METHOD OF MOUNTING AND MAINTAINING ELECTRIC CONDUCTOR IN A DRILL STRING

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Abstract

An insulated electric conductor employed in a tubular drill string to transmit electric energy between subsurface and surface locations is arranged within the drill string in a wound, helical, coiled, looped, folded, overlapped or other convoluted configuration. Preferably, the convoluted conductor, or a portion thereof, is maintained in tension. The convoluted configuration provides an excess length of conductor stored within the drill string which enables the conductor to be extended as the drill string is lengthened.

25 Claims, 9 Drawing Figures
METHOD OF MOUNTING AND MAINTAINING ELECTRIC CONDUCTOR IN A DRILL STRING

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 267,729, now abandoned filed in the U.S. Pat. Office on June 29, 1972.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved method for establishing and maintaining electric continuity through a drill string using an insulated electric conductor. The invention can be employed in wellbore telemetry operations and other operations wherein it is desired to transmit electric energy between the surface and a subsurface location in a well.

2. Description of the Prior Art

In the drilling of oil wells, gas wells, and similar boreholes, it frequently is desirable to transmit electric energy between subsurface and surface locations. One application where electrical transmission has received considerable attention in recent years is found in wellbore telemetry systems designed to sense, transmit, and receive information indicative of a subsurface condition. This operation has become known in the art as "logging while drilling." A major problem associated with wellbore telemetry systems proposed in the past has been that of providing reliable means for transmitting an electric signal between the subsurface and surface locations. This problem can best be appreciated by considering the manner in which rotary drilling operations are normally performed. In rotary drilling, a borehole is advanced by rotating a drill string provided with a bit. Lengths of drill pipe, usually about 30 feet long, are individually added to the drill string as the borehole is advanced. In adapting an electrical telemetry system to rotary drilling equipment, it will thus be appreciated that the means for transmitting an electric signal between subsurface and surface locations must be such as to permit the connection of additional pipe lengths to the drill string. An early approach to the problem involved the use of a continuous electrical cable which was adapted to be lowered inside the drill string and to make contact with a subsurface terminal. This technique, however, required withdrawing the cable each time an additional length was connected to the drill string. A more recent approach involves the use of a special drill pipe equipped with an electric conductor. Each pipe section is provided with connectors that mate with connectors of an adjacent pipe section and thereby provide an electrical circuit across the joint (See U.S. Pat. Nos. 3,518,608 and 3,518,609). Disadvantages of this system include the high cost of special pipe sections, the use of a large number of electric connectors (one at each joint), and the difficulty of maintaining insulation of the electric connectors at each joint.

Although the advantages and desirability of telemetry information from a subsurface location to the surface as drilling operations progress have long been appreciated, electrical telemetry systems have not proven successful mainly because of the unavailability of a reliable and practical conductor for transmitting electric signals to the surface.

SUMMARY OF THE INVENTION

The method of the present invention is adapted for use in a well drilling operation wherein an insulated electric conductor disposed in a pipe string used to drill a well is employed to transmit electric energy between a subsurface location within the pipe string and the surface.

A novel feature of the invention resides in placing the electric conductor in the pipe string in a configuration such that the length of the conductor is substantially longer than the distance between the subsurface and surface locations. This configuration provides an excess length of conductor stored within the drill string.

As each additional length of pipe is connected into the pipe string, thereby increasing the distance between the subsurface and surface locations, the conductor can be extended through the additional length of pipe by withdrawing a portion of the excess length of conductor from within the pipe string and threading it through the additional length of pipe.

Although the conductor can be arranged within the pipe string in a variety of convoluted configurations to provide the excess length, the preferred configuration is such that the conductor has overlapped longitudinal portions which preferably are disposed in parallel relation and extend axially with respect to the pipe string.

Another novel aspect of the present invention involves a method of shortening a pipe string and electric conductor within the pipe string as drilling progresses. Briefly, the method involves disconnecting both the pipe string and electric conductor at the surface, threading a conductor section through the additional length of pipe, and finally connecting the conductor section and length of pipe to the electric conductor and pipe string, respectively.

Still another novel feature of the invention resides in maintaining an electric conductor or at least a portion thereof within the pipe string in tension during drilling operations to remove or reduce slack in the conductor.

The method of the present invention permits the use of a continuous conductor from the subsurface location substantially to the surface. In the preferred embodiment, only one connector, located near the surface, is exposed to the drilling fluid. Moreover, the method can be employed in rotary drilling operations using conventional drill pipe.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of well drilling equipment provided with an electric conductor arranged within the pipe string in a preferred configuration.

