inner liner 23 may be also be made of a non-conductive material (e.g. having a conductivity lower than 100 (S/m) at 20 °C) to prevent eddy currents due to varying magnetic fields. It should also be noted that the length of each piston 12, 14 may differ from that shown in Figure 1. For example, each body 18 may extend over a greater portion of the production tubing 19. Each of the pistons 12, 14 further comprise a series of ring magnets provided along the body 18.

A first linear motor stator 30 and a second linear motor stator 32 are provided in the section of production tubing 19 shown. Each stator 30, 32 is configured for three-phase electrical power provided by the power cable 16 (which comprises three-phase conductors). As shown in Figure 1, the stators 30, 32 each comprise a set of electrically conductive coils 34 wound within the production tubing 19. Each coil 34 is in turn connected to one of the three-phase conductors of the power cable 16.

The control system 15 is provided to send appropriate signals (e.g. voltage and current waveforms or a carrier wave) from the VSD 17 through the power cable 16 to operate the pump 10 as desired. Thus, the VSD 17 is configured to switch automatically in order to drive the pistons 12, 14 in respective inwards and outwards strokes at a desired operating speed. Accordingly, on operation of the pump 10, the pistons 12, 14 travel in substantially opposite directions allowing fluid to be squeezed through the lower piston 14 on its downward stroke and then permitting the lower piston 14 to push the fluid upwardly on its upwards stroke while the upper piston 12 is squeezing the fluid through it on its corresponding downwards stroke.

Figure 2 illustrates the configuration of the three-phase conductors (A, B, C) of the power cable 16 and the arrangement of the coils 34 connected to the conductors A, B, C in both the first stator 30 and the second stator 32. Accordingly, the order of the coils 34 provided for the first stator 30 in this embodiment is A, B, C while the order of the coils 34 provided for the second stator 32 is A, C, B. It will be understood that changing the order of the coils (i.e. phases) in each stator 30, 32 results in the pistons 12, 14 being driven concurrently in opposite directions when current flows in the coils to generate the required magnetic fields to act on the magnets in the pistons 12, 14.

With reference to Figure 3, there is illustrated a pump 10' for lifting fluid from a wellbore in accordance with a second embodiment of the present invention. The pump 10' is similar to the pump 10 shown in Figure 1 so like reference numbers will be used for similar features. The pump 10' comprises a first piston 12 and a second piston 14. Each piston 12, 14 is configured for linear reciprocal movement generated by magnetic fields. A control system 15 is operable to control the magnetic fields to generate substantially concurrent opposed movement of the first and second pistons 12, 14 so as to provide a substantially continuous flow of fluid from the wellbore. The control system 15 comprises two three-phase power cables 40 and 42 and two variable speed drives (VSDs) 44, 46 arranged to generate the substantially concurrent opposed movement of the first and second pistons 12, 14, as will be described in more detail below. When employed downhole, the power cables 40 and 42 are preferably disposed between the production tubing 19 and the production casing of the wellbore.

Each piston 12, 14 comprises a hollow cylindrical body 18 provided on a substantially planar base 20. The base 20 defines a central fluid inlet 22 into the body 18. A non-return valve 24 is arranged to selectively open and close the inlet 22 depending on the direction of fluid flow. As illustrated, the valve 24 will open to allow flow in an upwards direction (e.g. to pump fluids from a well) but will close to prevent fluid flow in a downwards direction. The body 18 of each piston 12, 14 is configured to seal against the production tubing 19 so that fluid is only permitted to flow through the valves 24. The body 18 is further equipped with scraper rings 21 to prevent, e.g. scale, sand or wax, from attaching to an inner liner 23 provided on an inner surface of the production tubing 19, at least in the vicinity of the production tubing 19. The inner liner 23 is preferably made from a hard material to ensure that all wear is on the retrievable pistons 12, 14. The inner liner 23 may also be made of a non-conductive material to prevent eddy currents due to varying magnetic fields. It should also be noted that the length of each piston 12, 14 may differ from that shown in Figure 3. For example, each body 18 may extend over a greater portion of the production tubing 19. Each of the pistons 12, 14 further comprise a series of ring magnets provided along the body 18.

