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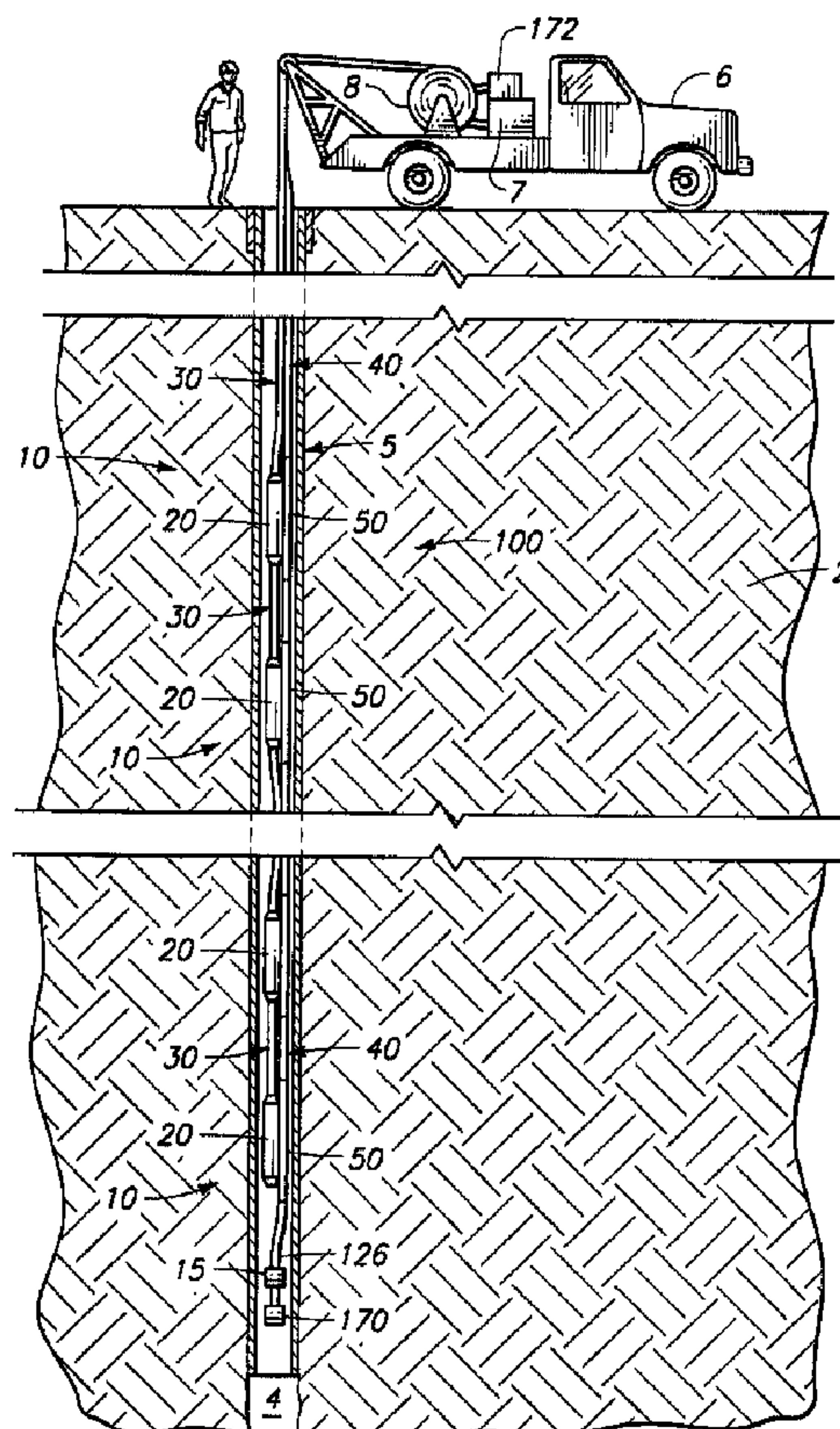
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(54) Titre : CHAPELET DE CAPTEURS BLOQUES PAR DES ELEMENTS DE BOURRAGE DISPOSES LE LONG D'UN
TUBE BOBINE
(54) Title: CLAMPED RECEIVER ARRAY USING COILED TUBING CONVEYED PACKER ELEMENTS



(57) Abrégé(suite)/Abstract(continued):

adapted to be received within a borehole and is therefore particularly useful for borehole seismology. The receiver array has a plurality of receivers connected together by a signal cable. The receivers include sensors which can be 3-component geophones. The apparatus is further provided with a fluid conduit running essentially parallel to the signal cable, the fluid conduit having expandible sections located adjacent to the receivers. The expandible sections expand in response to an increase of fluid pressure within the fluid conduit, contacting the associated receiver and thereby pushing the receiver into a coupled or clamped contact with the casing in the wellbore. The expandible sections have a resilient rubber outer sleeve which fits over a structural tensile strength element which is configured to conduct fluid with the fluid conduit while also providing mechanical strength for the apparatus to be deployed within a wellbore.

Abstract of the Disclosure

A clamped receiver array using coiled tubing conveyed packer elements is disclosed and described. The receiver array is adapted to be received within a borehole and is therefore particularly useful for borehole seismology. The receiver array has a plurality of receivers connected together by a signal cable. The receivers include sensors which can be 3-component geophones. The apparatus is further provided with a fluid conduit running essentially parallel to the signal cable, the fluid conduit having expandible sections located adjacent to the receivers. The expandible sections expand in response to an increase of fluid pressure within the fluid conduit, contacting the associated receiver and thereby pushing the receiver into a coupled or clamped contact with the casing in the wellbore. The expandible sections have a resilient rubber outer sleeve which fits over a structural tensile strength element which is configured to conduct fluid with the fluid conduit while also providing mechanical strength for the apparatus to be deployed within a wellbore.

DESCRIPTION

Clamped Receiver Array Using Coiled Tubing Conveyed Packer Elements

Technical Field

5 This invention relates to the field of geophysical seismic receivers, and more particularly to downhole geophysical receiver arrays.

Background of the Invention

10 An emerging area in the field of seismology is the area of borehole seismology. In traditional seismology, both a source and sensors have been either located at the surface, or the receiver have been located downhole while the source has been located on the surface. In borehole seismology, the source is placed in a borehole while the receivers may be either on the surface, or preferably in a borehole as well. This later mode is known as "cross-well seismology." Borehole seismology is particularly useful in determining the condition of an existing reservoir, following 15 the history of a producing reservoir, and exploring potential new reservoirs. Borehole seismology also makes it possible to routinely record shear waves which allows for mapping lithology of oil and gas reservoirs.

20 A limiting factor in borehole seismology has been the lack of receiver arrays for boreholes which provide the dense spatial sampling required to make use of the high seismic frequencies made possible by the consolidated geologic formation. Shear (S) waves, for example, have only half the wave length of compressional (P) waves, further increasing the need for dense spatial sampling. The recording of compressional waves as well as polarized shear waves makes it 25 possible to map the mechanical properties of oil and gas reservoirs, as well as map and distinguish between different fluids and the effect of lithology. This information may also be used to map differential field stresses, which is the primary source for differential permeability in a reservoir. Further, high signal to noise ratios, as well as a dense spatial sampling, will allow for direct use of

attenuation of compressional and shear waves for characterization of oil and gas reservoirs. This combination of seismic measurements will allow much more information to be extracted about the true nature of oil and gas reservoirs.

