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(54) **Cable**

(57) An improved electromechanical cable comprises: a core containing one or more electrical conductors and a filler material; and an armour sheath surrounding the core, wherein the armour sheath comprises one or

more layers comprising a plurality of interlocking strands. The cable may be especially suitable for suspending apparatus such as a submersible pump assembly within an oil or gas well.

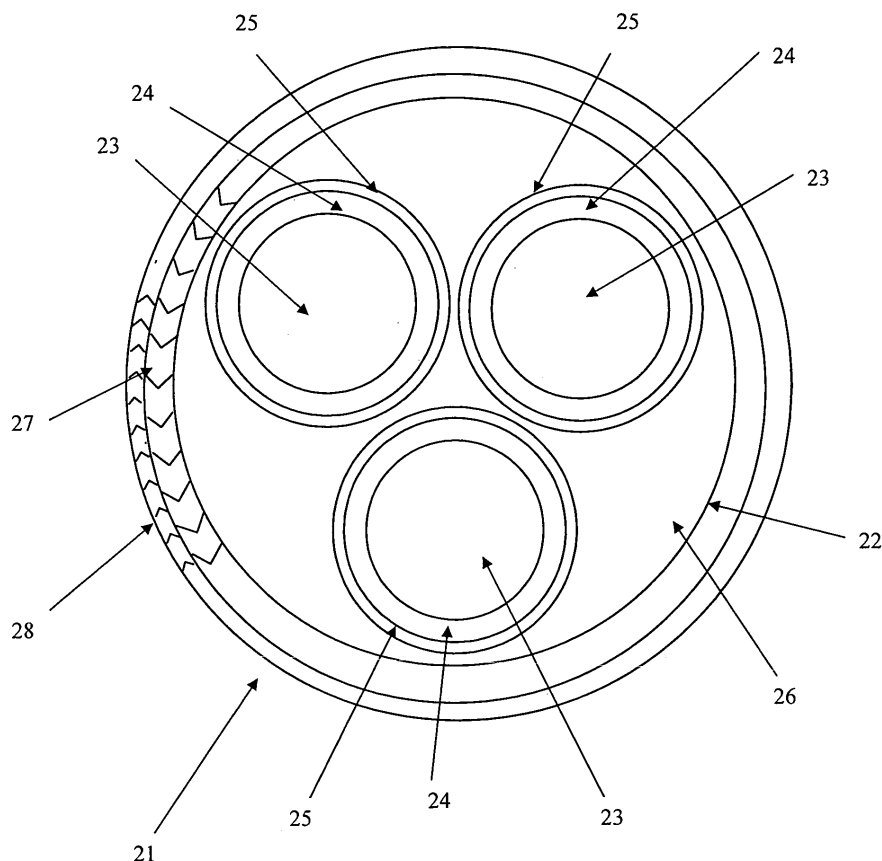


Figure 2

Description

[0001] This invention relates to electromechanical cables. In particular, it relates to an electromechanical cable comprising a core having at least one electrical conductor arranged longitudinally therein and an armoured layer or sheath surrounding the core. Such an electromechanical cable may be especially suitable for use in a well, e.g. for deploying equipment such as a pump assembly within an oil or gas well.

[0002] In use, such cables must be capable of supporting their own weight and that of the equipment coupled thereto and suspended therefrom. They must also be capable of providing electrical power to the equipment.

[0003] The invention also relates to apparatus for deployment within an oil or gas well, in particular apparatus such as an electric submersible pump assembly, which may advantageously be suspended from an electromechanical cable.

[0004] In the oil and gas industry, electrically-operated apparatus, e.g. an electric submersible pump, may be deployed within a well using coiled tubing or an armoured electromechanical cable.

[0005] To-date, industry attention has mainly been focused on the use of jointed production tubing or continuous coiled tubing to deploy electric submersible pumps.

[0006] In a typical coiled tubing system, an electrical cable may be clamped to the exterior of a tube or may be held or supported within the tube. The tube bears the load of the apparatus suspended therefrom, in use. Hence, the tube must be of sufficient tensile strength to support a submersible pump assembly. Coiled tubing may be more rigid and may have a considerably larger minimum bend radius than an electromechanical cable of equivalent tensile strength.

[0007] Typically, coiled tubing is stored on a reel. A reel of coiled tubing may typically have a considerably larger diameter than a drum of cable of equivalent tensile strength. The large size of a coiled tubing reel may mean that it is relatively expensive and/or difficult, cumbersome or otherwise inconvenient to move to a site and rig up over a well.

[0008] The bend radius of a tube or a cable may be defined as the minimum radius one can bend a tubing or cable to without kinking it, damaging it or shortening its life. The smaller the bend radius, the greater is the flexibility of the tube or cable.

[0009] Hence, a distinction between coiled tubing and armoured cable may be made by comparing the minimum bend radius to which an assembly may be repeatedly deformed without exceeding the elastic limit of the material, e.g. as evidenced by local buckling or the acquisition of a permanent set.

[0010] An armoured cable may contain tubular elements. However, unlike in coiled tubing, the tubular elements are typically relatively thin walled and do not bear the full weight of the cable assembly and the applied load; hence, they may be flexible and compliant with the re-

mainder of the cable.

[0011] Coiled tubing may acquire a permanent set on the drum. Therefore, an "injector head" assembly may be required in order to straighten the tubing prior to injecting it into a well. It may also allow tension to be maintained on tubing to prevent it springing; however, the tubing may be so highly stressed in bending that it acts like a watch spring if the drum and tube are not simultaneously restrained.

[0012] In contrast, cable, when placed under modest tension is self straightening and can be passed over a sheave wheel and directly into and out of a well without requiring any additional back tension, straightening or other handling systems.

[0013] A disadvantage associated with the use of coiled tubing having a cable held or supported within the tube is that the cable may occupy a significant portion of the space within the tubing, which may prevent or restrict effective pumping through the tubing, as may sometimes be desirable.

[0014] Hence, it may sometimes be advantageous to suspend an apparatus such as a pump within a well using an electromechanical cable, preferably an armoured electromechanical cable.

[0015] Electromechanical cables have been successfully used in oil wells, principally for electric-line data acquisition. Typically, these cables have a single internal copper conductor or a close-packed arrangement of seven internal copper conductors. Also, they tend to have a maximum diameter of around 0.5 inches (1.25 cm).

[0016] Larger diameter electromechanical cables are generally required for use with submersible pump assemblies. A submersible pump assembly may comprise a three-phase motor, in which case the electromechanical cable may comprise three conductors. In contrast with a cable having one or seven conductors, a cable comprising three conductors may contain significantly relatively more filler material in order to make the core round in cross-section.

[0017] In Figure 1 there is shown, in cross section, a typical prior art electromechanical cable 1. The electromechanical cable 1 comprises a core 2 of substantially circular cross section containing three electrically conducting wires 3. The wires 3 are surrounded by layers of insulating material 4, 5. The remaining volume of the core 2, i.e. between and around the wires 3, is filled with a flexible, typically polymeric, filler material 6. Encircling the core 2 are two layers of circular section steel armour strands 7, 8. The steel armour strands 7 in the inner layer are wound around the core 2 in a helix in a first direction; the steel armour strands 8 in the outer layer are wound in a helix in a direction opposite the first direction, i.e. the armour strands in the two layers are contra-wound.

