GRI-95/0428.1

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Final Report

Electric Drilling Motor for Coiled Tubing Drilling - Phase I

Prepared by:
CTES, L.C.
Conroe, Texas

Gas Research Institute

Drilling and Completion Group
March 1996

GRI 95/0428.1

FINAL REPORT - SUPPLEMENTAL DOCUMENTS

ELECTRIC DRILLING MOTOR FOR COILED TUBING DRILLING - FEASIBILITY STUDY PHASE I

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Contract No. 5095-210-3342
October 1995

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50272 - 101

REPORT DOCUMENTATION PAGE	1. REPORT NO. GRI-95/0428./	2.	3. Recipient's Accession No.

4. Title and Subtitle
Electric Drilling Motor for Coiled Tubing Drilling - Phase I

5. Report Date
October 1995 (date prepared)

6.

7. Author(s)
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8. Performing Organization Rept. No.

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10 Project/Task/Work Unit No.
13.23

11. Contract(C) or Grant(G) No.
(C) 5095-210-3342
(G)

12. Sponsoring Organization Name and Address
Gas Research Institute

13. Type of Report & Period Covered
Final Report
May 1995 - October 1995

14.

15. Supplementary Notes

16. Abstract (Limit: 200 Words)

Open hole drilling with coiled tubing (CT) is a relatively recent development in the oil and gas industry. Using continuous pipe to drill has many advantages over jointed pipe drilling because of the elimination of the pipe joints. Major improvements include tripping speed, sealing around the pipe and thus pressure control, location size, safety and environmental concerns. However, there are limitations associated with CT drilling (CTD) that must be addressed for this drilling technique to reach it's full potential.

Since the CT cannot be rotated, a downhole motor must be used. Moineaux type positive displacement mud motors are typically used for CTD. These motors are expensive for the short drilling life (25 to 100 hours) that they last before needing to be replaced. In early 1995, the Gas Research Institute commissioned this Phase I study to determine the feasibility of using an electric drilling motor instead of a moineaux type mud motor. This Phase I feasibility study accomplished the following:

- A review of historical and current electric drilling motor technology was performed
- A conceptual design for an electric drilling motor for CTD was developed
- A cost estimate for an electric drilling motor system was developed
- A market analysis was performed

This feasibility study concluded that an electric drilling motor system for CTD is feasible, and that such a system would have significant benefits over current motor technology.

17. Document Analysis
a. Descriptors

Slimhole, coiled tubing, drilling, drilling motors, electric motors, bottom hole assembly

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release Unlimited	Unclassified	28
	20. Security Class (this Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse

Optional Form 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

CONTENTS

EDM Related Patents

Russian Documents

Russian Document Translations

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United States Patent [19]

Mohn

[11] **Patent Number: 5,060,737**

[45] **Date of Patent: Oct. 29, 1991**

[54] **DRILLING SYSTEM**

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[73] Assignee: **Framo Developments (UK) Limited, London, England**

[21] Appl. No.: **443,016**

[22] Filed: **Nov. 29, 1989**

Related U.S. Application Data

[63] Continuation of Ser. No. 68,227, Jun. 30, 1987, abandoned.

[30] **Foreign Application Priority Data**

Jul. 1, 1986 [GB] United Kingdom 8616006

[51] **Int. Cl.**[5] **E21B 4/04; E21B 17/00**

[52] **U.S. Cl.** **175/104;** 174/47; 175/215; 175/320; 175/324; 439/194

[58] **Field of Search** 175/320, 104, 105, 103, 175/215, 324; 166/65.1; 174/47; 439/191, 192, 194, 195