FIG. 2 is a fragmentary view of FIG. 1 illustrating the disposition of the electric conductor at a time subsequent to that illustrated in FIG. 1.

FIGS. 3-6 are schematic views illustrating a preferred sequence of steps for adding a length of pipe into the pipe string.

FIG. 7 is an enlarged fragmentary view, shown partially in longitudinal section, of an improved apparatus useful in the present invention.

FIG. 8 is a top plan view of the upper guide of the assembly illustrated in FIG. 7.

FIG. 9 is a top plan view of the lower guide of the assembly illustrated in FIG. 7.
DESCRIPTION OF THE PREFERRED EMBODIMENTS

Conventional rotary drilling equipment, as schematically illustrated in FIG. 1, includes swivel 10, kelly 11, tubular drill string 12, and bit 13. These components, connected in the manner illustrated, are suspended from the drilling derrick 14 by means of rig hoisting equipment. The kelly 11 passes through rotary table 16 and connects to the upper end of the drill string 12. The term "drill string" as used herein refers to the column of pipe between the bit 13 and the kelly 11, and the term "pipe string" refers to the complete column of pipe including kelly 11. The major portion of the drill string 12 normally is composed of drill pipe with a lower portion being composed of drill collars. The drill string 12 consists of individual pipe sections connected together in end-to-end relation. In the lower three sections of FIG. 1, the diameters of the borehole and the drill string 12 have been expanded in relation to the upper section to reveal further details.

The borehole 17 is advanced by rotating the drill string 12 and bit 13 while at the same time drilling fluid is pumped through the drill string 12 and up the borehole annulus. The drilling fluid is delivered to swivel 10 through a hose attached to connection 18 and is returned to the surface fluid system through pipe 19. A Kelly bushing 20 couples the rotary table 16 to the kelly 11 and provides means for transmitting power from the rotary table 16 to the drill string 12 and bit 13. (The use of a power swivel eliminates the need for the kelly and rotary table. The present invention can be used with either system; for purposes of illustration, however, the invention will be described with reference to the kelly and rotary table system.)

As mentioned previously, it frequently is desirable to monitor a subsurface drilling condition during drilling operations. This requires measuring a physical condition at the subsurface location, transmitting this data as an electrical signal to the surface, and reducing the signal to a useful form. Typical situations where telemetry is applicable in drilling operations include drilling through abnormal pressure zones, drilling through zones where hole deviation is likely to be a problem, directional drilling, exploratory drilling, and the like.

Although the present invention may be employed in most any drilling operation wherein an electric conductor is used in pipe string to transmit electric energy between a subsurface location and a surface location, it finds particularly advantageous application in a wellbore telemetry system such as that illustrated in FIG. 1 comprising an instrument 21, an insulated electric conductor 22, and receiver 23.

The instrument 21 capable of measuring a subsurface condition and generating an electric signal indicative or representative of that condition is provided within the drill string 12. A variety of devices capable of sensing a physical condition are available. These include transducers for measuring pressure, temperature, strain and the like; surveying instruments for measuring hole deviation; and logging instruments for measuring resistivity or other properties of subsurface formations. The instrument 21 may be powered by batteries or by energy transmitted through conductor 22. Alternatively, a subsurface generator driven by fluid flowing through the drill string 12 may be used to power instrument 21.

The method of the present invention relates primarily to the electric conductor 22 employed within the drill string to transmit electric energy between surface and subsurface locations. The energy may be a signal generated by the subsurface instrument 21 and transmitted to the receiver 23 at the surface. Alternatively, the energy may be electric power transmitted from the surface to actuate or drive a subsurface instrument or motor. Or, energy may be transmitted down the conductor 22 to power the instrument 21, and simultaneously intelligence may be transmitted up the same conductor.

As applied in telemetry operations, it is preferred that the energy being transmitted be in the form of a pulsating signal. Information can be transmitted by varying the number, amplitude, width or spacing of a train of electrical pulses, or it can be transmitted by modulating the frequency or amplitude of the pulsating signal. More than one transducer or other device may be employed in the instrument 21 if desired, in which case a multiplexer may be used for sending the various signals over a single conductor.

The instrument 21 may be mounted directly in the drill string 12, or, as illustrated in FIG. 1, it may be a separate tool that is lowered into the drill string 12 on the conductor 22.