[0018] Spiral winding of the armour strands prevents the components of the cable coming apart when the cable is handled or manipulated, in use, e.g. wound around a reel or sheave wheel. Contra-winding of the strands in the two layers is intended to balance any torque which

may be generated when the cable is placed under an axial load.

[0019] There is, however, a problem with electromechanical cables of this design, because the filler material may be extruded through the armour strands, when the cable is under tension, in use, e.g. when a submersible pump assembly is suspended from the cable. It will be appreciated that this problem does not arise when coiled tubing is used. This may be one of the reasons why the oil and gas industry has tended to use coiled tubing for the deployment of submersible pump assemblies.

[0020] Extrusion of the filler material through the armour strands may be due to one or more of the following factors:

1. compression of the core from the external armour;
2. differential thermal expansion of the filler material as the cable is lowered into a well; and/or
3. swelling of the filler material due to inward diffusion of gas.

[0021] Considering a single armour strand, it will be appreciated that the strand forms a helix. Considering the strand in isolation, when placed in axial tension, it would extend until it straightened completely.

[0022] When an electromechanical cable as shown in Figure 1 is placed in tension, all of the individual circular section armour strands attempt to straighten, placing the core into compression.

[0023] Hence, it is the core of the cable that maintains the armour strands in a helix and it achieves this by exerting a radial outwardly acting force, this force being mobilized by radial shrinkage.

[0024] The core may not provide all of the support to the armour because to some extent the group of strands may act compositely as a compressive ring, limiting the ability of any individual strand to straighten. Nevertheless, the use of circular section armour strands may allow individual strands to move relative to their neighbours and were they not wound around a core the assembly may simply collapse under applied tension.

[0025] Thus, when such a known armoured electromechanical cable is placed in tension the core may be squeezed "like a tube of toothpaste". As the applied tension increases, the internal pressure increases proportionally. If the internal pressure of the core exceeds the contact pressure between adjacent strands, then the filler material of the core can be extruded through the cable armour.

[0026] Further, when in use within an oil or gas well, an electromechanical cable may be subjected to elevated temperatures and/or a gaseous phase comprising hydrocarbon gases and optionally additional gaseous species such as hydrogen sulphide and carbon dioxide.

[0027] At the elevated temperatures within an oil or gas well, the components of an electromechanical cable may undergo differential thermal expansion. In particular, the filler material may thermally expand relatively more

than the steel armour strands. Consequently, the filler material may be placed in compression, but being relatively deformable may extrude from the core through the outer armour.

[0028] Similarly, gases, e.g. hydrocarbon gases, may diffuse into the polymeric or elastomeric materials commonly used as core filler materials, causing the material to swell. The filler material may then extrude from the core through the outer armour. Embolism of these inwardly diffused gases within the core may be a further problem, e.g. as a consequence of rapid decompression when the cable and equipment attached thereto is pulled from a well.

[0029] In past attempts to alleviate some of the problems described above, the steel armour wires have been encapsulated in a polymer sheath to restrain them and limit the compressive forces imposed on the core.

[0030] Alternatively, pressure containment layers have been installed between the armour wires and the core.

[0031] For example, US 5,086,196 discloses an electro-mechanical cable for use in cable deployed pumping systems including a containment layer surrounding a cable core and constructed to restrain outward radial expansion of the core while permitting longitudinal expansion. In a preferred embodiment, the pressure containment layer is constituted by a strip wound helically upon the cable core at angles that are very low with respect to cross sectional planes of the cable and very high with respect to longitudinal planes.

[0032] It is a non-exclusive object of the present invention to provide an improved electromechanical cable which eliminates or at least alleviates or mitigates one or more of the problems associated with known electromechanical cables.

[0033] It is a further non-exclusive object of the invention to provide a submersible pump assembly including such an improved electromechanical cable.

[0034] According to a first aspect of the invention there is provided an electromechanical cable comprising: a core containing one or more electrical conductors and a filler material; and an armour sheath surrounding the core, wherein the armour sheath comprises one or more layers comprising a plurality of interlocking strands.

[0035] Preferably, the interlocking strands extend along at least part of the length of the electromechanical cable.

[0036] The interlocking strands may be disposed in a spiral or helix, preferably a helix having a high pitch, or in a direction substantially parallel to the longitudinal axis of the electromechanical cable.

[0037] The pitch of a spirally- or helically-wound element may be characterised by the angle at which it is wound relative to a plane transverse to the longitudinal axis of the spiral or helix. In this application, the terms "high pitch" or "long pitch" and the like pertaining to a spiral or helix refer to the size of this angle when the spiral or helix is not subjected to a load, e.g. an axial tensile

load. A spiral or helix may be considered to have a high pitch when this angle is 65° or more.

[0038] The provision of interlocking strands has certain advantages as compared with an electromechanical cable of the type shown in Figure 1.

[0039] In prior art electromechanical cable of the type shown in Figure 1, the armour strands are spiral wound around the core so as to create a composite structure that can be manipulated, e.g. bent, without the armour becoming detached, or individual strands becoming displaced relative to each other. Circular section armour strands have a relatively small contact area with their neighbouring strands in an armour layer and even less with strands within an adjacent, e.g. contra-wound, layer. Consequently, there is only little resistance to relative movement between strands and the spiral pitch must be relatively low to restrain the strands in position relative to each other and the core when the cable is manipulated, in use, e.g. passed over a sheave wheel, or wrapped around a cable drum for storage.

[0040] Advantageously, the provision of interlocking strands increases the strand-to-strand contact area, as compared with circular-section armour strands. Further, the bending radius of the cable at which individual strands can be displaced relative to another is greatly reduced. Hence, it may be possible to construct a reliable electromechanical cable in which the armour strands are wound around the core with a significantly higher helical pitch. Increasing the helical pitch of the armour strands has the beneficial effects of reducing cable compression and torque when the cable is placed in tension.

[0041] The armour sheath may bear a substantial part, preferably all, of an axial load applied to the cable.

[0042] The interlocking strands may bear a substantial part, preferably all, of an axial load applied to the cable.

[0043] Preferably, the interlocking strands may provide a mechanical arch or anti-compression ring capable of resisting radial compression, e.g. an incompressible tubular body around the core.

[0044] The interlocking strands may be made from a material having a sufficiently high tensile strength, preferably a metal such as steel.

[0045] The interlocking strands may be coated, e.g. to increase friction therebetween and/or to improve corrosion resistance.

[0046] The armour sheath and/or the interlocking strands may advantageously be adapted to perform both of these functions, i.e. bearing a substantial part of an axial load applied to the cable and providing a mechanical arch or anti-compression ring for resisting compression of the cable.