5 In order to record and collect this required volume of measurements from borehole seismology, what is needed is a seismic receiver array which may be deployed within a borehole and which has the capability of detecting both compressional and shear waves, as well as transmitting this information from the borehole to the surface where it may be further collected and/or processed. However, the borehole environment makes it difficult to record useful seismic 10 data for borehole seismology. Merely lowering an array of hydrophones into a borehole is typically insufficient to record the data necessary for useful borehole seismology. Hydrophones are susceptible to recording energy from tube wave noise, which may obscure useful seismic signals. Further, in a gas filled well hydrophones are useless, as the gaseous fluid in the borehole do not conduct the energy from the borehole to the hydrophone.

15 U.S. Patent number 3,690,166 to Grice describes a downhole tool configured to bore into shallow mud in an ocean-bottom environment. The tool itself is supported by an instrument cable (Grice Fig. 6, item 33) which includes a fluid hose 60. The fluid hose provides the fluid used to allow the tool to bore into the shallow mud. The tool is provided with inflatable 20 bags 86 and 87 which have valves 91 and 92 to allow fluid from the fluid hose 60 to enter the inflatable bags 86 and 87. In this manner, the fluid bags can urge the measuring instrument 22 against the bore hole. Because of the location of the inflatable bags and the source of the inflating fluid described in Grice, there is no assurance that the instrument will be sufficiently coupled with the bore hole when the inflatable bags are inflated. Further, the inflatable bags disclosed in Grice 25 are susceptible to mechanical damage as a result of being located on the exterior portion of the tool. More importantly, the use of the instrument cable 33 and the hose 60 in Grice to support the instrument means that the tool is not rigidly supported, and may rotate within the borehole. In

applications where the orientation of the tool within the borehole (i.e., the azimuth of the tool) is important, such as when the tool conveys geophones, this can be a significant limitation.

U.S. Patent number 5,027,918 to Cole describes a downhole tool which includes 5 azimuth sensing equipment. The apparatus of Cole is supported by a cable assembly (Cole Fig. 1, item 32). A tube 33, which does not convey the sensing tool, provides fluid to an inflatable actuator 20, which pushes the contact rod 22 into contact with the inner surface 31 of the wellbore (see fig. 2 of Cole). While this design overcomes the shortfall of the design described by Grice in that it claims to allow the azimuth of the tool to be determined, it does require the addition of 10 additional instrumentation and components to provide azimuth sensing capabilities. Further, while the design described by Cole claims to allow the azimuth to be determined, it does not allow for the azimuth to be established at a particular desired position as a result of the tool being supported by the relatively flexible cable assembly.

15 U.S. Patent number 5,111,903 to Meynier describes a downhole sensor configured to be coupled to a wellbore through the use of an expandible chamber (ductile skirt 10 of Fig. 2 of Meynier). The tool provides for a plurality of expandible chambers E1, E2, etc to be suspended from the tool body 1 (see Meynier Fig. 1). Tool body 1 is supported by an electrobearer cable 3. The tool body 1 incorporates an internal hydraulic pump 21 for inflating the expandible chambers. 20 Thus, expandible chamber E1 bears the weight of those expandible chambers suspended therefrom. Further, the tool described by Meynier is susceptible to the same limitations as the tools described by Grice and Cole - that is, the tool is essentially free to rotate azimuthally within the wellbore, such that one has no assurance of the azimuthal position of the tool (or any of the expandible chambers) within the wellbore.

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Therefore, what is needed is a receiver which can be used for borehole seismology. More particularly, what is needed is a receiver array which can be deployed within a borehole and

which will record shear and compressional waves useful in characterizing the reservoir, as well as transmit the received data to a surface location where it may be utilized.

Brief Description of the Drawings

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Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

10 Fig. 1 is an environmental view showing one embodiment of a receiver array described herein deployed within a borehole in a reservoir.

Fig. 2 is a side elevation view showing one embodiment of a portion of a receiver array described herein deployed within a borehole.

15 Fig. 3 is a sectional view of the receiver array shown in Fig. 2.

Fig. 4 is a side elevation detail of an expandable section connector which can be used in the receiver array described herein.

20 Fig. 5 is a sectional detail of an expandable section connector which can be used in the receiver array described herein.

Fig. 6 is a side elevation view showing the receiver array of Fig. 2 in a activated position wherein the receiver is coupled to the borehole wall.

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Fig. 7 is an alternate embodiment of the receiver array shown in Fig. 2.

Fig. 8 is a top sectional view of the receiver array shown in Fig. 7.

Fig. 9 is a sectional view of a positioning device which may be used in a receiver array as described herein.

5 Fig. 10 is a plan view of a positioning ring used to maintain the position of the receiver relative to the expansive element.

Summary of the Invention

10 An apparatus for detecting geophysical energy is disclosed. The apparatus has a receiver configured to receive geophysical energy, the energy being characterized by certain characteristics associated with geophysical energy. The receiver converts the geophysical energy into a signal which is representative of at least one characteristic of the geophysical energy. The device further includes a signal transport device configured to accept the signal from the receiver and relay the signal to a remote location. The apparatus further includes a fluid conduit configured 15 to contain a pressurized fluid. The fluid conduit has an expandable section which is located proximate to the receiver. The expandable section is responsive to an increase in pressure within the fluid conduit, causing the expandable section to expand and press against the receiver. The receiver may thusly be pressed against the inside of a wellbore to achieve beneficial coupling 20 between the receiver and a wellbore.

The system described herein provides for 1) a small receiver pod; 2) low weight of the receiver pod; 3) high clamping force provided by the expandable element; and 4) high clamp force to weight ratio.

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Detailed Description of a Preferred Embodiment of the Invention

An apparatus for detecting geophysical energy is described herein. The apparatus comprises a receiver, a signal transport device, and a fluid conduit having an expandible section located proximate to the receiver. An increase of fluid pressure within the fluid conduit causes the expandible section to expand, pressing against the receiver to increase coupling of the receiver with a solid surface, allowing improved signal reception by the receiver. The expandible sections may be considered as packer elements when used within a borehole.

10 Preferably, the apparatus comprises a plurality of receivers and a common fluid conduit, the common fluid conduit having a plurality of expandible sections located proximate to each receiver, such that an increase of pressure within the fluid conduit will cause essentially simultaneous expansion of all of the expandable sections. Thus, when the receiver array is for example located within a borehole, the expandible sections may all be actuated at an essentially common instant to cause the receivers to be clamped within the wellbore at essentially the same time. The fluid conduit 40 can be fabricated from tubing such as production tubing. More preferably, the fluid conduit comprises coiled tubing which is disposed between the expandible sections. Coiled tubing is tubing which can be deployed from a spool as shown in Fig. 1. Thusly, the apparatus may be described in this embodiment as a clamped receiver array using coiled tubing 15 20 conveyed packer elements.

In the receiver array embodiment, a large number of receivers may be coupled together over a long distance, for example 1,000 meters (m) or more. Thus, when the receiver array is deployed within a borehole, a support mechanism is preferably provided to support the 25 weight of the receiver array while it is in an unclamped position. One embodiment of the invention described herein incorporates tensile strength members to eliminate the need for a separate support mechanism to support the weight of the apparatus within a wellbore. When the receiver array is deployed within a wellbore, local receivers, and the outer surface of the

expansible section proximate to the receiver, will normally be exposed to localized pressures within the wellbore. One method of causing the expansible section to expand and move the receiver into contact with the wellbore wall is to increase the pressure within the fluid conduit to a pressure greater than that within the wellbore at that point. Thus, a differential pressure is 5 generated to actuate the apparatus to cause coupling of the receiver within the wellbore. In one embodiment, the apparatus includes a flow or pressure fused valve located at the end of the fluid conduit which is disposed within the wellbore to allow fast acting response of the expansible sections in response to a pressure increase within the fluid conduit over the local pressure within the wellbore.