The conductor 22 extends from a terminal on the subsurface instrument 21 substantially through the drill string 12, and connects to a suitable surface terminal which is electrically connected to receiver 23. In this preferred embodiment the conductor extends through the kelly and connects to a terminal at device 25 located at the upper end of the kelly 11. Kelly conductor 24 serves to interconnect conductor 22 and device 25. It should be observed, however, that conductor 24 may be embedded in the kelly 11, in which case the conductor 22 will extend to the upper end of the drill string 12 and connect to conductor 24 at that location. In order to facilitate the addition of pipe sections to the drill string 12, however, it is preferred that conductor 24 be disposed within kelly 11 as illustrated and extend slightly more than the length of one pipe section below the kelly 11.

If telemetry operations are to be performed while the kelly 11 and drill string 12 are rotating, the upper end of conductor 24 will be connected to device 25 capable of transmitting electric energy from a rotating member to a stationary member. Device 25 may be a rotary transformer having a rotor secured to the kelly 11 and a stator secured to the stationary portion of the swivel 10, or it may be a slip ring and brush assembly. Device 25 and electric conductor 38 provides means for transmitting signals from the conductor within the pipe string to receiver 23. The return path for the electric circuit may be provided by a variety of grounding circuits but preferably is through the pipe string or conductor armor. Conductor 39 of the return path connects stationary portion of device 35 and receiver 23. If telemetry operations are to be performed at times when the drill string 12 and kelly 11 are stationary, the conductors 38 and 39 may be connected directly to conductor 24 through a suitable connector. In this situation, conductors 38 and 39 will be disconnected when the kelly 11 and drill string 12 are rotated. Other means for transmitting the signal to the receiver 23 include a wireless transmitter connected to conductor 22 and located on a rotating member, e.g. kelly 11.
The receiver 23 is an instrument capable of receiving the signal generated by instrument 21 and reducing it to useful form.

In accordance with one aspect of the present invention, the conductor 22 is arranged within the drill string 12 in a configuration such that the length of the conductor 22 is substantially longer than the distance between the subsurface location of instrument 21 and a surface location. As described in detail below, the excess length of conductor 22 stored in the drill string 12 permits the conductor 22 to be extended as the drill string 12 is lengthened. A portion of the conductor 22 is arranged in a wound, coiled, helical, folded, looped or other convoluted configuration that provides the excess length. It is preferred, however, that the conductor 22 be arranged in an overlapped configuration such as that illustrated in FIGS. 1 and 7. This configuration provides the conductor 22 with longitudinal portions 26, 27, and 28 which are disposed in parallel relation and extend axially with respect to the drill string 12. The overlapped configuration permits the excess length of conductor to be almost double the distance between the subsurface location of the instrument 21 and the surface.

The apparatus for installing and maintaining the conductor 22 in the overlapped configuration comprises an upper guide 29 secured to the drill string 12, and a lower movable guide 30. In the installed position, the conductor 22 extends upwardly from the instrument 21, around the upper guide 29, downwardly from the upper guide 29, around the lower guide 30 and upwardly from the lower guide 30 to the upper end of the drill string where it connects to conductor 24. The guides 29 and 30 are shown schematically in FIG. 1 and in detail in FIGS. 7-9.

As best seen in FIG. 4, conductor 24 has a lower tail section 33 which extends slightly more than the length of one pipe section below kelly 11. The lower end of tail section 33 is provided with connector 32 which is adapted to mate with connector 31 attached to the upper end of conductor 22. The conductor 22 is then joined to conductor 24 at a point slightly below the top pipe section 34 of the drill string 12 (see FIG. 3). The electric conductor thus extends from a terminal on instrument 21 to a surface terminal within kelly 11 and comprises conductor 22 and conductor 24 connected together by connectors 31 and 32.

The connectors 31 and 32, in addition to providing a water tight connection, should have sufficient mechanical strength to support the conductor 22 and associated subsurface equipment. For example, this connection may be provided by a threaded housing or it may be provided by an assembly which includes latching dogs to impart sufficient mechanical strength to the connectors.

As mentioned previously, the excess conductor, e.g. overlapped portions 27 and 28, permit the conductor 22 to be extended as the drill string 12 is lengthened. The drill string 12 is normally composed of individual pipe sections approximately 30 feet in length. A length of pipe will be added to the drill string 12 for each incremental advance of the borehole. Normally the additional length of pipe is one pipe section. However, the additional length may include two or more pipe sections connected together. In any event, the borehole advancement is sufficient to permit the addition of a length of pipe. Each additional length of pipe, one pipe section in this example, may be connected into the pipe string by the procedure described below with reference to FIGS. 3 and 6. The procedure for installing the equipment as depicted in FIG. 3 will be described later.