A first linear motor stator 30 and a second linear motor stator 32 are provided in the section of production tubing 19 shown. Each stator 30, 32 is configured for three-phase electrical power provided by the three-phase power cables 40, 42 (which each comprise three-phase conductors). The first motor 30 is connected to the power cable 40 and the second motor 32 to the power cable 42. As shown in Figure 3, the stators 30, 32 each comprise a set of, respective, electrically conductive coils 34, 35 wound within the production tubing 19. Each coil 34 for the first motor 30 is in turn connected to one of the three-phase conductors of the power cable 40 and each coil 35 for the second motor 32 is in turn connected to one of the three-phase conductors of the power cable 42.

The control system 15 is provided to send appropriate signals (e.g. voltage and current waveforms or a carrier wave) from the VSDs 44, 46 through the power cables 40, 42 to operate the pump 10’ as desired. Thus, the VSDs 44, 46 are configured to switch automatically in order to drive the pistons 12, 14 in respective inwards and outwards strokes at a desired operating speed. Accordingly, on operation of the pump 10’, the pistons 12, 14 travel in substantially opposite directions allowing fluid to be squeezed through the lower piston 14 on its downward stroke and then permitting the lower piston 14 to push the fluid upwardly on its upwards stroke while the upper piston 12 is squeezing the fluid through it on its corresponding downwards stroke.

Figure 4 illustrates the configuration of the three-phase conductors (A, B, C) of the power cables 40, 42 and the arrangement of the coils 34, 35 connected to the conductors A, B, C in both the first stator 30 and the second stator 32 for the embodiment shown in Figure 3. Accordingly, the order of the coils 34 provided for the first stator 30 in this embodiment is A, B, C and the order of the coils 34 provided for the second stator 32 is also A, B, C. It will be understood that applying different frequencies, i.e. changing the phase sequence of the applied current and voltage, on the coils 34, 35 in the stators 30 and 32 results in the pistons 12, 14 being driven in opposite directions when current flows in the coils 34, 35 to generate the required magnetic fields to act on the magnets in the pistons 12, 14.

Figure 5 shows a side perspective view of a portion of a piston 50 which may be employed in either of the pumps 10, 10’ shown in Figures 1 and 3. The piston 50 comprises a squirrel cage rotor 52 having an iron (or steel) hollow cylindrical body 54 surrounded by a network of un-insulated longitudinal copper bars 56 which are joined by a series of continuous copper rings 58 to form permanently short-circuited rectangular windings 60 around the periphery of the piston 50. Arrows indicate an induced rotating current around which flows around each winding 60 and which can interact with a magnetic field created by the stator coils 34, 35 to generate a force which moves the piston 50 in a desired direction. It should be noted that Figure 5 only shows a section of the piston 50 and, in practice, the piston 50 can be expanded in an axial direction.

Figure 6 shows a schematic part cross-sectional view of a top portion of a pump 70 in accordance with a fourth embodiment of the present invention, in which the piston 72 shown includes a magnetic position indicator 74. In practice, the features of the pump 70 may be incorporated into the pumps 10, 10’ shown in Figures 1 and 3. Thus, in addition to the piston 72 comprising a series of large ring magnets 76 provided along the body 78 in order to generate the desired movement of the piston 72 in the presence of a magnetic field generated by the large coils 80 of the stator 82, the piston 72 further comprises one or more (in this case three) small ring magnets 84 and the stator 82 further comprises a small coil 86. Accordingly, when the small ring magnets 84 pass through the small coil 86, a current will be induced in the small coil 86 and this signal can be relayed to the VSD to indicate the position of the piston 72 relative to the stator

82. More specifically, the small coil 86 will be connected together with the large coils 80 and will generate a signal at the VSD with a frequency that is different to that set by the VDS for operation of the large coils 80.

It will be appreciated by persons skilled in the art that various modifications may be made to the above embodiments without departing from the scope of the present invention, as defined by the claims.

CLAIMS:

1. A pump for lifting fluid from a wellbore, the pump comprising:
   a first piston and a second piston, each piston being configured for linear reciprocal movement generated by magnetic fields; and
   a control system operable to control said magnetic fields to generate substantially concurrent opposed movement of the first and second pistons so as to provide a substantially continuous flow of fluid from the wellbore.