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Fig. 1 shows an exemplary receiver array in an environmental view wherein the receiver array is deployed within a wellbore 5 in an earth formation 2. In the embodiment shown in Fig. 1, the apparatus 100 may properly be described as a downhole clamped receiver array. The receiver array 100 has a plurality of receiver sections 10 having receivers 20 connected by a common signal cable 30. Essentially parallel to the signal cable 30 is the fluid conduit 40. The fluid conduit 40 has expansible sections 50 located adjacent to receivers 20. Fluid conduit 40 preferably comprises coil tubing such that the apparatus can be wound onto a spool 8 which can be supported by a vehicle 6, allowing easy transportation and deployment of the apparatus within a wellbore. Although in the preferred embodiment a plurality of receivers and expandable sections 15 are employed in the apparatus, it is understood that the apparatus may be constructed and deployed using only a single receiver and a single expansible section. For exemplary purposes only, a signal cable 30 can be provided with between 20 and 2000 receivers spaced between about 0.3 m and 60 20 m apart.

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Turning now to Fig. 2, a detail of the apparatus 10 having a single receiver 20, associated fluid conduit 40, and expansible section 50 is shown deployed within a wellbore having a casing 5. The apparatus preferably further includes positioning devices 70 which are useful in positioning and protecting the receiver 20 and the fluid conduit 40 within the casing 5.

Centralizing the receiver 20 and the fluid conduit 40 within the casing 5 is beneficial to reduce unwanted contact between these components while the apparatus 10 is being inserted into the casing. Such unwanted contact can cause damage to the apparatus, and is therefore undesirable. The positioning device 70 can also be utilized to connect the signal cable 30 to the fluid conduit 40 to reduce relative movement therebetween. In one embodiment of the invention wherein only a single receiver is employed, the signal cable section 114 and the fluid conduit section 112 are terminated shortly below positioning device 116. In a first variation on the single receiver embodiment, the signal cable section 114 and the fluid conduit section 112 are absent or terminated just below the receiver second end 26 and the expandable section second end 118, respectively.

In yet an alternate embodiment of the apparatus, several receivers 20 can be connected to the signal cable 30 between expandable sections 50. That is, receiver arrays wherein certain receivers are not provided with dedicated expandable sections may be employed.

Turning now to Fig. 3, a cross-sectional view of the apparatus 10 of Fig. 2 is shown. The major components of the apparatus 10 shown in Fig. 3 are the receiver 20, the signal cable 30, the fluid conduit 40, and the expandable section 50. The expandable section 50 is connected to fluid conduit sections 42 and 112 by expandable section connector 60. The apparatus 100 of Fig. 1 can further include an orienting device 170, which can comprise a gyroscopic orienting apparatus. Orienting device 154 is useful for determining the compass direction of the apparatus 100 in the borehole 5. Each component will now be described in further detail.

The Receiver

The receiver 20 is a receiver configured to receive geophysical energy and record certain characteristics associated with the geophysical energy. The geophysical energy may be characterized by such characteristics such as frequency, amplitude, polarization, and the direction

propagation of the energy wave associated with the geophysical energy. Preferably, the receiver has sensors 22 which can comprise 3-component or 3-dimensional geophones, also known as three component geophones. Such geophones record geophysical seismic energy moving in a vertical direction, and a first and second horizontal direction. One example of sensors used in a receiver in the present invention are 30 Hz, 3-component geophones having a frequency range of 10 Hz to 1,000 Hz and being digitized with a sample rate of between and including 2 ms and $\frac{1}{4}$ ms. In addition to the 3-component sensor described, 1, 2, or 4-component sensors may also be employed.

In one example, the receiver 20 includes a polyurethane pod or casing 142 having a diameter of 7 cm and a length of approximately 30 to 36 cm. The geophones 22 are preferably epoxied within the casing 142. The geophones 22 are preferably further potted in a semi-rigid rubber/plastic compound to absorb thermal and pressure strain on the geophone holder 144. Holder 144 is preferably fabricated from aluminum. The geophone holder 144 is preferably potted with R828 Epon epoxy, available from Shell Chemical Company.

The receiver 20 is held in relative position to the expandible section 50 by positioning device 70, as described below. The receiver 20 of Fig. 3 preferably further includes locator ring 156 which is configured to prevent the receiver 20 from moving laterally with respect to the fluid conduit 40. Locator ring 156, shown in detail in Fig. 10, includes an opening 160 to receive receiver 20, and a concave portion 158 to receive the expandible section 50.

Signal Cable

In response to geophysical energy received by sensor 22, the receiver 20 produces a signal which can then be communicated to a remote location, such as to a surface location where the signal may either be recorded or further processed. A device for communicating the signal can

include the signal cable 30 of Fig. 3. Other signal transmitting devices may be employed, such as radio transmission. The signals can be transmitted to recorder 172 of Fig. 1.

5 Signal cable 30 further includes a signal conductor 36. Examples of signal conductors 36 are metal wires or optical fibers. For example, in a receiver array having 80 3-component receivers resulting in 240 channels for data transmission, a 256 twisted pair cable was used for the signal conductors. The twisted pairs were of #28 wire with thin braided shield around the bundle. The wires were coated with a dual copolymer/polypropylene insulation rated at 176°C (350°F). The cable was jacketed with double extruded polyurethane jacket, each layer having a 10 thickness of 2.3 mm. The signal cable in the example further included a central Kevlar strength member having a 1600 kg break strength.

15 Signal cable 30 can be an analog cable with each sensor 22 hardwired directly to the remote location (as for example the surface). Alternately, the sensors 22 can be locally digitized and the digital data or signal can be multiplexed and sent to the remote location on multiplexed signal conductors 36. The benefit of using multiplexed signal conductors is that a lesser number of signal conductors is required. For example, in the example described herein wherein 240 sensors were employed, 256 twisted pairs were used. However, if the sensors are provided with digitizers to digitize the signal, and 4 signal channels are used, then a 64 twisted 20 pair signal conductor arrangement can be employed. The use of optical fibers can reduce the number of signal conductors even further.

Fluid Conduit

25 The fluid conduit 40 of Fig. 3 is used to communicate a fluid to the expandible section 50. The fluid can be used to expand the expandible section 50 causing the receiver 20 to be pressed up against the inner wall 3 of the borehole casing 5. This is shown graphically in Fig. 6

where receiver 20 has been pushed up against the inner side wall 3 due to expansion of the resilient sleeve 52 which comprises a part of expandible section 50 and fluid conduit 40.

In one embodiment, the fluid conduit 40 comprises a continuous piece of coil tubing having resilient expandible sleeves such as rubber bladders placed over the outside of the tubing at expandible section locations 50. In those positions where the rubber bladder is placed over the coil tubing, the tubing is provided with holes to allow fluid within the fluid conduit to be forced outside of the fluid conduit, thus causing the rubber bladder 52 to expand and push the receiver 20 into the casing 5. In this embodiment, the rubber bladder 52 is secured to the coiled tubing by metal straps 154 of Fig. 4. Fluid conduit 40 can be a length of standard tubing or a length of coiled tubing.