As shown in FIG. 3, drilling has progressed to the point that one additional pipe section, e.g. section 36, must be added into the pipe string 12. Pipe section 36 is disposed in a shallow borehole 37 (commonly referred to as a "mouse hole") below the derrick floor. Initially, the kelly 11 and drill string 12 are elevated and the drill string 12 is suspended in the rotary table 16. The kelly 11 is then disconnected from the drill string 12 and is elevated sufficiently to pull the tail section 33 of kelly conductor 24 completely out of the drill string 12. Thus the kelly 11 is elevated slightly more than the length of one pipe section. As the kelly 11 is elevated, the mated connectors 31 and 32 and a portion of conductor 22 are pulled through the top pipe section 34 of the drill string 12. This also pulls the lower guide 30 up the drill string 12 a distance about equal to one-half the length of pipe section 34 and shortens the overlapped portions 27 and 28 of conductor 22. With a slotted support plate 35 positioned between connector 31 and pipe section 34 to support the upper end of conductor 22, connector 32 is separated from connector 31 breaking electric continuity and placing the equipment in the condition illustrated in FIG. 4.

The kelly 11 is then swung over into alignment with the pipe section 36. The tail section 33 of conductor 24 is threaded through the pipe section 36 and the kelly 11 is joined to the upper end of pipe section 36 (see FIG. 5). The kelly 11 and pipe section 36 are then raised and aligned with the drill string 12. The tail portion 33 extends a short distance, e.g. 1-3 feet, below pipe section 36 permitting the connector 32 to be mated with connector 31 reestablishing electric continuity from the subsurface terminal at instrument 21 to the surface terminal at device 25. With the connectors 31 and 32 mated, the support plate 35 is removed. The lower guide 30 draws the connectors 31 and 32 a short distance downwardly into the drill string 12. If internal upset drill pipe is used, the tail portion 33 preferably should be sufficiently long to permit the connectors 31 and 32 to move downwardly within the drill string 12 to clear the upset restriction at the pipe joint.

The lower end of pipe section 36 is then connected to the drill string 12 (see FIG. 6). Section 36 thus is inserted or added into the pipe string by connecting one end to the drill string 12 and the other end to kelly 11. The kelly 11 and drill string 12 are then lowered until the kelly bushing 20 engages the rotary table 16. Drilling will then continue until another pipe section must be added. The upper end of conductor 22 is threaded upwardly through the additional pipe section 36, and another pipe section is added into the pipe string by the procedure described above and depicted in FIGS. 3-6. This operation may continue until the excess length of conductor 22 is used up. This occurs when the lower guide 30 engages or approaches upper guide 29 (see FIG. 2). The conductor 22, guides 29 and 30 and instrument 21 are then withdrawn from the drill string 12. It should be observed, however, that the excess length of conductor can be restored within the drill string 12 after it has been completely or partially used up. This may be achieved by merely connecting a con-
ductor of the desired length to the upper terminal end 31 of conductor 22 and introducing an additional length of conductor into the drill string 12. The lower guide 30 is thus lowered within the drill string 12, increasing the lengths of overlapped portions 27 and 28. The amount of conductor that can be added in this manner can be about equal to the amount of excess conductor used up.

Details of preferred construction of guides 29 and 30 are shown in FIGS. 7-9. The upper guide 29 comprises a generally cylindrical body 41, a semicircular member 42 secured to body 41, and a plurality of arms 43 pivotally mounted on the body 41. Formed in body 41 is an axial opening 44 and side slot 45 which are sized to receive conductor 22.

The outer periphery of semicircular member 42 is provided with a groove 62, the radius of which is approximately equal to the radius of conductor 22.

Each of the arms 43 fits into a longitudinal slot 46 formed in the body 41 and is pivotable about a pin 47. The length of each slot 46 is such that an arm 43 mounted therein can be pivoted about pin 47 to a fully retracted position within slot 46. An upper, flat surface 49 of each arm 43 engages a downwardly facing surface formed in body 41. The arms 43 extend radially outwardly beyond the internal diameter of the drill string 12 and are adapted to rest on an annular notched shoulder 50 formed in the box end of a pipe section. Shoulder 50 may be provided by milling the box end of the pipe section in which guide 29 is to be retained, or alternatively may be provided by a special sub. Each arm may also be secured to body 46 by a shear pin 48 to prevent the upper guide 29 from being jarred out of the mounting notch.