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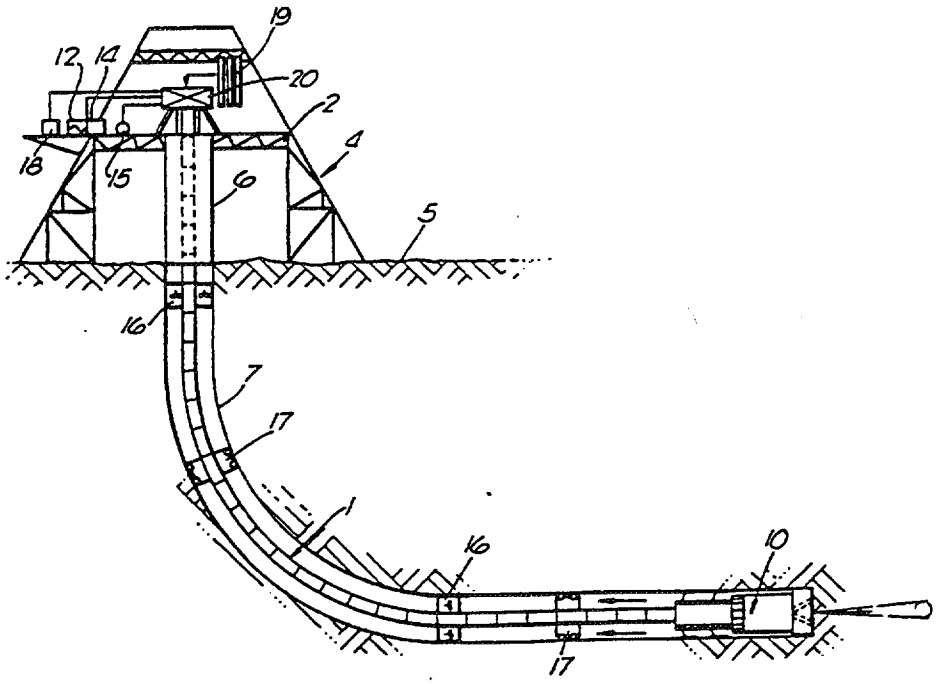
Primary Examiner—Hoang C. Dang

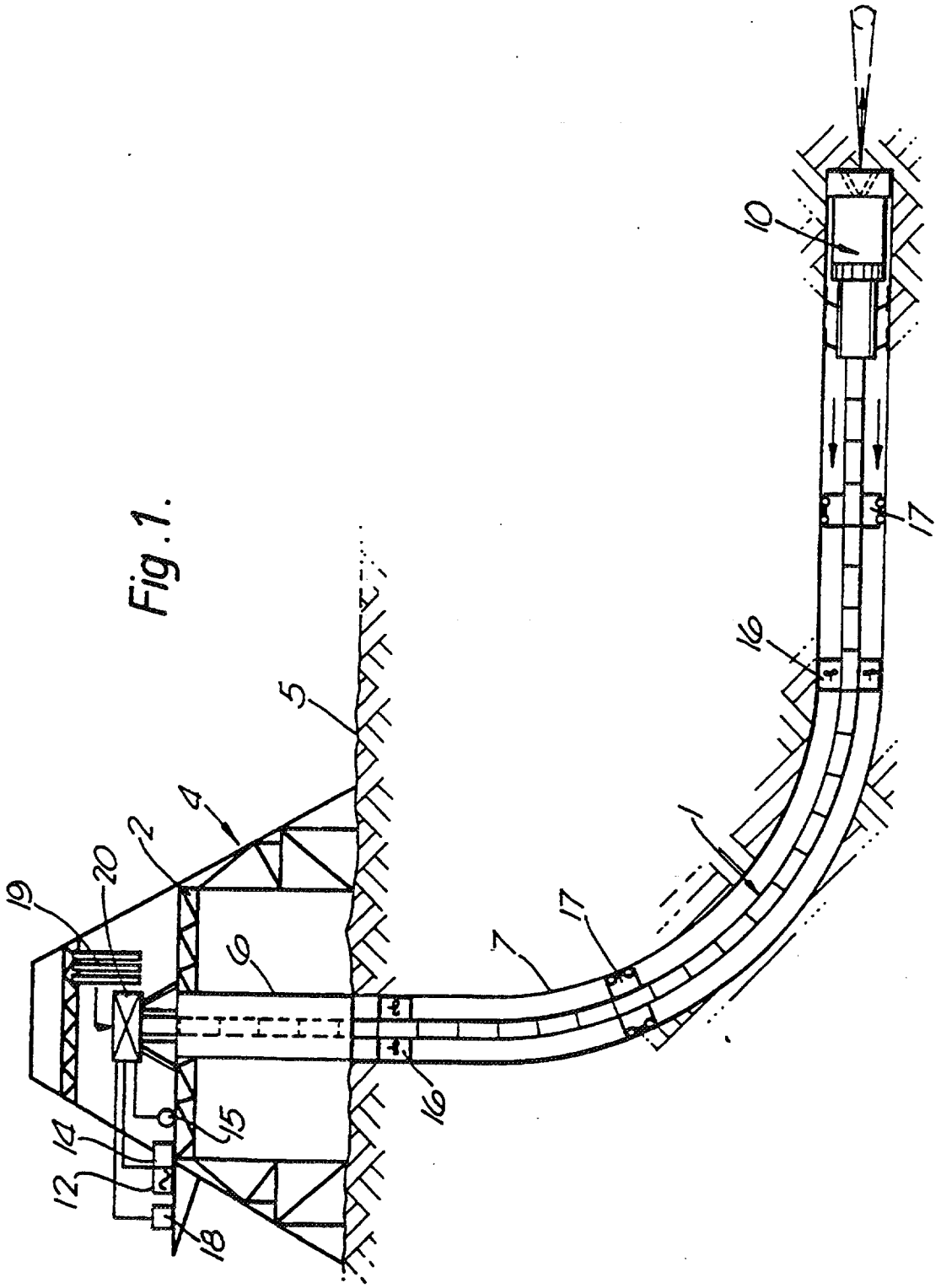
Attorney, Agent, or Firm—Young & Thompson