Coil tubing is a preferred material choice for the fluid conduit 40 since the fluid conduit may then be deployed on an industry standard coiled tubing rig, as indicated in Fig. 1. Such rigs allow the tubing to be wrapped on a spool rather than pieced together by individual straight pipe lengths. This allows a simpler deployment of the apparatus in the field. Preferably, the coiled tubing is between about 2.3 cm and 7.9 cm (0.9 in. and 3.1 in.) in diameter. The only practical limit on the length of coiled tubing which may be employed is the weight which must be supported by the coiled tubing when it is deployed within a borehole. Coiled tubing lengths of 9000 m and greater may be employed in the apparatus disclosed herein.

In a first embodiment of the fluid conduit 40 described above, a resilient sleeve 52 is disposed about the outside diameter of a continuous piece of coiled tubing. In a preferred embodiment, non-continuous segments of coiled tubing are used between expandible sections 50. Expansible sections are preferably provided with a resilient sleeve 52 having an uninflated outside diameter approximately equal to the outside diameter of the coil tube 42. In this way, a constant diameter for the fluid conduit 40 may be maintained, allowing ease of spooling of the fluid conduit, it being appreciated that when a resilient sleeve 52 having an outside diameter greater

than the outside diameter of the coiled tube 42 is used, the fluid conduit will not be spooled in a smooth continuous manner.

5 Most preferably, the fluid conduit 40 further comprises an expandible section connector 60 which advantageously includes an expandible section tensile member 54.

Positioning Device

A positioning device 70 shown in Fig. 3 which can be used in the embodiment 10 described herein is shown in further detail in Fig. 9. Fig. 9 shows a plan view of the positioning device 70 of Fig. 3. The positioning device 70 comprises a first half 144 and a second half 146 which are coupled together by fasteners 148 and 150, which may comprise threaded couplers. When coupled together, the first half 144 and the second half 146 define a first opening 152 which 15 can receive fluid conduit 40 of Fig. 6, and a second opening 153 which can receive the signal cable 30. In this manner, the fluid conduit 40 can be held in relative position to signal cable 30 and hence receiver 20. This allows the receiver 20 to be accurately positioned with respect to the expandible section 50. In addition to positioning the receiver in the wellbore, the positioning device is also useful in dampening noise in the wellbore ("tube waves"), which are conducted by casing 5 of Fig. 1.

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Expandible Section - Preferred Embodiment

Turning to Fig. 4, a detail of the upper end 122 of the expandible section 50 of the fluid conduit 40 shown in Fig. 3 is provided in detail. The expandible section 50 includes an 25 expandable sleeve 52 which is preferably a resilient sleeve. The sleeve may be fabricated from any material having a tendency to expand when subjected to a differential pressure and preferably returned to its original size and shape once the applied pressure has been removed. The resilient sleeve 52 may also be described as a rubber bladder. A preferable material of construction is a

nitrile elastomer. More preferably, the resilient sleeve 52 is fabricated from nitrile having a hardness of duro 60. An alternate material of construction for the resilient sleeve 52 is viton having a hardness of duro 60.

5 The resilient sleeve 52 is coupled to the main coiled tubing section 42 of the fluid conduit 40 by the expandable section connector 60. The expandable section connector 60 includes coiled tubing end fitting 62 and expandable section connector end fitting 64. Expandable section connector 60 further preferably and advantageously includes expandable section tensile member 54. Coiled tubing end fitting 62 securely engages the primary coiled tubing 42. One method for such secure engagement is to swage the end of coiled tubing 42 over the coiled tubing end fitting 62. Another method to secure the coiled tube 42 to the end fitting 62 is by welding. O-rings 66 and 68 are preferably provided to provide a fluid-tight seal between the coiled tubing 42 and the coiled tubing end fitting 62.

15 The expandable section tensile member 54 is securely held in place against the expandable section end fitting 64 by an appropriate method as a swage fitting. O-rings 63 and 65 are employed to provide a fluid-tight seal between expandable section tensile member 54 and expandable section connector end fitting 64.

20 Coiled tubing end fitting 62 is securely engaged by expandable section connector end fitting 64 by a method such as threads 69. Expandable sleeve 52 is preferably disposed about the outer diameter of expandable section tensile member 54 and the exposed portion of expandable section connector end fitting 64. The expandable sleeve 52 is securely held in such position by a metal strap 154, which can be fabricated from stainless steel. In this manner, the fluid conduit 40 provides a continuous strength member to support the apparatus when it is deployed for example within a wellbore. As seen in Fig. 4, this also provides a constant outside diameter for the fluid conduit 40.

In operation, fluid within fluid conduit 40 may pass into the expandable section connector 60 by way of fluid passage 101 which is disposed in the coiled tubing end fitting 62. Expandable section connector end fitting 64 is likewise provided with a fluid passage 124 allowing fluid to pass into the expandable section tensile member 54. The expandable section tensile member 54 is preferably a coiled tubing section. In one example, coiled tubing section 42 is a 3.8 cm (1.5 in. nominal) diameter coiled tubing, and expandable section tensile member 54 is a 2.5 cm (1 in. nominal) diameter coiled tubing section.

Preferably, the hollow tubing used for expandable section tensile member 54 is provided with holes 56 allowing fluid to pass from within the fluid conduit into the space 110 between the outside diameter of the expandable section tensile member 54 and the resilient sleeve 52. When the fluid pressure within the fluid conduit is increased beyond the pressure at the outside diameter of the expandable sleeve 52, the expandable sleeve is caused to expand in an outward manner, thus pushing against the receiver 20 of Fig. 3 and causing the receiver 20 to move against the inner wall 3 of the casing 5.

Turning to Fig. 5, a complete elevation view of the expandable section connector 60 of Fig. 4 is shown. Upper end 122 and lower end 124 are shown with respect to similar upper and lower ends of Fig. 3. The expandable section connector 60 has a first expandable section connector end fitting 64 and a second expandable section connector end fitting 61. Swaged about, or welded to, each of the expandable section connector end fittings is expandable section tensile member 54, which here comprises a 2.5 cm diameter (1 in. nominal) hollow coiled tubing section 54. Advantageously, the threads 69 in the first expandable section connector end fitting 64 are provided in a first direction, while the threads 106 in the second expandable section connector end fitting 61 are provided in a second direction. For example, thread 69 may be right hand threads while threads 106 may be left hand threads. In this example, the expandable section connector 60 can be rotated in a single direction to engage coiled tubing end fittings at each end of the expandable section connector 60. When the expandable section connector 60 is rotated in the

opposite direction, the coiled tubing end fittings at each end of the expandable section connector 60 will be disengaged from the connector. This has the beneficial effect of allowing expandable sections 50 to be removed from the fluid conduit 40 without the need to rotate one end or the other of the fluid conduit 40 with respect to the expandable section 50. This beneficial feature can be 5 utilized for example to replace expandable sleeves 52 which may become damaged or worn in use.

Outer Sleeve

In yet an alternate embodiment, the signal cable 30, receivers 20, and the fluid 10 conduit 40, may be received within a secondary coiled tubing 130. This is shown in side elevation view in Fig. 7 and in a plan sectional view in Fig. 8. When the expandable sections 50 within the fluid conduit 40 expand, the receivers 20 will be pushed out of the secondary coiled tubing 130 into contact with the inner wall 3 of the casing 5. In this embodiment, the secondary coiled tubing 130 essentially acts as a protective outer sleeve in which the apparatus 10 is protectively contained 15 until such time as the apparatus is to be activated within the borehole. Once the pressure within the expandable section 50 is reduced, the receivers 20 and signal cable 30, retract back into the secondary coiled tubing 130.