2. The pump according to claim 1 wherein the control system comprises a single power cable which is configured to generate the substantially concurrent opposed movement of the first and second pistons.

3. The pump according to claim 1 wherein the control system comprises two power cables, each one being configured to control a single one of the first and second pistons.

4. The pump according to any preceding claim wherein the pump comprises a first linear motor stator and a second linear motor stator disposed in-line so as to respectively generate the linear reciprocal movement of the first and second pistons.

5. The pump according to claim 4 wherein the linear motor stators are configured for three-phase electrical power provided by a power cable which comprises three-phase conductors.

6. The pump according to claim 4 or claim 5 wherein the stators are permanently disposed on production tubing.

7. The pump according to claim 6 wherein the stators are provided on one or more pre-configured sections of production tubing, which are in turn connectable in series with other standard sections of production tubing.

8. The pump according to claim 6 or claim 7 wherein the stators are mounted on the exterior of the production tubing or within the thickness of the production tubing itself.

9. The pump according to claim 8, when dependent upon claim 5, wherein the stators each comprise a set of electrically conductive coils wound around (or in the thickness of) the production tubing and each coil is connected to one of the three-phase conductors of an associated power cable.

10. The pump according to claim 9 wherein the order of the coils provided for the first stator is different to the order of the coils provided for the second stator.

11. The pump according to claim 10 wherein each stator comprises coils ordered in opposite directions so as to make the pistons move in opposite directions.

12. The pump according to any one of claims 9 to 11 wherein each stator comprises multiple sets of coils so as to generate a required force and distance of travel of each piston.

13. The pump according to any preceding claim wherein the control system comprises at least one variable speed drive configured to switch automatically in order to drive the pistons in respective inwards and outwards strokes.

14. The pump according to claim 13 wherein the control system is configured to alter the speed of operation of the pump by providing different signal frequencies through a power cable.

15. The pump according to any one of claims 12 to 14 wherein a position indicator is provided to relay signals to the control system to confirm that the pistons are operating as intended.

16. The pump according to claim 15 wherein the position indicator is constituted by a series of relatively small magnets provided along the length of each piston or stator for generating feedback through a power cable, on a frequency other than that which is driving the pistons.

17. The pump according to any preceding claim wherein one or more stops is provided to limit the movement of each piston.

18. The pump according to claim 17 wherein at least one stop is electrically activated to generate a force opposite to the movement of the piston to stop the piston before it is moved in the opposite direction.

19. The pump according to claim 17 wherein at least one stop is passive and is constituted by a permanent magnet or mechanical stop provided at one or more ends of each stator.

20. The pump according to any preceding claim wherein one or more switching elements are provided to control the movement of each piston independently.

21. The pump according to claim 20 wherein the switching elements are controllable using different frequencies on a power cable to those employed to operate the pump.

22. The pump according to claim 20 or claim 21 wherein the switching elements may be configured to turn each piston on and off and/or to turn each coil or set of coils on and off.

23. The pump according to any one of claims 20 to 22 wherein the switching elements enable the pistons to move in the same directions.

24. The pump according to any one of claims 20 to 22 wherein the switching elements are employed to ensure that the movement of the first and second pistons is phased so that both pistons do not stop and turn at the same time.

25. The pump according to any one of claims 20 to 24 wherein the switching elements comprise solid state switches and/or reed switches.

26. The pump according to any one of claims 20 to 25 wherein a fibre optic cable is provided to activate the switching elements.

27. The pump according to any preceding claim wherein, in use, a power cable is disposed between a production tubing and a casing of the well.

28. The pump according to claim 5 wherein each piston is configured such that it can be retrieved and replaced without requiring extraction of the production tubing.

29. The pump according to claim 28 wherein each piston comprises a lifting lug.

30. The pump according to any preceding claim wherein each piston comprises a magnetic element constituted by a permanent magnet, an electromagnet or a squirrel cage rotor.