[57] **ABSTRACT**

A drilling system comprises a drill string (1) incorporating inbuilt tubular conductors (25), a mud supply passage, and passages for protective or other fluids. The drill string can be advanced by selectively actuable pistons (51,60) exposed to drilling mud flow, by electrically driven traction units (71,74) engaging the drill hole wall or by a linear electric motor element (82) co-operating with a drill hole casing (24), which can be moved thereby relative to the drill string. The drill bit (106) of the drill unit is driven rotatably by an electric motor (111,112) or reciprocably by a linear electric motor (125). The drill unit can be of two relatively slidable parts, with fluid pressure, which may be generated within the unit (189) axially loading the drill bit. Drilling forms can be resisted by clamps (129) clamping the unit and/or the drill string to the drill hole wall. The drilling direction can be adjusted by use of these clamps.

26 Claims, 7 Drawing Sheets





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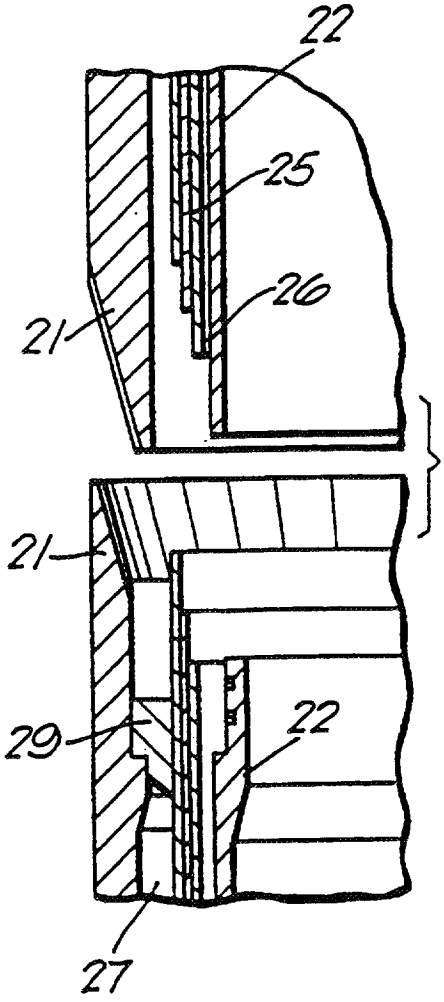