Operation

20 Returning to Fig. 1, as described previously, the apparatus is preferably actuated by inflating the expandable sections 50 to cause the receivers 20 to be pressed against the casing 5. This can be accomplished by increasing the pressure within the fluid conduit 40 to a pressure beyond that inside the wellbore 4, thus causing the expandable sections to expand. In a first 25 embodiment, a static fluid can be maintained within the fluid conduit 40 having a pressure maintained by a pressure source 7 of Fig. 1 which can comprise a pump or a compressor.

More preferably, a fluid is circulated within the fluid conduit 40. In this embodiment, the lower-most end 126 of the fluid conduit 40 is provided with a flow restrictor 15. The flow restrictor can comprise a valve configured to close when the pressure within the fluid conduit rises to a certain preselected pressure. More preferably, the flow restrictor 15 comprises a 5 fused valve configured to close at a preselected differential pressure between the pressure within the fluid conduit 40 and the wellbore 4. The apparatus 100 can be actuated by increasing the pressure of fluid within the fluid conduit 40 by fluid pressure source 7 for example. The fused valve 15 advantageously provides a fast acting response to pressure increases within the fluid conduit 40. When the expandable sections 50 have been actuated, the receivers are caused to move 10 towards the casing 5 as shown in Fig. 6. Once the pressure within the fluid conduit 40 drops below a preselected pressure differential with the pressure in the wellbore 4, the fused valve 15 opens allowing fluid to be circulated through the fluid conduit 40.

When the apparatus is deployed in a reservoir in which the borehole is filled with a 15 liquid fluid, it is preferable to use the same liquid fluid within the fluid conduit as the working fluid to expand the expandable sections. This will provide a pressure balanced system prior to closing the valve. This is critical to the proper function of the packers. In other applications, the apparatus can be deployed within a wellbore in which a gaseous fluid is contained, as for example 20 in a natural gas field. In this application, it is preferably to use a gaseous fluid within the fluid conduit as the working fluid to expand the expandable sections.

Industrial Applicability

The present invention is useful in the field of borehole seismology, and particularly 25 in the field of cross-well seismology wherein an energy source is placed in a first borehole and the receivers are located in a second borehole. Borehole seismology is particularly useful in determining the condition of an existing reservoir, following the history of a producing reservoir,

and exploring potential new reservoirs. Borehole seismology also makes it possible to routinely record shear waves which allows for mapping lithology of oil and gas reservoirs.

The present invention provides for a large number of receivers to be placed in a borehole, which provides the dense spatial sampling required to make use of the high seismic frequencies made possible by the consolidated geologic formation. The invention is particularly useful for assisting in recording of compressional waves as well as polarized shear waves, which makes it possible to map the mechanical properties of oil and gas reservoirs, as well as map and distinguish between different fluids and the effect of lithology. This information may also be used to map differential field stresses, which is the primary source for differential permeability in a reservoir. The present invention also improves the signal to noise ratios of received seismic energy by improving the coupling of the receiver to the borehole wall. These features allow for direct use of attenuation of compressional and shear waves for characterization of oil and gas reservoirs. This combination of seismic measurements allows much more information to be extracted about the true nature of oil and gas reservoirs.

The invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims.

WHAT IS CLAIMED IS:

1. An apparatus for detecting geophysical energy, the apparatus having a receiver configured to receive geophysical energy characterized by a plurality of characteristics and convert said geophysical energy into a signal representative of at least one characteristic of said geophysical energy, the apparatus further having a signal transport device configured to accept said signal and relay said signal to a remote location, the apparatus further comprising:

10 a fluid conduit configured to contain a pressurized fluid, said fluid conduit supporting the receiver array from the remote location, said fluid conduit comprising an expandible section located proximate to said receiver, said expandible section defined by an outside dimension and configured to increase said outside dimension and press against said receiver in response to an increase of fluid pressure within said fluid conduit.

15 2. The apparatus of claim 1 wherein said signal transport device comprises a signal cable comprising a signal conductor, said signal cable being connected to said receiver.

3. The apparatus of claim 2 wherein said signal conductor comprises an optical fiber.

20 4. The apparatus of claim 1 wherein said receiver comprises a 3-component geophone.

5. The apparatus of claim 1 wherein said fluid conduit comprises coiled tubing, and wherein said expandible section comprises a resilient material.

25 6. The apparatus of claim 5 wherein said fluid conduit is defined by a fluid conduit outside diameter, said expandible section is defined by an expandible section outside diameter, and

wherein said fluid conduit outside diameter is essentially equal to said expandible section outside diameter.

7. The apparatus of claim 5 wherein said resilient material is selected from the group consisting of nitrile elastomer and viton.
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8. The apparatus of claim 7 wherein said nitrile elastomer or viton has a hardness of about duro 60.
- 10 9. The apparatus of claim 1 further comprising a plurality of receivers in spaced-apart relationship, said fluid conduit further comprising a plurality of expandible sections in spaced apart relationship, individual said receivers being located proximate individual said expandible sections.
- 15 10. The apparatus of claim 9 wherein said fluid conduit further comprises a plurality of coiled tubing sections, individual coiled tubing sections disposed between individual said expandible sections.
11. The apparatus of claim 1 further comprising a positioning device attached to said fluid conduit for positioning said receiver within a borehole
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12. The apparatus of claim 10 further comprising a plurality of positioning devices for positioning said apparatus within a borehole, individual said positioning devices being attached to individual said coiled tubing sections.
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13. The apparatus of claim 10 further comprising a plurality of expandible section connectors, individual expandible segment connectors being disposed between individual said

expandable sections and adjacent individual said coiled tubing sections to connect said individual expandable sections with said individual coiled tubing sections.

14. The apparatus of claim 13 wherein individual said expandable section connectors comprise first ends connected to individual first expandable sections and individual first coiled tubing sections, and second ends connected to said individual first expandable sections and individual second coiled tubing sections. said first ends of said of said individual expandable section connectors being threaded in a first threading direction to engage said first coiled tubing sections in response to rotation of said individual expandable section connectors in a first direction of rotation, and said second ends of said of said individual expandable section connectors being threaded in a threading direction opposite to said first threading direction to engage said second coiled tubing sections in response to rotation of said individual expandable section connectors in a first direction of rotation.
15. The apparatus of claim 14 further comprising a plurality of coiled tubing end fittings, individual said coiled tubing end fittings comprising first ends configured to threadably engage individual said expandable section connectors, and second ends configured to engage individual said coiled tubing sections.
16. The apparatus of claim 15 wherein individual coiled tubing sections are compression fit over said second ends of individual said coiled tubing end fittings.
17. The apparatus of claim 16 further comprising a plurality of coiled tubing end fitting seals, individual said coiled tubing end fitting seals being disposed about said second ends of individual said coiled tubing end fittings to form a seal between said individual coiled tubing end fittings and said coiled tubing sections.

18. The apparatus of claim 13 further comprising a plurality of expandable section tensile members, individual said tensile members being attached to individual coiled tubing sections between which are disposed individual expandable sections, such that when a tensile load is applied to said individual coiled tubing sections, said individual tensile members bear at least a portion of said tensile load.

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19. The apparatus of claim 14 wherein individual said expandable section connectors further comprise expandable section tensile members, said expandable section tensile members being disposed between said expandable section connector first ends and said expandable section connector second ends such that when said first coiled tubing sections and said second coiled tubing sections are subjected to a common tensile load, said tensile members bear at least a portion of said tensile load.

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20. The apparatus of claim 19 wherein individual said tensile members further comprise hollow tubing allowing fluid communication between said first coiled tubing sections and said second coiled tubing sections.

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21. The apparatus of claim 20 wherein individual said expandable sections further comprise a resilient sleeve disposed about said hollow tubing, said resilient sleeve having an outer surface defining said outside dimension, such that said resilient sleeve expands to increase said outside dimension in response to said increase of fluid pressure within said conduit.