31. The pump according to claim 30 wherein each piston comprises one or more ring magnets.

32. The pump according to claim 5 wherein the opposed motion of the pistons is achieved by switching two of the three-phase conductors of the power cable between the first and second stators.

33. The pump according to any preceding claim wherein each piston comprises a non-return valve allowing fluid to flow through the piston in an upwards (production) flow direction and preventing fluid from flowing through the piston in a downwards flow direction.

34. The pump according to claim 33 wherein the pistons are configured to seal against the production tubing, in use, so that fluid is only permitted to flow through the non-return valves.

35. The pump according to claim 6 wherein the stators have an inner liner comprising non-conductive material.

36. The pump according to claim 35 wherein the first and second pistons have at least one external scraper ring configured to prevent material from attaching to the inner liner.

37. A pump substantially as hereinbefore described with reference to the accompany drawings.

38. A system comprising two or more pumps according to any preceding claim.

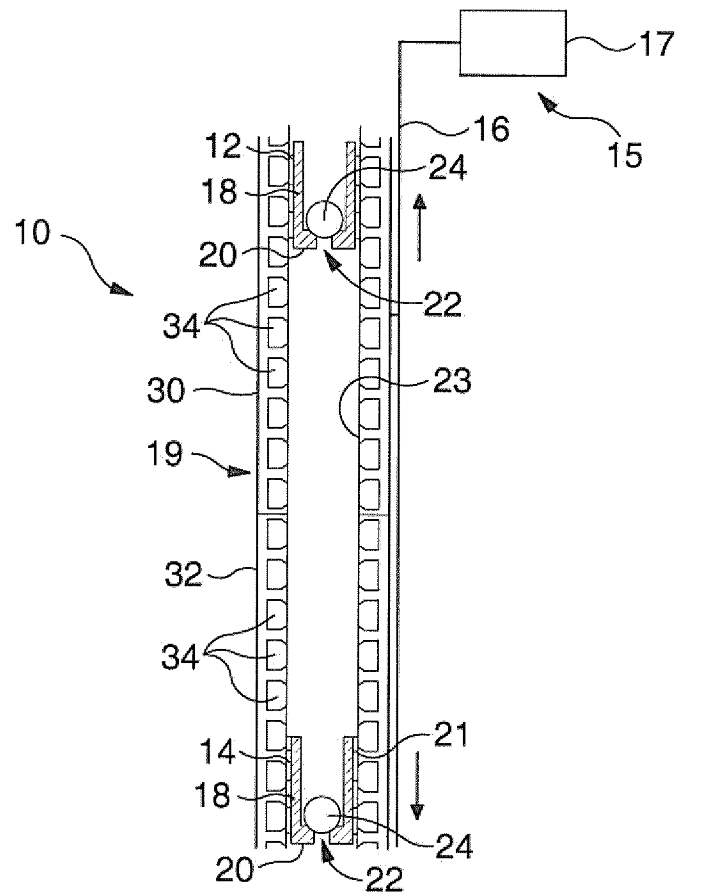
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FIG. 1

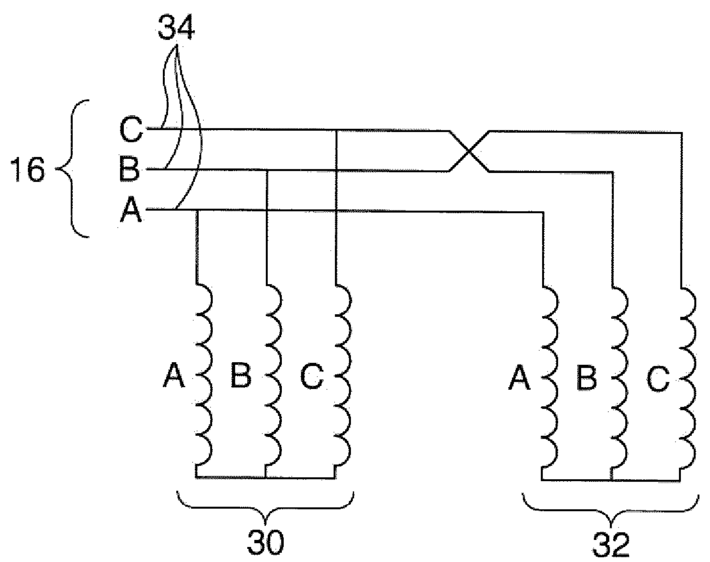
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FIG. 2