The lower guide 30 includes a body 51, a sheave 52, and a weight 53. The body 51 has an upper nose section 54 provided with a side opening slot 55. The width of slot 55 is slightly larger than the diameter of conductor 22. The sheave 52 is journaled in body 51 by bolt 57 and bearing 58. The weight 53 attached to the lower end of body 51 may be provided by a plurality of cylindrical sections connected together in end-to-end relation and may include a centralizer 60 secured thereto. The weight 53 should be sufficiently large to maintain a downward biasing force on the conductor to remove or reduce slack in at least a portion of the conductor. Preferably, the weight should maintain the conductor in tension. Experience has shown that slack cable can be damaged by drilling fluid flowing through the drill string 12. A 40-pound weight has served satisfactorily for a three-sixteenth inch armored cable.

The surface equipment for lowering or raising the conductor 22 and associated equipment within the drill string 12 can be similar to cablehandling equipment used in well logging operations. Such equipment normally includes a power winch containing a conductor wound thereon and a sheave suspended from the rig drawworks for guiding the conductor into or out of the drill string 12.

The conductor 22 and associated equipment may be installed in the drill string 12 by the following procedure. With the kelly 11 disconnected from the drill string 12, instrument 21 is lowered into the drill string 12 on conductor 22. The conductor 22 is unreeled from a power winch and fed into the drill string 12 until the instrument 21 reaches the desired subsurface location. The drill string 12 normally will be provided with a suitable releasable latching means for receiving and engaging the instrument 21.

With the instrument 21 properly located, the conductor 22 extends to the surface. On the rig floor, the conductor 22 is wound about the upper and lower guides 29 and 30 in the configuration shown in FIG. 7, except that the guides 29 and 30 will be positioned in end-to-end abutting engagement. In installing the conductor 22 on guide 30, the sheave 52 is first removed from body 51 by disconnecting bolt 57, and with the conductor 22 wound thereon is then reinstalled on body 51. The guides 29 and 30 with conductor wound thereon is then inserted into the upper end of the drill string 12. Arms 43 of the upper guide 29 fit into the notches of shoulder 50.

At this point, it will be observed that the conductor 22 extends from instrument 21 upwardly to the upper guide 29, around semiconductor member 42, downwardly to the lower guide 30, around sheave 52, and upwardly through slot 55 of guide 30 and opening 44 of guide 29. This arrangement provides the conductor 22 with a convoluted configuration comprising overlapped portions 26, 27, and 28. The lower guide 30 is suspended on a looped portion of the conductor 22.

Additional lengths of conductor 22 is then unreel from the winch and fed through opening 44 of the upper guide 29 lowering the lower guide 30 in the drill string 12. Overlapped portions 27 and 28 are lengthened as the lower guide 30 descends within the drill string 12. The conductor 22 which extends from the instrument 21 to the upper guide 29 passes between adjacent bow springs of centralizer 60 (if used) and through a guide member 61 strapped to the weight 53. Member 61 and centralizer 60 prevent the lower guide 30 from twisting with respect to the upper guide 29.

The conductor 22 is fed into the drill string 12 until its upper terminal end provided with connector 31 engages the upper guide 29. In the embodiment wherein the kelly 11 is provided with conductor 24 as illustrated in FIG. 4, it is preferred to position connector 31 a short distance above the upper guide 29. This may be achieved by adding a pipe section, preferably a short pipe section, to the drill string 12 and pulling the connector 31 and a portion of conductor 22 through the short pipe section. A second pipe section is then added to the drill string 12 in the manner described above with reference to FIGS. 3-6. The short pipe section permits the mated connectors 31 and 32 to be lowered a short distance below the top pipe section of the drill string without engaging guide 29 and the second pipe section is needed to accommodate the tail section 33 of conductor 24.

In other embodiments, as for example where conductor 22 connects to a conductor 24 embedded in kelly 11 and no tail section is employed, it will not be necessary to use the short pipe section or to add the second pipe section.