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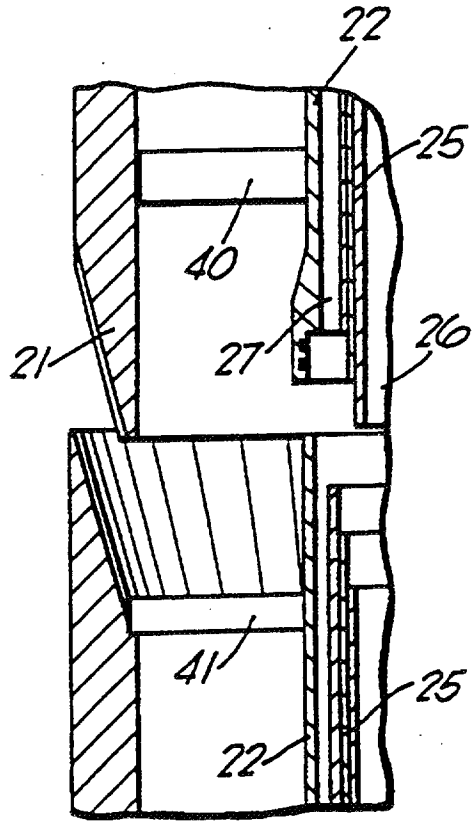

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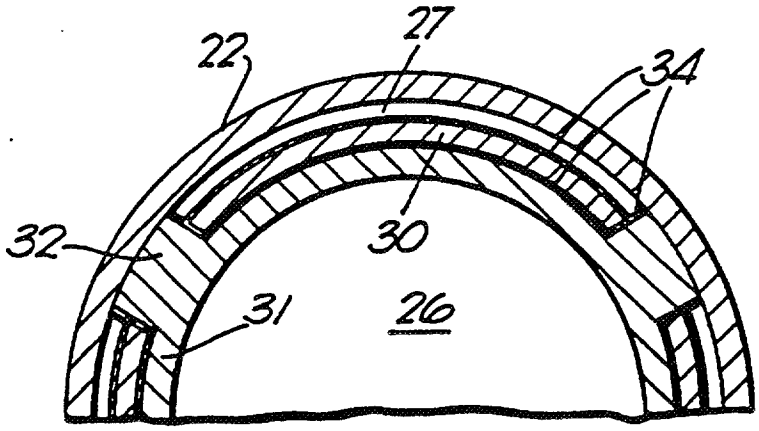

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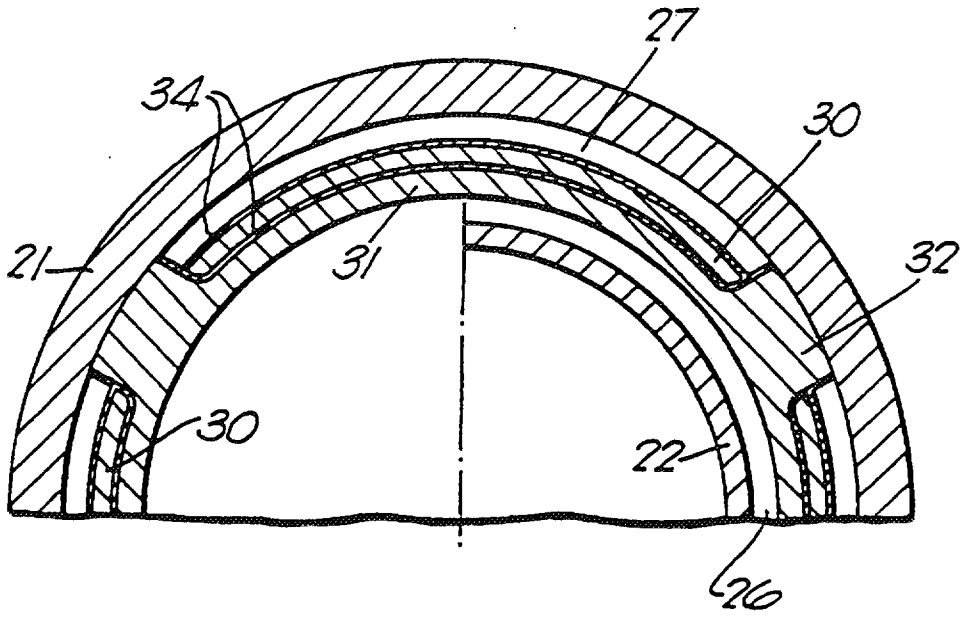