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22. The apparatus of claim 21 wherein individual said hollow tubing comprise tubing sidewalls having an inner surface and an outer surface and a hole disposed therethrough, and wherein said resilient sleeve further comprises an inner surface proximate to said hollow tubing outer surface, such that fluid pressure within said hollow tubing may be communicated to said resilient sleeve inner surface.

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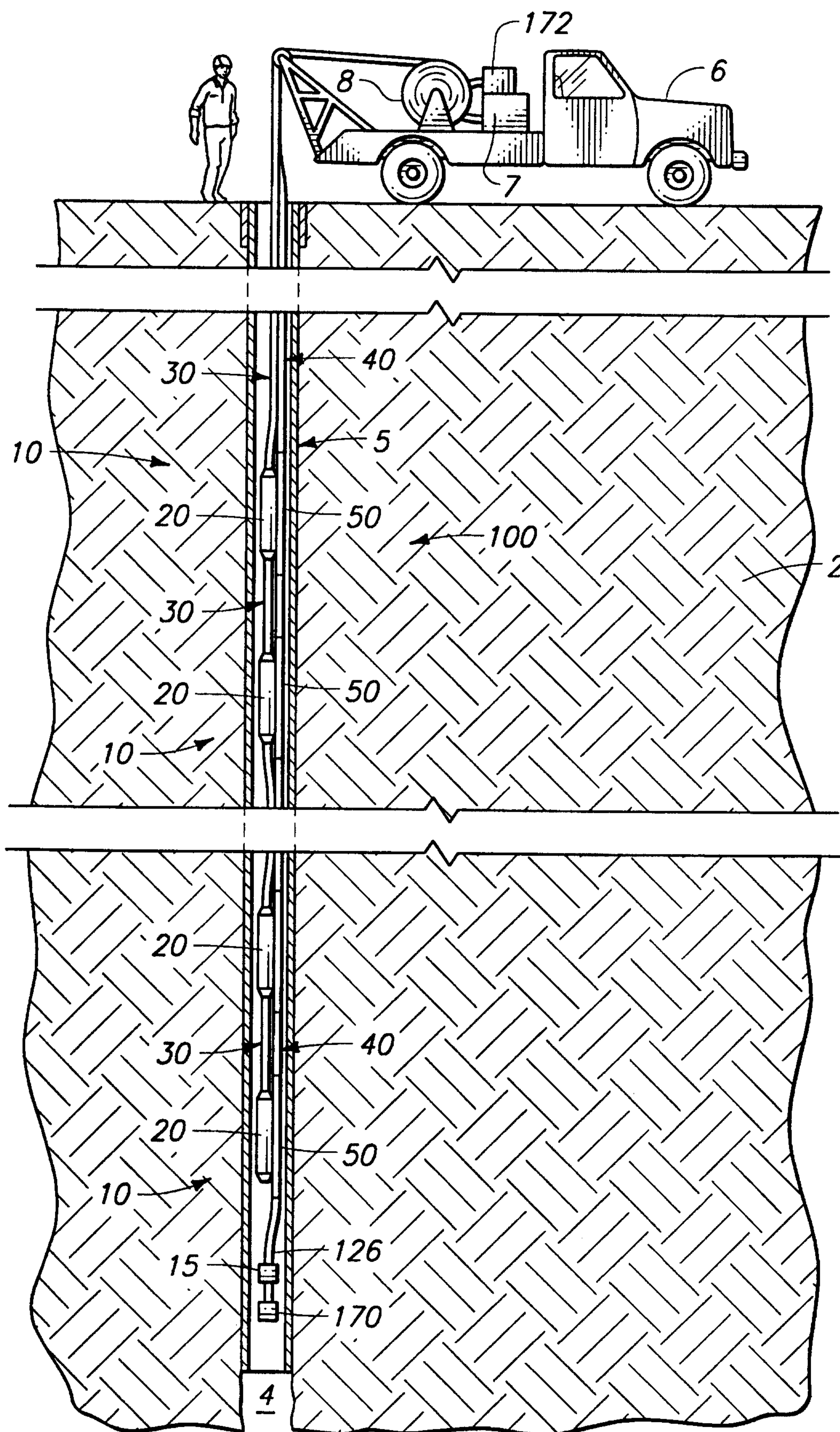
23. The apparatus of claim 22 wherein said hollow tubing comprises coiled tubing.
24. The apparatus of claim 1 wherein said fluid conduit has a first end configured to be received within a borehole and a second end to which a fluid may be provided, said fluid conduit further comprising a valve connected to said first end.
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25. The apparatus of claim 24 wherein said valve is configured to close in response to a preselected pressure differential which may exist between said fluid conduit and a borehole in which said valve may be located.

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26. The apparatus of claim 25 wherein said valve is a fused valve.
27. The apparatus of claim 1 wherein said fluid conduit is defined by an outside diameter, and wherein said outside diameter is sufficiently constant to allow said fluid conduit to be wound onto a spool.
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28. The apparatus of claim 2 wherein said receivers are held in positional relationship to said expandible sections by couplers, said couplers securing said cable to said fluid conduit.
- 20 29. The apparatus of claim 28 wherein said couplers are reusably decoupleable.
30. The apparatus of claim 28 wherein said couplers comprise positioning devices for positioning said receivers within a borehole.