During drilling operations, additional pipe sections are added to the drill string 12 as the borehole 17 is advanced until it becomes necessary to change the drill bit 13 or until the excess length of conductor 22 is used up. The length of excess conductor 22 stored in the drill string normally will be sufficient to complete at least one bit run. The capabilities of a particular bit, of course, will depend on the types of strata being drilled but normally will be between about 500 and 3,000 feet.
When it becomes necessary to withdraw the drill string 12 from the borehole, as for example to replace the bit 13, the conductor 22 and associated equipment will first be retrieved from the drill string 12 by the following procedure. The Kelly 11 is disconnected from the drill string 12 and the mated connectors 31 and 32 are pulled through the top pipe section of the drill string 12. Connector 32 is disconnected from connector 31 and conductor 22 is withdrawn from the drill string 12 by reeling it on a power winch. The excess portions 27 and 28 are shortened until the lower guide 30 abuts the upper guide 29. A sufficient amount of tension is then pulled on the conductor 22 to shear the shear pins 48 (if used) holding the arms 43 of the upper guide 29 in place. This permits the arms 43 to pivot free of shoulder 50 and to retract within body 41 which releases the upper guide 29 from the drill string 12. The assembly is then retrieved from the drill string 12. The apparatus is disconnected from the conductor 22 and the remaining conductor 22 with the instrument 21 is retrieved. The drill string 12 is then withdrawn in the usual manner. The drill string 12 with a new bit 13 is lowered into the borehole. With the bit 13 located about two pipe lengths above the bottom of the borehole, the conductor 22 which was withdrawn from the borehole may be reinstalled in the drill string 12. However, if additional excess length of conductor is desired, a longer conductor must be employed.

The conductor 22 usable in the preferred embodiment of the present invention should have the following properties. It should have a breaking strength sufficiently high to support the guides 29 and 30 and instrument 21 and to permit shearing of pins 48 (if used); it should have an operating temperature at least equal to the maximum subsurface temperature encountered; and it should be sufficiently flexible to permit it to be arranged in the proper convoluted configuration. One particular conductor that has been successfully tested is a single conductor three-sixteenth inch armored cable manufactured by Vector Cable Company and sold as type 1-18P. Tests have shown that this cable can be bent around guides having a 2-inch pitch diameter. The tests employed upper and lower guides similar to those illustrated in FIGS. 7, 8, and 9. Materials and dimensions of the upper and lower guides were as follows:

**Upper Guide (29):**

<table>
<thead>
<tr>
<th>Material</th>
<th>Outside diameter, inches</th>
<th>Length, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 1018 Steel</td>
<td>1 11/16</td>
<td>43/4</td>
</tr>
</tbody>
</table>

**Semicircular Member (42):**

<table>
<thead>
<tr>
<th>Material</th>
<th>AISI 1018 Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width, inches</td>
<td>5/8</td>
</tr>
<tr>
<td>Pitch diameter, inches</td>
<td>2</td>
</tr>
</tbody>
</table>

**Arms (43):**

<table>
<thead>
<tr>
<th>Material</th>
<th>AISI 1018 Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial extent of outer ends, inches</td>
<td>1 11/16</td>
</tr>
</tbody>
</table>

**Lower Guide (30):**

<table>
<thead>
<tr>
<th>Material</th>
<th>Brass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, inches</td>
<td>8</td>
</tr>
<tr>
<td>Outside diameter, inches</td>
<td>1 1/2</td>
</tr>
</tbody>
</table>

**Sheave (52):**

<table>
<thead>
<tr>
<th>Material</th>
<th>Phosphor Bronze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch diameter, inches</td>
<td>1 3/10</td>
</tr>
<tr>
<td>Width, inches</td>
<td></td>
</tr>
</tbody>
</table>

An instrument suspended on the cable was lowered into internal upset drill pipe to a depth of about 400 feet. The drill pipe had an outside diameter of 4.5 inches, an inside diameter of 3.64 inches, and an upset inside diameter of 2.81 inches. The upper and lower guide assembly with the cable properly arranged thereon was then placed in the upper end of the drill pipe. About 600 feet of cable were introduced into the drill pipe forming overlapped portions having lengths of about 300 feet each. This arrangement provided about 1,000 feet of cable disposed in the drill pipe, about 600 feet of which was excess cable. Drilling mud was flowed through the drill pipe for about 2 hours. The cable and guides were then withdrawn from the drill pipe without difficulty.