[0047] Preferably, the armour sheath may be substantially self-supporting, e.g. because the interlocking strands may act compositely without relying on the core. Hence, voids may be provided in the core. Such voids may help to counter the effects of expansion of the filler material as a result of heat or inward diffusion of gases.

[0048] Preferably, the voids or local clusters thereof

may be discrete from one another so as not to provide easy diffusion paths through the filler material within the core.

[0049] The voids may be incorporated within the filler material by including hollow beads within the filler material during manufacture, e.g. extrusion.

[0050] The interlock between neighbouring strands may be a mechanical interlock, preferably provided by a pair of matched surfaces. The pair of matched surfaces may bear on each other and/or may be complementarily shaped, e.g. such that a formation or protrusion on one strand is "received" by a formation or depression on its neighbouring strand. The matched surfaces may be curved or comprise a curved portion, or may be substantially flat or planar.

[0051] The interlocking strands may have any suitable transverse cross-sectional shape. For example, they may be chevron-shaped or trapezoidal in cross-section.

[0052] Preferably, the angle of pitch of the interlocking strands may be in excess of 70°, more preferably in excess of 80°, most preferably in excess of 85°. It should be appreciated that for a given cable, the most preferred pitch may depend on the diameter of the cable and/or the transverse cross-sectional dimensions of the interlocking strands.

[0053] Preferably, at least some of the interlocking strands may be disposed in a direction substantially parallel to the longitudinal axis of the cable. Because the strands interlock, they may still act compositely even when disposed in a direction substantially parallel to the longitudinal axis of the cable.

[0054] The armour sheath may comprise an inner layer of interlocking strands and an outer layer of interlocking strands. Preferably, the interlocking strands of at least the inner layer may be disposed in a direction substantially parallel to the longitudinal axis of the cable.

[0055] Advantageously, when the interlocking strands of the inner layer are disposed in a direction substantially parallel to the longitudinal axis of the cable, the inner layer may not generate any significant or appreciable compression of the core.

[0056] Alternatively, the interlocking strands of the inner and outer layers may be contra-wound in helices having a high pitch.

[0057] In an electromechanical cable in which the armour sheath comprises more than one layer comprising a plurality of interlocking strands, the layers may have the same or different radial thicknesses as each other.

[0058] Preferably, the one or more layers comprising a plurality of interlocking strands may each have a substantially uniform radial thickness.

[0059] The electromechanical cable may further comprise one or more tensile load-bearing elements, e.g. a wire, rod, tube, rope or the like, running in a longitudinal direction through the core. The one or more tensile load-bearing elements may be made from a material having a high tensile strength such as a metal, e.g. steel, or high-strength fibre, e.g. Kevlar® or the like. A tensile load-

bearing element may run substantially along the longitudinal axis of the cable.

[0060] Preferably, the cable further comprises a thin, substantially non-load-bearing, impermeable skin or membrane outside the core. The skin or membrane may be adapted to provide a barrier to inward diffusion of gases, e.g. hydrocarbon gases, in use. The skin or membrane may be provided inside or outside the armour sheath. Alternatively, the skin or membrane may also be provided within the armour sheath, e.g. between a pair of layers comprising a plurality of interlocking strands.

[0061] The skin or membrane may comprise a thin, flexible metal layer. Advantageously, the metal may be relatively corrosion resistant, e.g. the metal may comprise tin steel, stainless steel, aluminium or an alloy thereof. Alternatively or additionally, the skin or membrane may comprise a suitable non-metallic material such as a polymeric compound, in particular, a rubber compound.

[0062] Preferably, the skin or membrane may be less than 5 mm, more preferably less than 3 mm thick. For example, where the skin or membrane is metallic, the preferred thickness may be 1 mm or less.

[0063] The cable may include from one to seven, i.e. one, two, three, four, five, six or seven, electrical conductors. Preferably, the cable may contain three electrical conductors; hence it may be especially suitable for use with an electric submersible pump assembly having a three-phase motor.

[0064] A cable having seven electrical conductors may also be suitable for use with a three-phase motor; a pair of conductors for each phase and one spare, e.g. for communication with a downhole instrument.

[0065] The one or more electrical conductors may be circular in transverse cross section.

Advantageously, however, they may be shaped to minimise or reduce the amount of filler required within the core. Hence, some or all of the one or more electrical conductors may be asymmetrical and/or non-circular in cross-section.

[0066] Preferably, the one or more electrical conductors may be sector-shaped in cross-section. For instance, in an electromechanical cable having three conductors, each of the conductors may have a cross-sectional shape approximating to a third of a circle.

[0067] The cable may further comprise one or more layers of helically-wound armour strands outside the armour sheath; for instance, two layers of contra-wound armour strands, which strands may be circular in cross-section. The one or more layers of helically-wound armour strands may be provided outside or inside the or a non-load-bearing, impermeable skin or membrane.

[0068] Preferably, the armour sheath may have a thickness in the radial direction of from 0.2 to 5 mm, preferably from 1 to 4 mm.

[0069] The electromechanical cable may have a diameter of from 20 to 100 mm, preferably from 25 to 60 mm.

[0070] The electromechanical cable may further comprise at least one conduit running in a longitudinal direc-

tion through the core, through which a fluid may pass.

[0071] The electromechanical cable may also contain one or more data transmission or control lines for passing signals or information to or from an apparatus suspended from the cable. For example, these may be copper conductors or optical fibres.

[0072] In a second aspect of the invention, there is provided an electromechanical cable comprising: a core containing one or more electrical conductors and a filler material; a tensile load-bearing element; and a thin, substantially non-load-bearing, impermeable skin or membrane outside the core.

[0073] The tensile load-bearing element may be provided by one or more of: one or more elements, e.g. a wire, rod, tube, rope or the like, running in a longitudinal direction through the core and/or an armour sheath surrounding the core and located either inside or outside the skin or membrane.

[0074] The armour sheath may comprise one or more layers comprising a plurality of interlocking strands.

[0075] It is envisaged that the improved electromechanical cable of the present invention may have particular utility in submersible pump assemblies intended for deployment within an oil or gas well.

[0076] Such a submersible pump assembly may comprise a pump and a motor for driving the pump, the pump or motor being coupled or connected to an end of an electromechanical cable according to the present invention.

[0077] In a preferred assembly, the cable may be connected to the motor, the motor being located between the cable and the pump, when the assembly is deployed down a well.

[0078] Preferably, the motor may be a three phase motor. The motor may be a permanent magnet motor.

[0079] Preferably, the pump may be a positive displacement pump, more preferably a twin screw pump.

[0080] The pump may be operable in a first, forwards direction and a second, reverse direction.

[0081] Examples of a number of pumps or pump assemblies with which the improved electromechanical cable of the present invention may advantageously be used are disclosed in the applicant's European patent application EP07254955.3, the entire contents of which are incorporated herein by reference.

[0082] A submersible pump or pump assembly deployed using an improved electromechanical cable according to the invention may be relatively reliable, efficient and easy to install, use and maintain. Deployment of a submersible pump using an improved electromechanical cable according to the invention may be appropriate or advantageous for a wide variety of wells including new wells or wells at sites where it would be difficult, expensive or otherwise undesirable to install a workover rig or other apparatus associated with use of coiled tubing. Also, such a cable-deployed submersible pump assembly may have particular utility in wells which it is desired to bring back to production, and/or to boost the pro-

duction rate and/or efficiency of existing wells.