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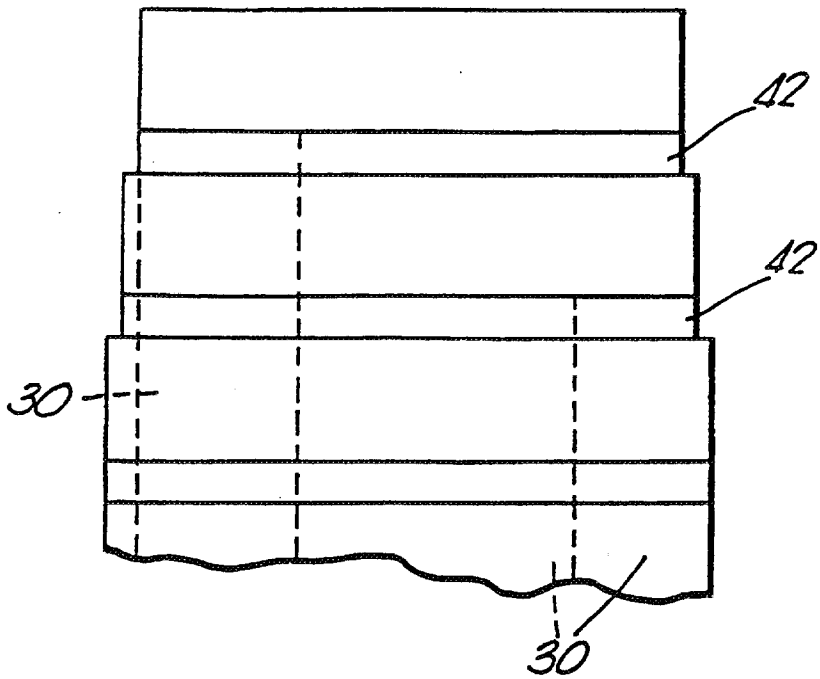

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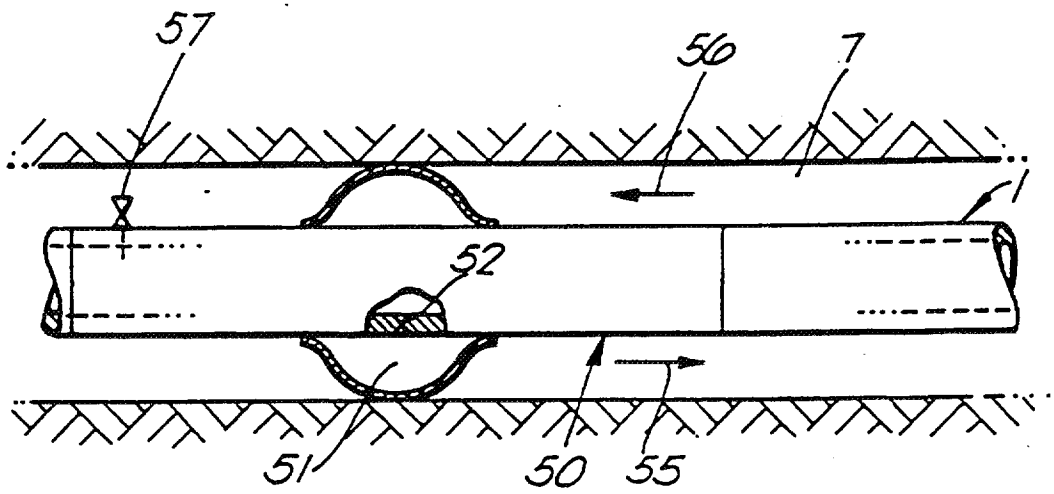