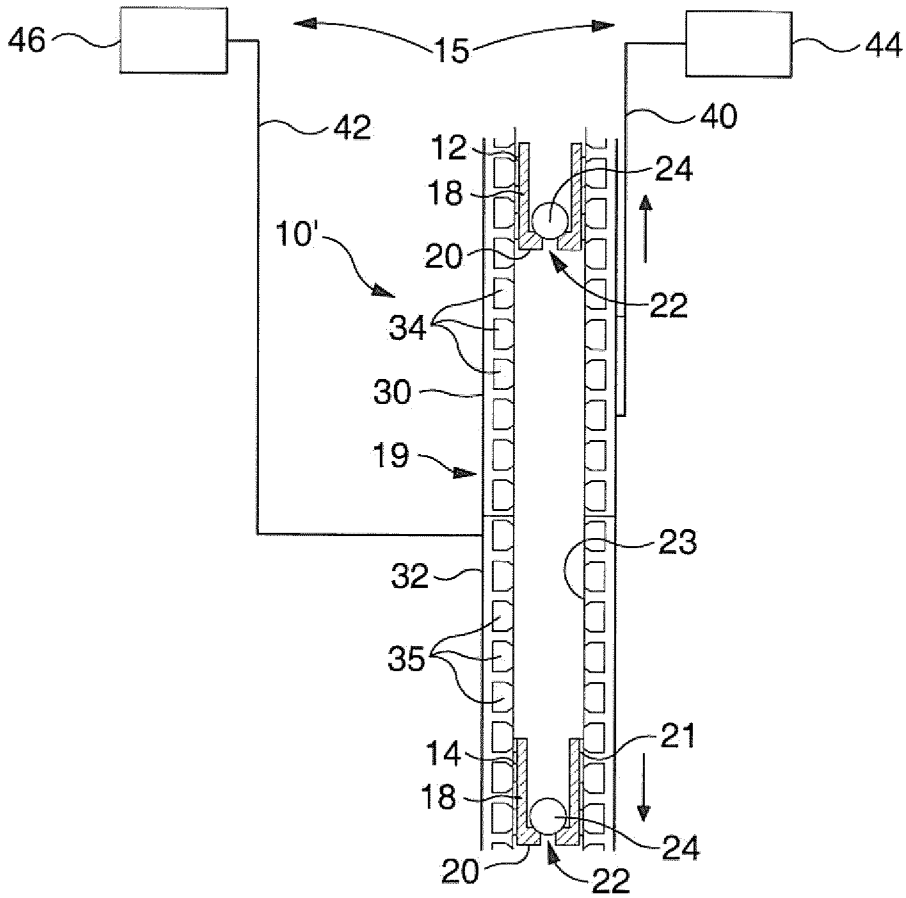
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FIG. 3

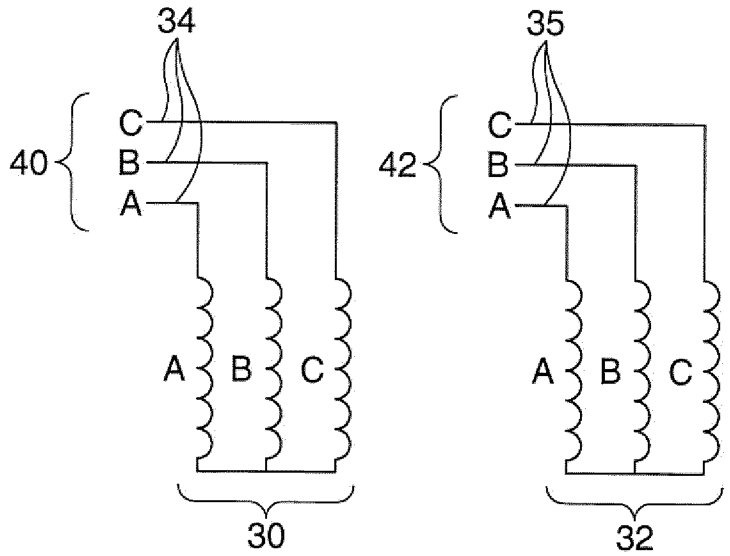
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FIG. 4