A variation of the invention involves use of a separate retriever cable for pulling the conductor 22 through a length of pipe to be added to the drill string. In this variation, the retriever cable which can be a wireline is threaded through the length of pipe to be added to the drill string. With the additional length of pipe suspended in elevators above the drill string, the retriever cable is connected to the upper terminal end of conductor; one end of the additional pipe length is connected to the drill string; the retriever cable is pulled through the additional pipe length threading conductor 22 upwardly through the additional pipe length. The conductor 22 is reconnected to conductor 24 and added pipe is connected to kelly 11. In this embodiment it should be noted that the threading or extending of a portion of conductor 22 is performed before the additional length of pipe is connected into the pipe string; in the embodiment described earlier, the step of extending the conductor was performed after the additional length of pipe was connected into the pipe string.

As mentioned previously, the present invention also contemplates an improved method for lengthening a pipe string while at the same time lengthening an electric conductor provided therein. The method involves lowering an insulated conductor 22, preferably an armored cable free of connectors, to a subsurface terminal near the lower end of a pipe string used to drill a well; threading a conductor section, e.g., section 33, through a length of pipe to be added to the pipe string; connecting the conductor section 33 to conductor 22; and finally connecting the pipe length into the pipe string. The conductor section 33 preferably is connected to a surface terminal; it may also be initially disconnected from the surface terminal and connected to the surface terminal during the operation for lengthening the pipe string and conductor.

Although the present invention has been described with reference to conventional rotary drilling operations, it can also be used with other types of drilling equipment including turbo drills and positive displacement hydraulic motors. These devices normally include a motor or turbine mounted on the lower end of the drill string and adapted to connect to and drive a bit. The motor or turbine powered by the drilling fluid drives the drill bit while the drill string remains stationary. When this type subsurface drilling device is used in directional drilling operations, the present invention
provides a highly useful means for transmitting directional data to the surface.

We claim:
1. In a method of drilling a well wherein an insulated electric conductor is employed in a drill string to transmit electric energy between a subsurface location in said drill string and a location substantially at the surface, the improvement which comprises placing said conductor in said drill string in a configuration such that the total length of said conductor is substantially longer than the distance between said subsurface and surface locations; adding a length of pipe to said drill string to increase the distance between said subsurface and surface locations; and threading said conductor through said length of pipe.

2. In a well drilling operation wherein an insulated electric conductor is employed internally of a pipe string to transmit electric energy between a subsurface location and a location substantially at the surface, an improved method for extending said electric conductor through lengths of pipe which are individually added to said pipe string as the drilling progresses which comprises storing a length of conductor within said pipe string which is in excess of the distance between said locations; extending a portion of said electric conductor through a length of pipe to be added into said pipe string; connecting said length of pipe into said pipe string.

3. A method as defined in claim 2 wherein the step of storing a length of conductor in the pipe string provides an excess length of conductor at least equal to said length of pipe to be added into said pipe string.

4. A method of installing an insulated electric conductor in a tubular drill string in a well which comprises placing said conductor internally of said drill string; arranging said conductor to form overlapped portions having an upper loop and a lower loop within said drill string; and introducing additional conductor into said drill string while lowering said lower loop within said drill string to lengthen the overlapped portions as defined in claim 4 and further comprising biasing said upper loop and said lower loop apart to remove slack in said conductor.

5. In a method of drilling a well wherein an insulated electric conductor is employed in a pipe string to transmit electric energy between subsurface and surface locations in said pipe string, the improvement which comprises placing said conductor in said pipe string in a configuration such that the length of said conductor is substantially longer than the distance between said subsurface and surface locations; and extending said conductor through individual lengths of pipe as each of said lengths is added to said pipe string.

6. A method as defined in claim 6 wherein the step of extending said conductor through individual lengths of pipe is performed after each of said lengths of pipe is added into said pipe string.

7. A method as defined in claim 6 wherein the step of extending said conductor through lengths of pipe is performed before each of said lengths of pipe is added to said pipe string.

8. A method as defined in claim 6 wherein the configuration of said conductor is convoluted.

9. A method as defined in claim 6 wherein the configuration of said conductor is convoluted.

10. A method as defined in claim 6 wherein the step of extending said conductor includes withdrawing a portion of said conductor from said pipe string and threading said portion through each length of pipe as said length of pipe is added to said pipe string.

11. A method as defined in claim 6 wherein said conductor is placed in said pipe string in a configuration such as to provide overlapped portions having an upper loop and a lower loop.

12. A method as defined in claim 11 wherein the lower loop is biased downwardly to remove slack from a portion at least of said conductor.