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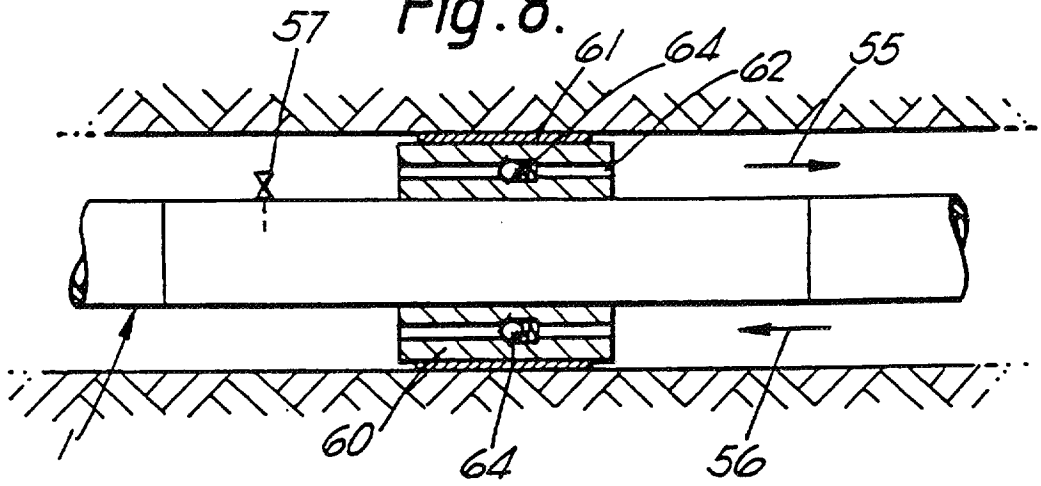

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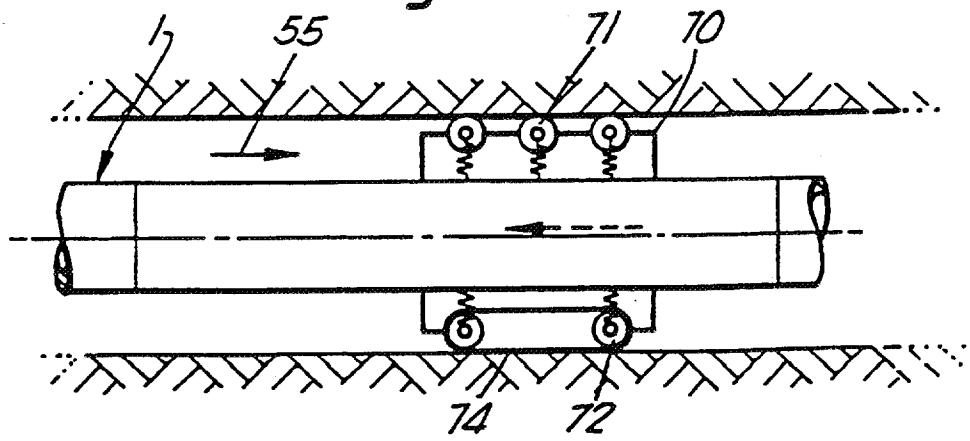