[0083] A method of withdrawing or injecting fluid from or into a well, e.g. an oil or gas well, may comprise use of an electromechanical cable according to the present invention to deploy a pump assembly within the well and to transmit power to the deployed pump such that the pump withdraws or injects fluid from or into the well.

[0084] A method of deploying an apparatus within a well, e.g. an oil or gas well, may comprise suspending the apparatus from an electromechanical cable according to the present invention.

[0085] In order that the invention may be more fully understood, certain preferred embodiments thereof will now be described by way of example only with reference to the accompanying drawings in which:

Figure 2 shows a transverse cross-sectional view of a first embodiment of an electromechanical cable according to the present invention;

Figure 3 shows a transverse cross-sectional view of a second embodiment of an electromechanical cable according to the present invention;

Figure 4 shows a transverse cross-sectional view of a third embodiment of an electromechanical cable according to the present invention; and

Figure 5 shows a transverse cross-sectional view of a fourth embodiment of an electromechanical cable according to the present invention.

[0086] Referring now to Figure 2, there is shown, in transverse cross-section, a first embodiment of an electromechanical cable 21 according to the present invention. The electromechanical cable 21 comprises a core 22 of substantially circular transverse cross-section containing three electrically conducting wires 23. The wires 23 are surrounded by layers of insulating material 24, 25. The remaining volume of the core 22, i.e. the interstitial space between and around the wires 23, is filled with a flexible, typically polymeric, filler material 26.

[0087] Encircling the core 22 is an armour sheath comprising two layers of steel armour.

Each layer comprises a plurality of interlocking strands 27, 28 arranged around the whole circumference of the cable 21. For convenience, in Figure 2, the strands 27, 28 are shown only in respect of a portion of the circumference of the cable 21.

[0088] As shown in Figure 2, each of the strands 27 in the inner layer has a chevron shape in transverse cross-section with the point of each chevron pointing in an anticlockwise direction around the circumference of the cable 21. Each of the strands 28 in the outer layer has a chevron shape in transverse cross-section with the point of each chevron pointing in a clockwise direction around the circumference of the cable 21. The inner layer is thicker in the radial direction than the outer layer.

[0089] Figure 3 shows, in transverse cross-section, a second embodiment of an electromechanical cable 31 according to the present invention. The electromechan-

ical cable 31 comprises a core 32 of substantially circular cross section containing three electrically conducting wires 33. The wires 33 are surrounded by layers of insulating material 34, 35. The remaining volume of the core 32, i.e. the interstitial space between and around the wires 33, is filled with a flexible, typically polymeric, filler material 36. Encircling the core 32 is an armour sheath comprising two layers of steel armour. Each layer comprises a plurality of interlocking strands 37, 38 arranged around the whole circumference of the cable 31. For convenience, in Figure 3, the strands 37, 38 are shown only in respect of a portion of the circumference of the cable 31.

[0090] As shown in Figure 3, each of the strands 37 in the inner layer has a chevron-type shape in transverse cross-section with the "point" of each chevron being curved and pointing in an anticlockwise direction around the circumference of the cable 31. Each of the strands 38 in the outer layer has a similar chevron-type shape in cross section with the curved "point" of each chevron pointing in a clockwise direction around the circumference of the cable 31.

[0091] Figure 4 shows, in cross-section, a third embodiment of an electromechanical cable 41 according to the present invention. The electromechanical cable 41 comprises a core 42 of substantially circular transverse cross-section containing three electrically conducting wires 43. The wires 43 are surrounded by layers of insulating material 44, 45. The remaining volume of the core 42, i.e. the interstitial space between and around the wires 43, is filled with a flexible, typically polymeric, filler material 46.

[0092] Encircling the core 42 is an armour sheath comprising two layers of steel armour.

Each layer comprises a plurality of interlocking strands 47, 48 arranged around the whole circumference of the cable 41. For convenience, in Figure 4, the strands 47, 48 are shown only in respect of a portion of the circumference of the cable 41.

[0093] As shown in Figure 4, the strands 47, 48 have a trapezoidal "voussoir" transverse cross-section. The inner layer is thicker in the radial direction than the outer layer.

[0094] In Figure 5, there is shown in transverse cross-section, a fourth embodiment of an electromechanical cable 51 according to the invention. The electromechanical cable 51 comprises a core 52 of substantially circular transverse cross-section containing three electrically conducting wires 53. The remaining volume of the core 52, i.e. the interstitial space between and around the wires 53, is filled with a flexible, typically polymeric, filler material 56. The wires 53 are sector-shaped in transverse cross-section and have curved corners to minimise or reduce thinning of the filler material 56 and/or reduce electrical stress.

[0095] Encircling the core 52 is an armour layer comprising two layers of steel armour.

Each layer comprises a plurality of interlocking strands

57, 58 arranged around the whole circumference of the cable 51. For convenience, in Figure 5, the strands 57, 58 are shown only in respect of a portion of the circumference of the cable 51.

[0096] As shown in Figure 5, each of the strands 57 in the inner layer has a chevron shape in transverse cross-section with the point of each chevron pointing in an anticlockwise direction around the circumference of the cable 51. Each of the strands 58 in the outer layer has a chevron shape in transverse cross-section with the point of each chevron pointing in a clockwise direction around the circumference of the cable 51. The inner layer is thicker in the radial direction than the outer layer. It is also envisaged that the interlocking strands may have the curved chevron or trapezoidal transverse cross sections shown in Figures 3 and 4 respectively.

[0097] The interlocking strands 27, 28, 37, 38, 47, 48, 57, 58 shown in the armour layers of Figures 2 to 5 may be contra-wound helices having a high pitch. A preferred pitch may be in the region of from 80° to 88°.

[0098] While the strands of one or more of the layers may be disposed substantially parallel to the longitudinal axis of the cable and such a conformation would be ideal as regards torque and compression of the core under tension (both would be substantially eliminated), a helix or spiral may be preferred as it may have benefits when handling or manipulating the cable, in use.

[0099] The strands in one of the layers, e.g. the or an outer layer, may have a high helical pitch, while those of another layer, e.g. the or an inner layer, may be disposed in a direction substantially parallel to the longitudinal axis of the cable. The torque generated by the or a helically-wound layer may be relatively small, due to the relatively high pitch of the helix; hence, it may not be necessary to contra-wind strands in two layers of armour to balance the torque in the cable.

[0100] Further, it may sometimes be advantageous to provide a cable with some torque imbalance such that when the cable is lowered into a well, in use, and the tension released such as when a suspended load (e.g. a pump) is landed on to a support or supporting element, it may have a tendency to slacken off above the pump and form a helix, e.g. around the inside of the well casing. This may help to isolate a pump assembly lowered by and suspended from the cable from the effects of cable movement once landed. Also, as the cable may be located towards the periphery of the fluid flow stream through the well, fluid erosion of the armour sheath may be reduced.