13. A method of establishing and maintaining electric continuity between a subsurface location and surface location in a pipe string used to drill a well which comprises placing an electric conductor in said pipe string which extends between said subsurface and surface locations and which has a length substantially in excess of the distance between said subsurface and surface locations; advancing said well sufficiently to require lengthening said pipe string; adding a length of pipe into said pipe string; and extending a portion of said electric conductor through said length of pipe.

14. A method of establishing electric continuity within a pipe string in a well between a subsurface location and a location substantially at the surface which comprises placing an insulated electric conductor in said pipe string to extend from said subsurface location to said surface location; convoluting at least a portion of said conductor within said pipe string such that the length of said conductor in said pipe string exceeds the distance between said subsurface and surface locations; and tensioning at least a portion of said conductor to reduce slack in said conductor.

15. In a method of drilling a well using a pipe string wherein the pipe string is lengthened as the well becomes deeper by disconnecting the pipe string at the surface and adding a length of pipe into the pipe string by connecting said length of pipe at each end to the pipe string, the method of providing electric continuity between a subsurface location in the pipe string and a location substantially at the surface of the well, which comprises placing an insulated electric conductor in the well within the pipe string to extend from said subsurface location near the lower end of said pipe string to said surface location, said conductor having a length substantially in excess of the distance between said subsurface and surface locations; breaking said electric continuity by separating said conductor substantially at the surface when the addition of said length of pipe is to be made into the pipe string; and reconnecting said electric conductor before both ends of the additional length of pipe are connected into said pipe string to include a length of electric conductor extending through said additional length of pipe.

16. A method as defined in claim 15 which includes the step of removing slack from at least a portion of the conductor in the pipe string.

17. A method as defined in claim 15 in which a portion of the conductor in the pipe string is withdrawn therefrom after the conductor is separated and is extended through said additional length of pipe.

18. A method as defined in claim 15 in which at least a portion of the electric conductor lowered within the pipe string is convoluted such that the length of said conductor between said subsurface and surface locations exceeds the distance between said locations.

19. A method as defined in claim 18 wherein said convoluted conductor includes overlapped portions having an upper loop and a lower loop.

20. A method as defined in claim 19 and further comprising biasing said upper and lower loops apart.

21. A method as defined in claim 19 wherein said.
upper loop is supported on said pipe string and said lower loop is biased downwardly.

22. In a method of drilling a well using a pipe string, an improved method of establishing and maintaining electric continuity through said pipe string between a subsurface location in the well and a surface location which comprises lowering in said pipe string an insulated electric conductor to extend between said locations and having a substantially length in excess of the distance between said locations; advancing said well sufficiently to require the insertion of an additional length of pipe into said pipe string; disconnecting said pipe string and separating said electric conductor at the surface; threading electric conductor through an additional length of pipe; reconnecting said electric conductor to reestablish electric continuity between said locations through said pipe string including said additional length of pipe; and inserting said additional length of pipe into said pipe string.

23. A method of establishing and maintaining electric continuity in a drill string in a well as said well is being drilled which comprises lowering an insulated electric conductor in said drill string to extend from a subsurface location near the lower end of said drill string substantially to the surface; convoluting a portion of said conductor such that the length of conductor in said drill string is in excess of the distance between said subsurface location and the surface; threading an electric conductor section through a length of pipe to be added to said drill string; connecting said conductor section to said electric conductor; and connecting said length of pipe to said drill string.

24. A method for establishing and maintaining electric continuity between a subsurface terminal within a pipe string used to drill a well and a surface terminal which comprises placing an insulated electric conductor in said pipe string to extend between said terminals and which has a length substantially in excess of the distance between said terminals; advancing said well sufficiently to require an additional length of pipe in said pipe string; disconnecting said pipe string at a point near the surface; withdrawing a conductor section from said pipe string; separating said conductor section from the remainder of said conductor; threading said conductor section through a length of pipe; reconnecting said conductor section to the remainder of said conductor; and connecting said length of pipe into said pipe string.

25. A method of electrically connecting a first electric terminal located within a pipe string at a subsurface location in a well with a second electric terminal located near the surface of the well which comprises lowering within the pipe string an electric conductor which is longer than the distance between the terminals; securing the lower end of said conductor at said subsurface location in electrical connection with said first electric terminal; locating the upper end of said conductor at said surface location in electrical connection with said second electric terminal; and convoluting and tensioning at least a portion of said electric conductor between said terminals so as to remove slack in said electric conductor.

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