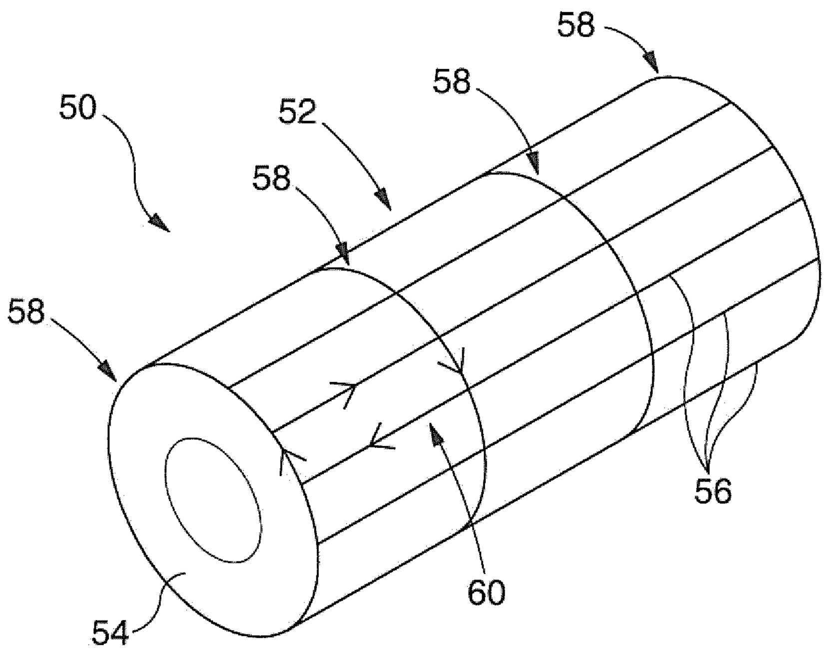

FIG. 5

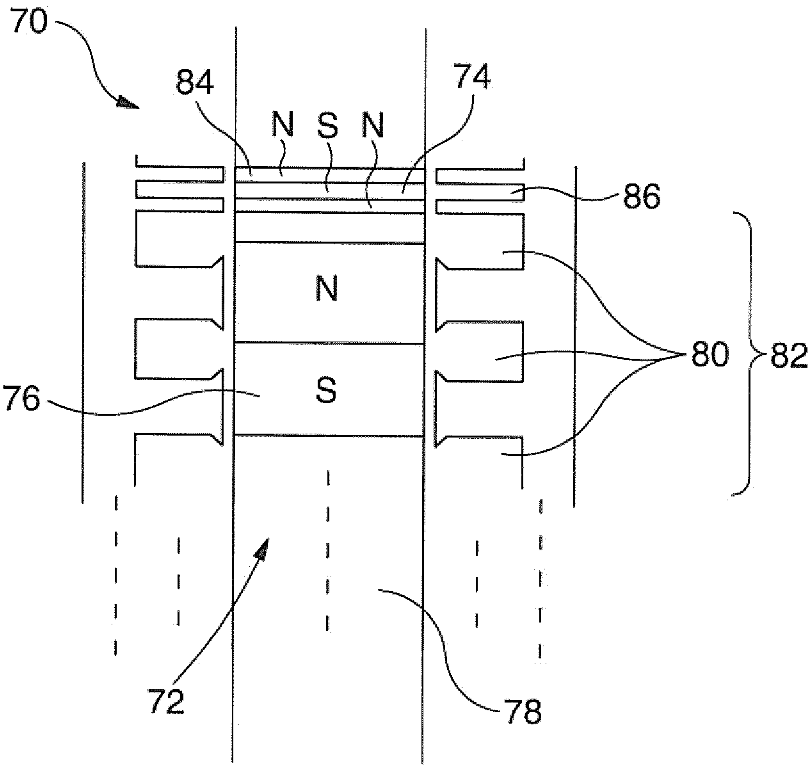

FIG. 6