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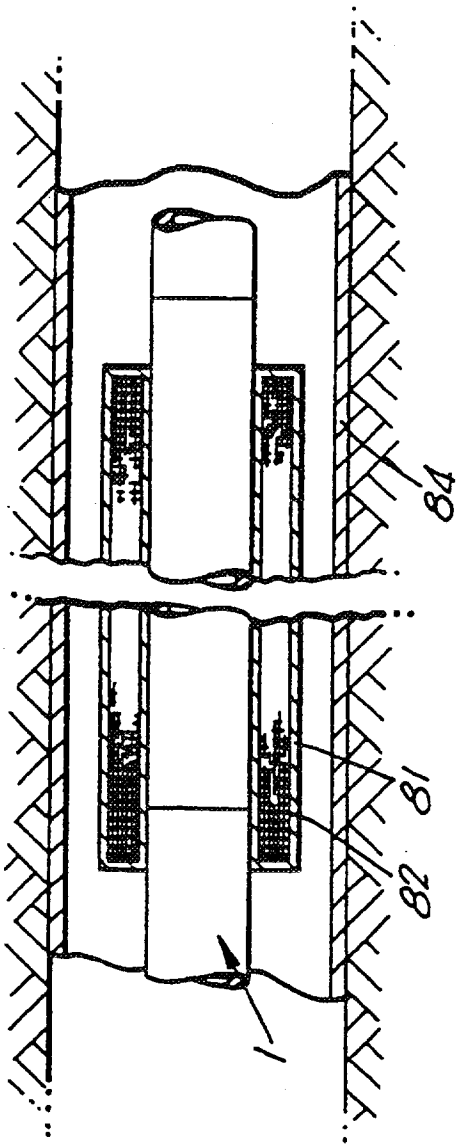
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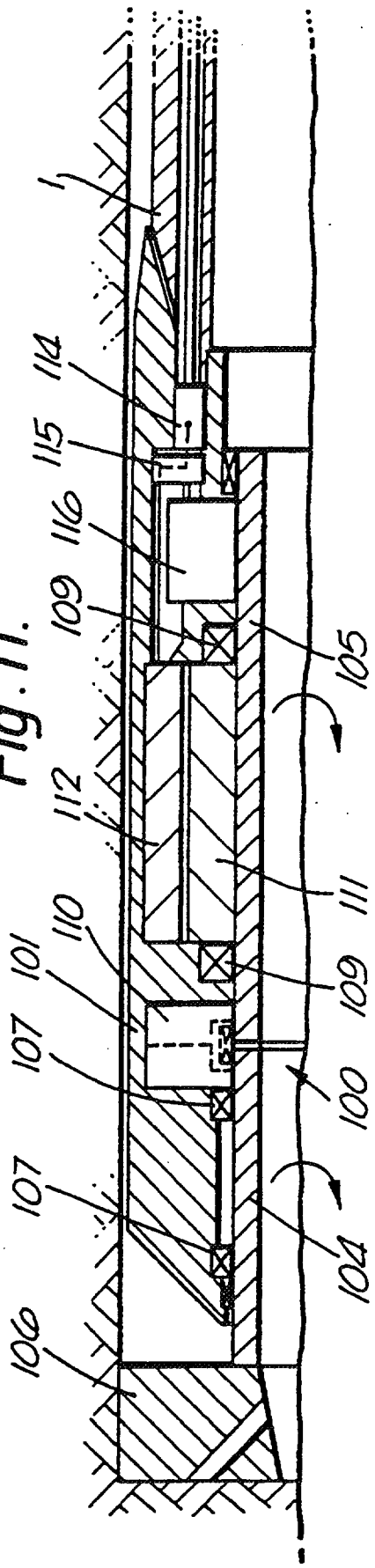