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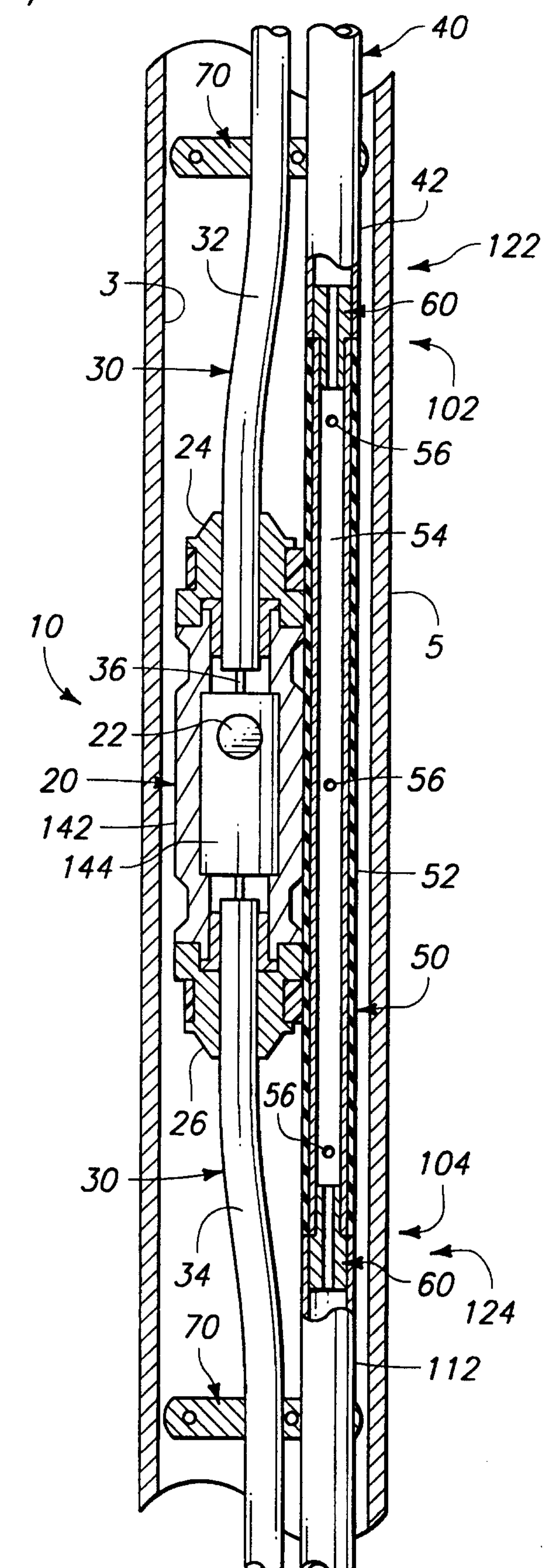
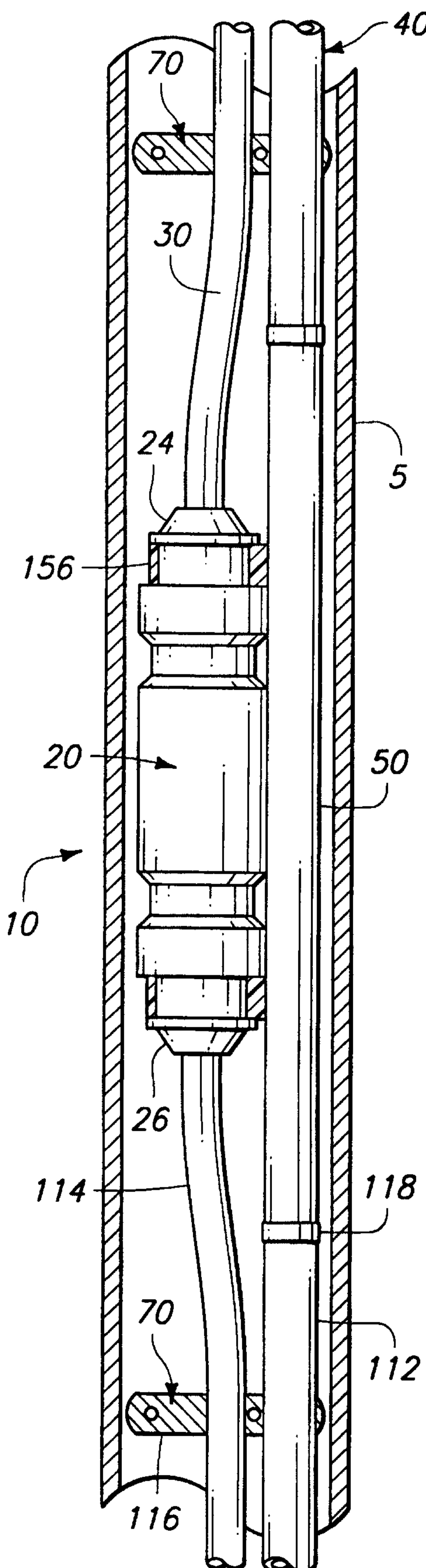
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FIG 5