[0101] In use, an electromechanical cable according to the present invention, e.g. as shown in any one of Figures 2 to 5, is provided at a first end with a connector for connection to, for example, an electric submersible pump. A short amount of cable is spooled off a reel carrying a length of the cable such that the connector is provided at the free end of the cable. Typically, the connector is used to connect the cable to a first side of a motor. A pump is then connected to a second side of the

motor, e.g. so that the motor is above the pump when the assembly is suspended in a well. Using a winch or the like, the pump and the motor are lowered down the well, suspended from the cable. The cable is spooled off the reel until the pump and motor reach the desired location within the well. The pump and/or motor are releasably secured in place within the well, e.g. by engagement with a packer. The pump is activated by sending current down the conductors within the electromechanical cable so as to operate the motor.

[0102] If one or more of the pump, the motor or the electromechanical cable develop a problem or fail, operation of the pump is stopped and the cable is withdrawn from the well. The cable is withdrawn until the pump and motor that remain attached thereto are pulled out of the well for servicing.

[0103] A number of potentially beneficial modifications may be made to the embodiments of electromechanical cable shown in Figures 2 to 5.

[0104] For instance, the non-circular conductors shown in Figure 5 may be incorporated within the embodiments shown in Figures 2 to 4.

[0105] The use of one or more non-circular conductors offers a number of benefits, especially in cables carrying a number of conductors that cannot easily be closely packed within the transverse cross-sectional shape of the core. In general, the filler material serves no useful function within the core other than to create a symmetrical, typically circular, transverse cross section. In particular, the filler typically does not add rigidity, tensile strength or improved electrical insulation to the cable. Further, as discussed previously, in use, the filler may extrude out from the core and through the armour of an electromechanical cable.

[0106] Advantageously, the provision of one or more non-circular conductors within the core of the cable may significantly reduce the amount of filler material required for a given cross-section of cable. As shown in Figure 5, in a cable having three conductors, the conductors may advantageously be shaped as three sectors of a circle, each sector corresponding to approximately one third of a circle. Similarly, a cable may comprise two conductors of approximately semi-circular cross section or four conductors of approximately quarter-circular cross section.

[0107] Of course, almost any combination of conductors could be used. For instance, the conductors need not necessarily all have the same cross-sectional shape or area. Typically, it is preferred that the combination of conductors would "pack" together to form a substantially symmetrical, e.g. substantially circular, transverse cross section to minimise the amount of filler material required.

[0108] A further advantage stemming from the provision of one or more non-circular conductors within the core of the cable is that the cross-sectional area of the cable may be reduced for an equivalent conductor area.

[0109] Accordingly, the cable may have a smaller diameter for a given strength. Hence, smaller cable drums may be required to store a cable. Moreover, in use, the

cable would take up less space within a well bore, which may allow it to be used in narrower wells and/or permit an increase in the rate of fluid injection or withdrawal into or from a given well.

[0110] Advantageously, as a consequence of reducing the diameter of the cable for a given strength, it will be appreciated that the pressure from the well acting upwards on the cable may be reduced. Hence, the person skilled in the art will appreciate that when the cable is used with wellhead pressure control equipment, e.g. in which highly viscous grease is used to seal the cable in place within flowtubes as is known in the art, the extruding force, i.e. the upwards force on the cable due to the well pressure from below, may be reduced.

[0111] In addition, one or more additional features may beneficially be incorporated within the embodiments shown in Figures 2 to 5.

[0112] For instance, a thin, impermeable skin or membrane of tin steel may be provided around the outside of the armour sheath. The skin or membrane will be flexible and substantially non-load bearing; its main purpose is to prevent or restrict inward diffusion of gas, e.g. hydrocarbon gas, into the core of the cable.

[0113] Alternatively, the skin or membrane could be located between the armour sheath and the core or between two layers within the armour sheath.

[0114] Further, the embodiments shown in Figure 2 to 5 may also be provided with a central steel wire rope running through the core along the longitudinal axis of the cable. The arrangement and/or shape of the conductors would have to be changed to accommodate the steel wire rope. For instance, the cross-sectional shape of the non-circular conductors shown in Figure 5 could be changed such that they would "pack" together to form an annulus around the steel wire rope.

[0115] The steel wire rope will carry a proportion of the applied tensile load on the cable. Hence, the stress within the armour sheath may be substantially reduced.

[0116] If the steel wire rope or other tensile load-carrying element within the core is adapted to carry substantially the entire tensile load on the cable, in use, then the armour sheath may not need to bear much or any of the load. Hence, the armour sheath may not compress the core, in use, and may principally fulfil the function of mechanically protecting the core. Accordingly, the armour sheath need not (but may) comprise interlocking strands. Thus, for example, one or more layers of circular section armour strands may be used. Alternatively, the cable may be armoured by a simple interlocked metal strip wound around the core, e.g. of the type commonly employed for conventional submersible oil well cables. Armour of this type is not load-bearing and comprises a single continuous band or strip of metal, e.g. steel, wound around the core with a low pitch, typically around 10°, such that the band or strip interlocks with itself.

[0117] While the improved electromechanical cable of the invention has been described with reference to cer-

tain specific embodiments, it will be readily apparent to the person skilled in the art that many modifications could be made without departing from the scope of the invention.

[0118] For instance, an improved electromechanical cable, which cable may be suitable for use in a well, e.g. an oil or gas well, may include one or more of the following features: an armour sheath comprising one or more layers comprising a plurality of interlocking strands disposed in a helix or spiral of any pitch or substantially parallel to the longitudinal direction of the cable; one or more non-circular conductors; a skin or membrane adapted to provide a barrier to inward gas diffusion; and/or one or more tensile load-bearing elements located within the core of the electromechanical cable.

[0119] Also, the electromechanical cable and/or the core thereof may be of any suitable transverse cross-sectional shape. While the embodiments described herein typically have had a substantially circular transverse cross-sectional shape, it is envisaged that other cross-sectional shapes may also be suitable, e.g. other curved or curvilinear shapes such as ellipses, ovate forms and/or polygonal shapes, preferably having one or more curved sides or corners.

[0120] Also, while the electromechanical cable of the present invention may be particularly well suited for use in a well, particularly an oil or gas well, it is envisaged that the cable may have utility in many other environments, applications or situations, in which it is required to suspend an apparatus on a cable and provide electrical power to the apparatus at the same time.

Claims

1. An electromechanical cable comprising: a core containing one or more electrical conductors and a filler material; and an armour sheath surrounding the core, wherein the armour sheath comprises one or more layers comprising a plurality of interlocking strands.
2. An electromechanical cable as claimed in claim 1, wherein the interlocking strands extend along at least part of the length of the electromechanical cable.
3. An electromechanical cable as claimed in claim 1 or claim 2, wherein the interlocking strands are disposed in a helix having a high pitch or in a direction substantially parallel to the longitudinal axis of the electromechanical cable.
4. An electromechanical cable as claimed in any one of the preceding claims, wherein the armour sheath is substantially self-supporting.
5. An electromechanical cable as claimed in claim 4

comprising a plurality of discrete voids and/or local clusters of voids within the filler material.