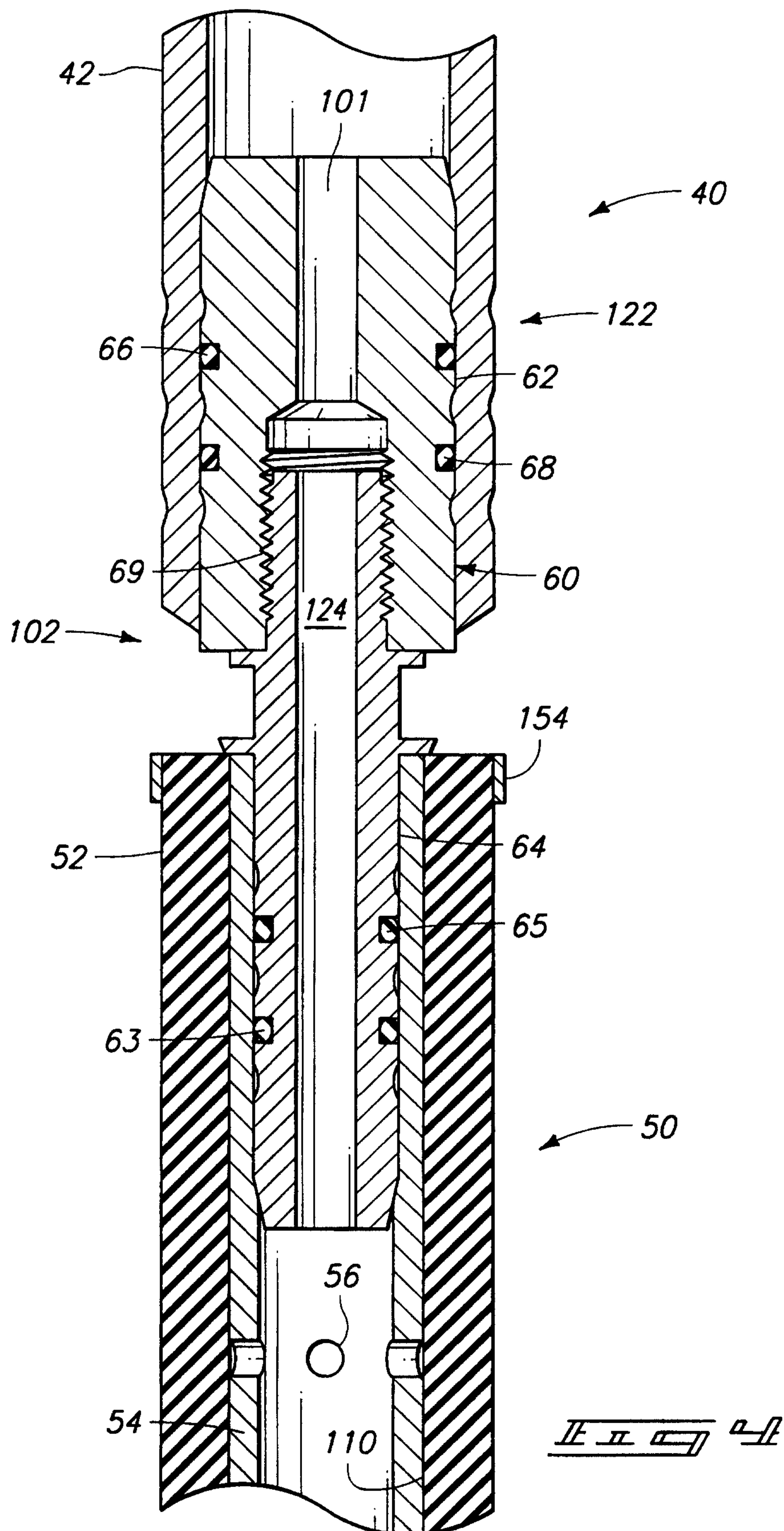
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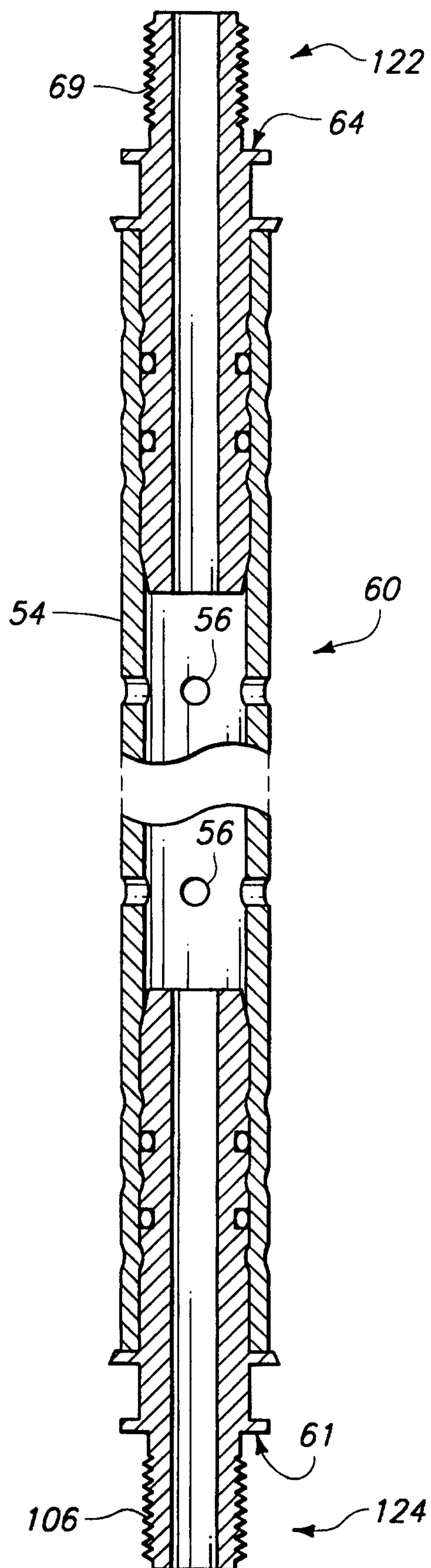
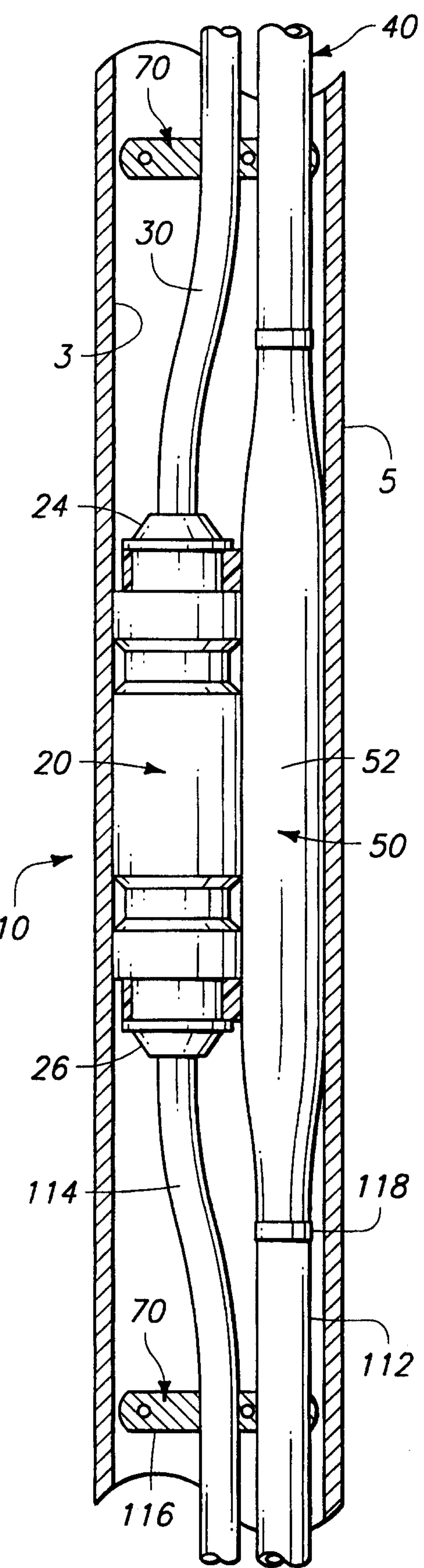
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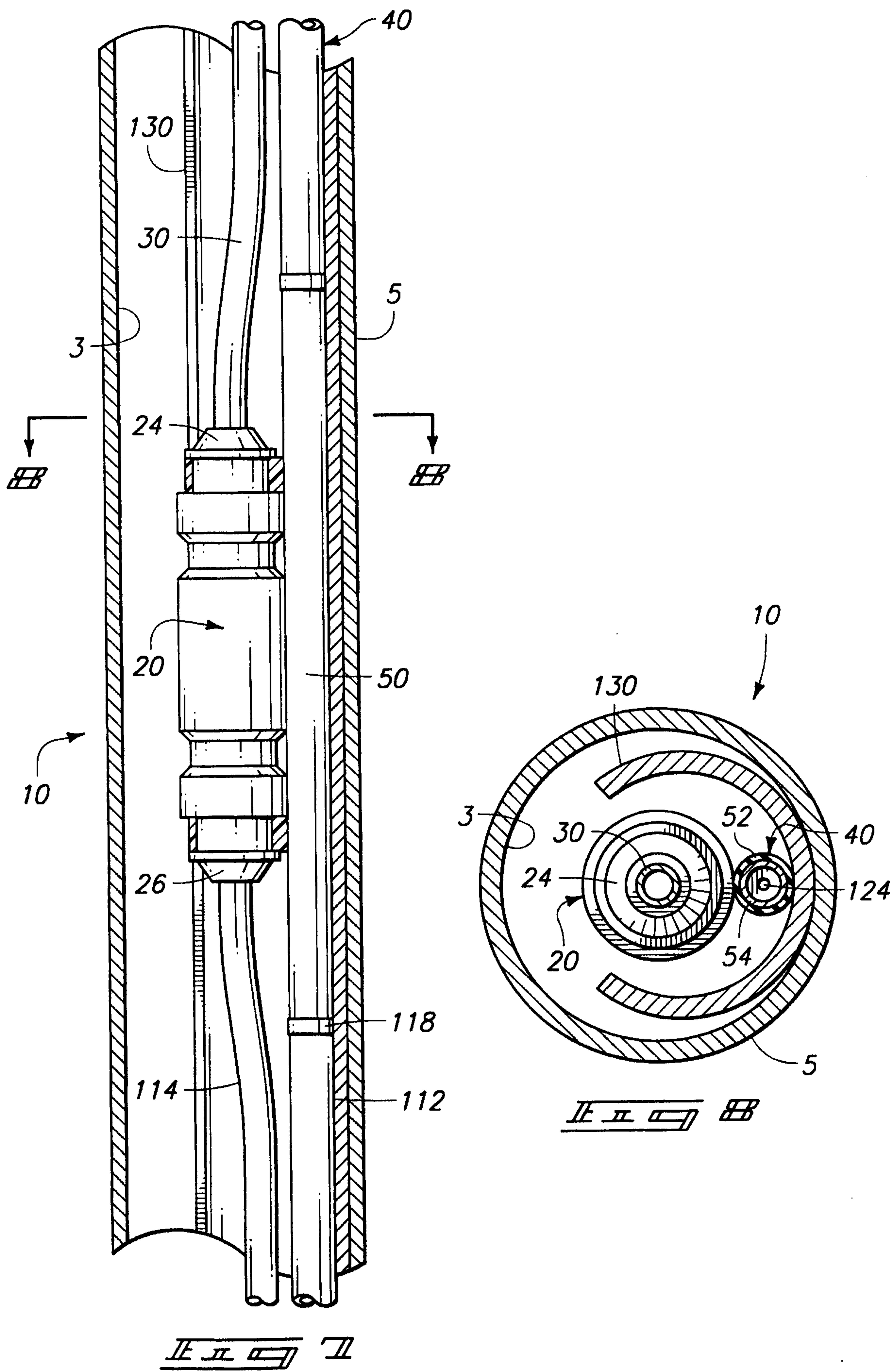
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FIG 5FIG 6

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