6. An electromechanical cable as claimed in any preceding claim, wherein the armour sheath comprises an inner layer of interlocking strands and an outer layer of interlocking strands. 5
7. An electromechanical cable as claimed in claim 6, wherein the interlocking strands of at least the inner layer are disposed in a direction substantially parallel to the longitudinal axis of the cable. 10
8. An electromechanical cable as claimed in any one of the preceding claims, wherein the interlock between neighbouring strands is a mechanical interlock provided by a pair of matched surfaces. 15
9. An electromechanical cable as claimed in any one of the preceding claims, wherein the interlocking strands are chevron-shaped or trapezoidal in cross-section. 20
10. An electromechanical cable as claimed in any preceding claim further comprising a tensile load-bearing element running through the core in a longitudinal direction. 25
11. An electromechanical cable as claimed in any preceding claim further comprising a thin, substantially non-load-bearing, impermeable skin or membrane outside the core. 30
12. An electromechanical cable as claimed in any preceding claim, wherein one or more of the electrical conductors is non-circular in cross-section. 35
13. A submersible pump assembly comprising a pump and a motor for driving the pump and an electromechanical cable as claimed in any one of claims 1 to 12, wherein the pump or motor is coupled or connected to an end of the electromechanical cable. 40
14. A method of withdrawing or injecting fluid from or into a well comprising use of an electromechanical cable as claimed in any one of claims 1 to 12 to deploy a pump or pump assembly within the well. 45
15. A method of deploying an apparatus within a well comprising suspending the apparatus from an electromechanical cable as claimed in any one of claims 1 to 12. 50

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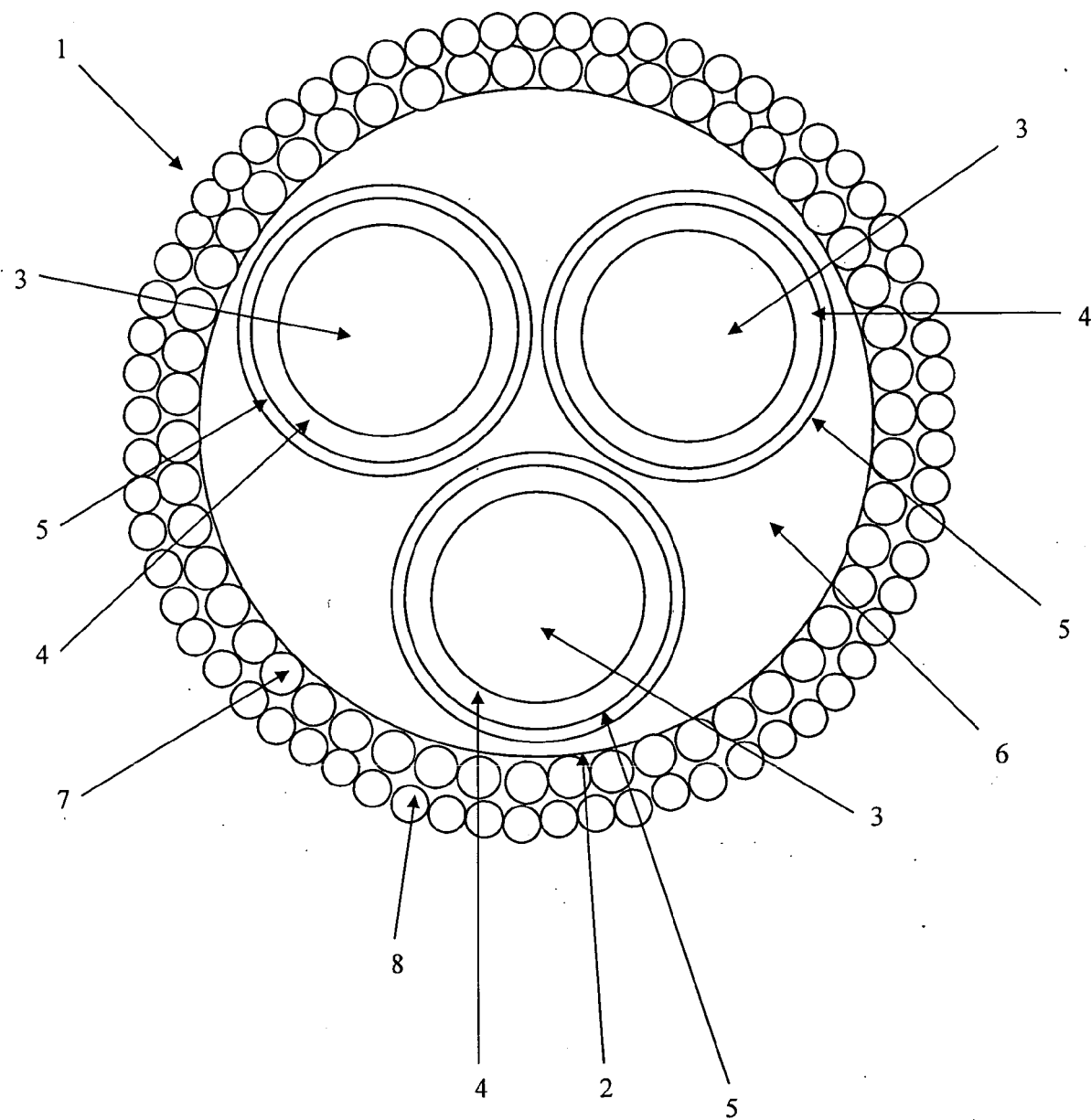


Figure 1

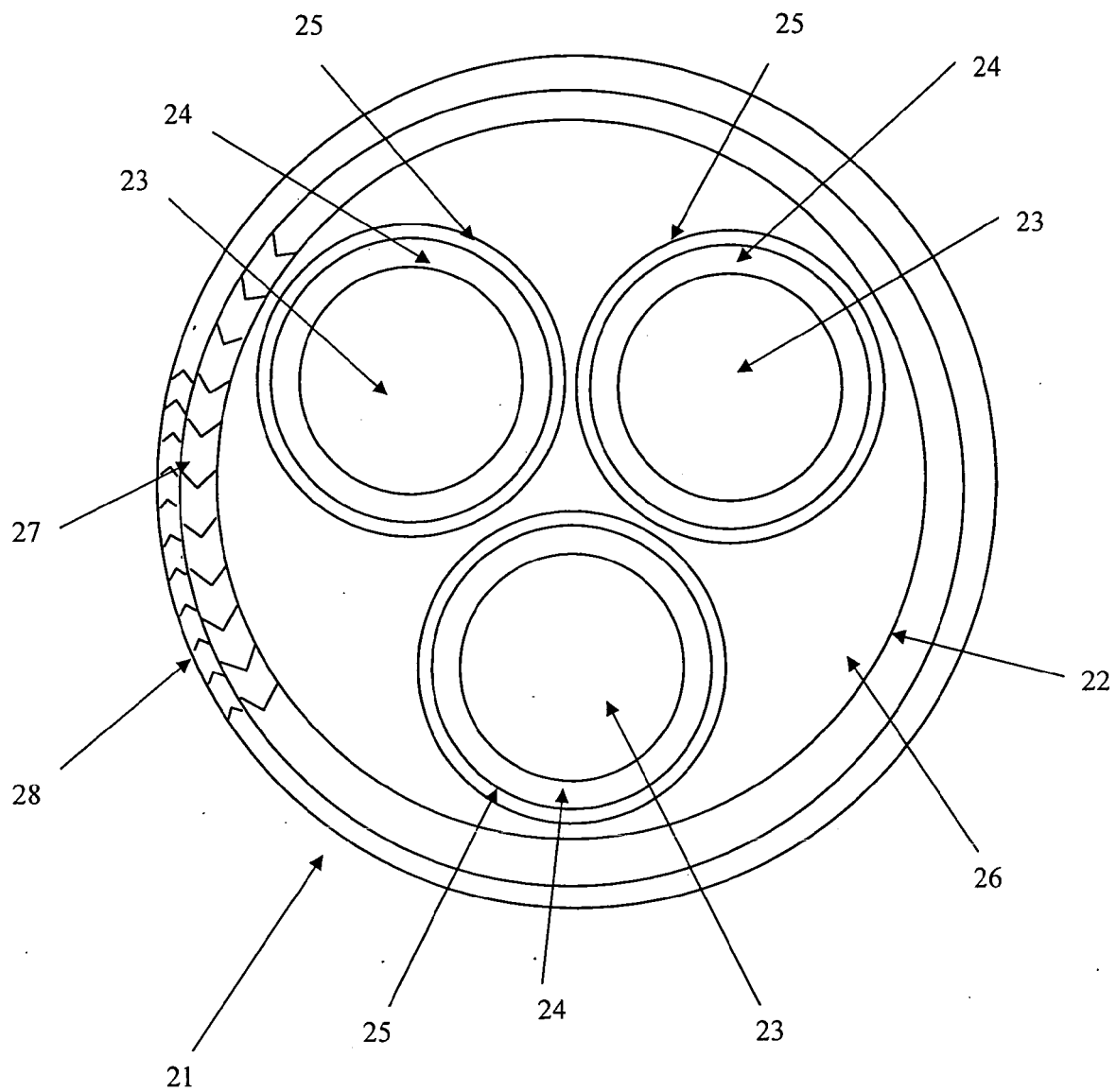


Figure 2

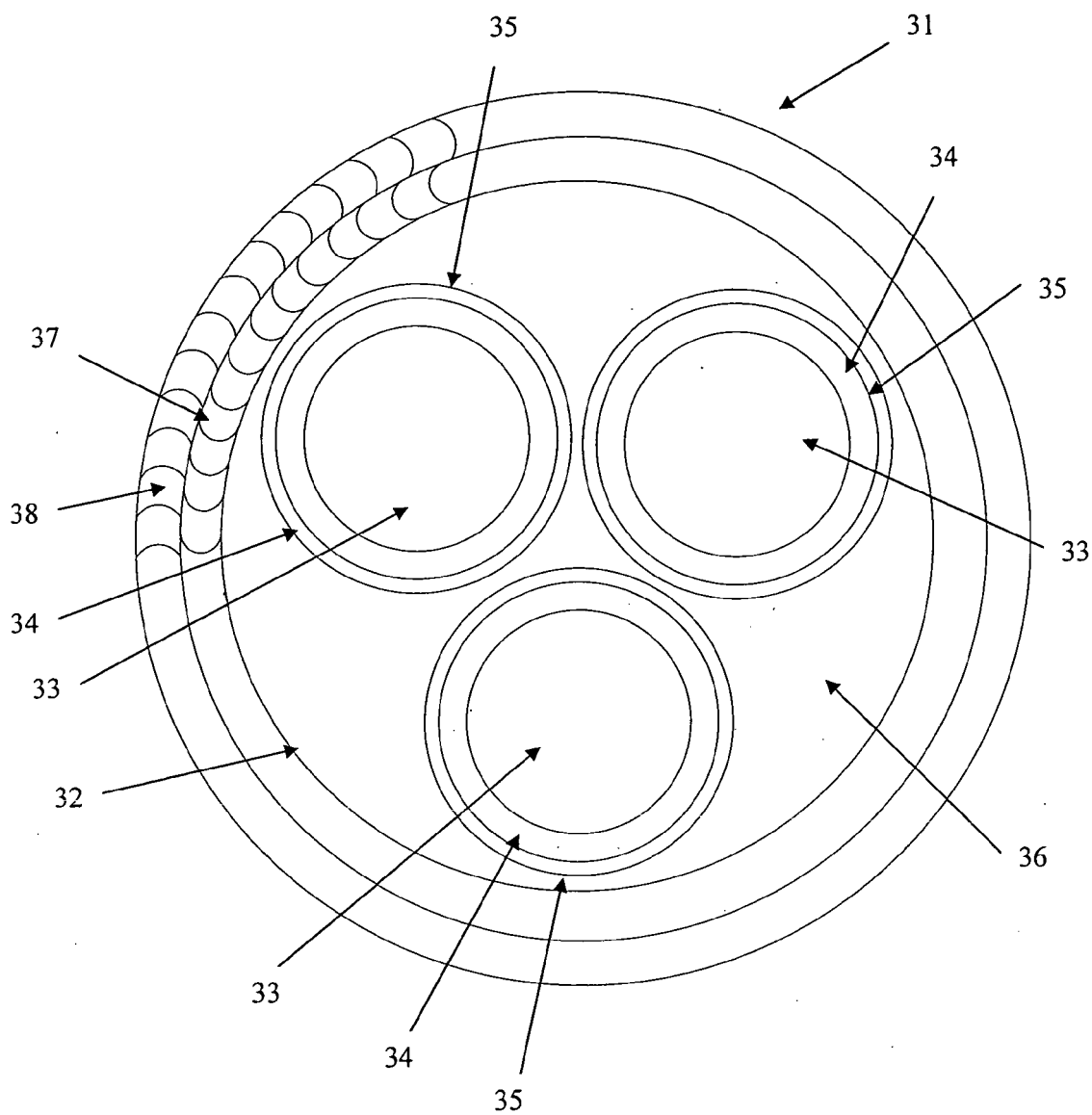


Figure 3

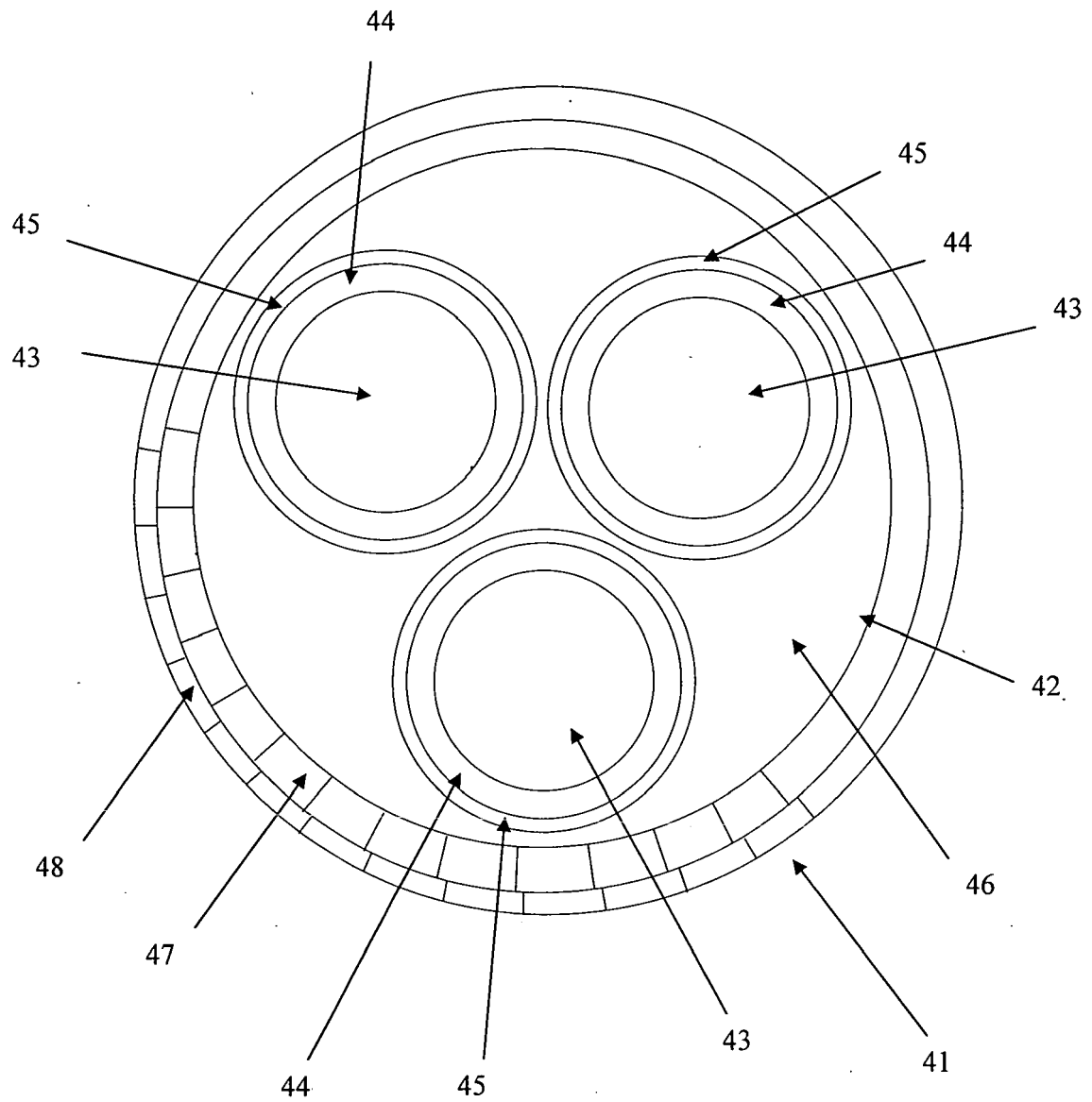


Figure 4

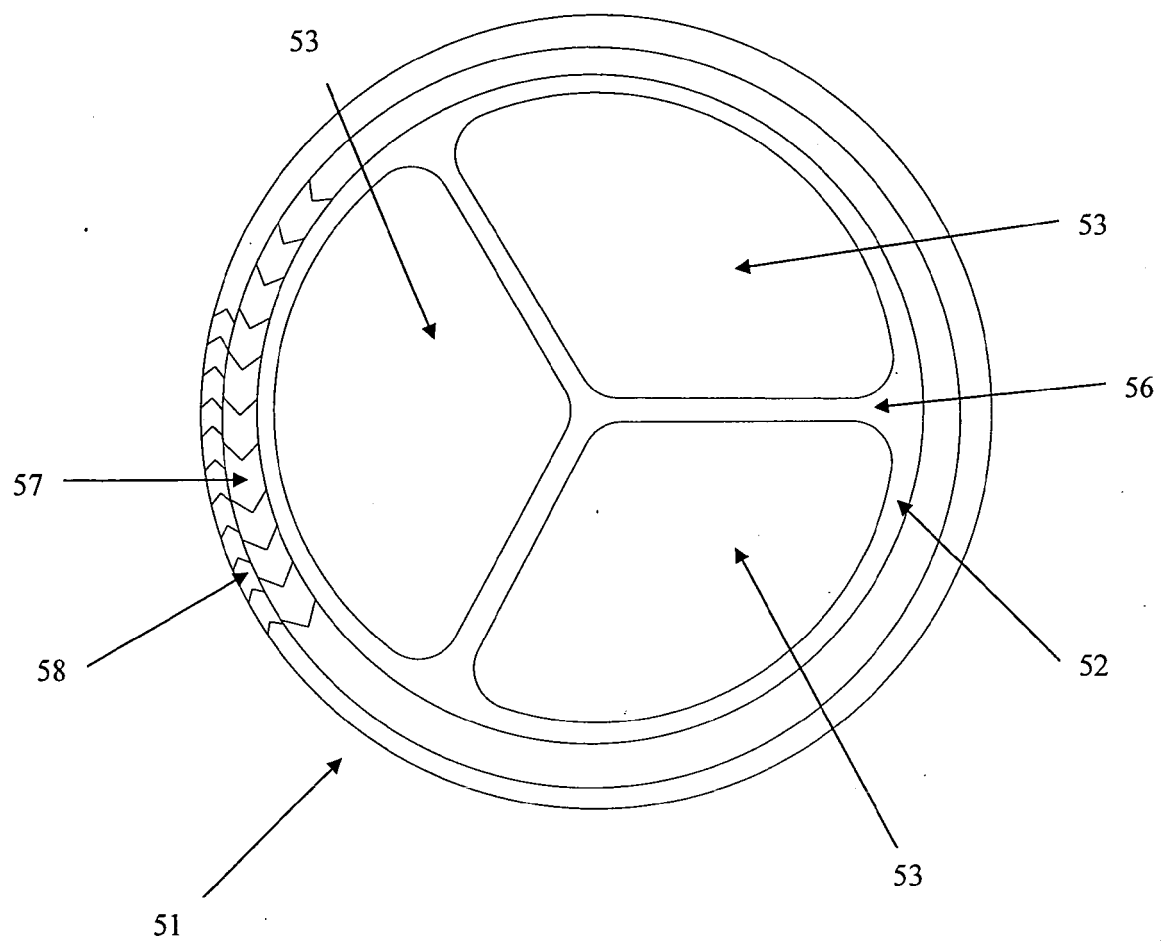


Figure 5



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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 2 June 2009	Examiner Knack, Steffen
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EUROPEAN SEARCH REPORT

Application Number
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CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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