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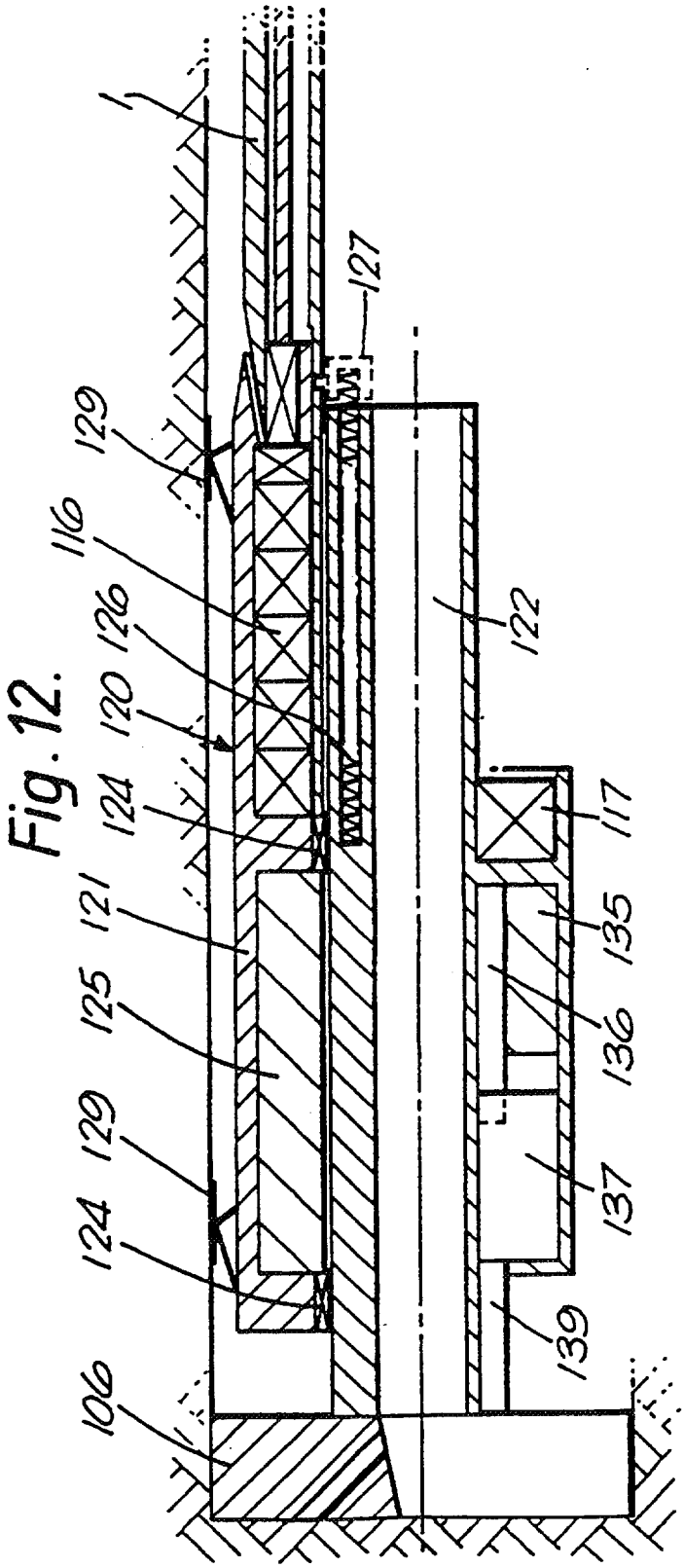
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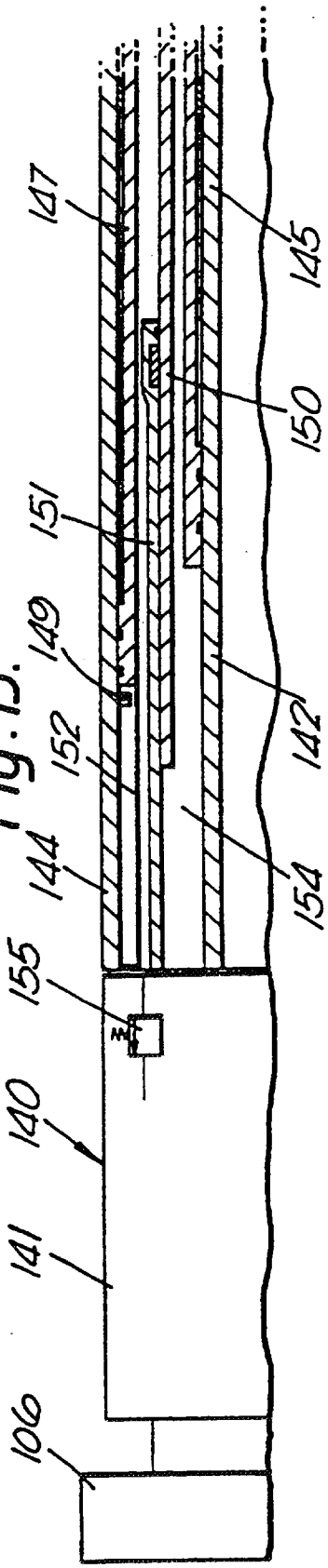
Fig. 12.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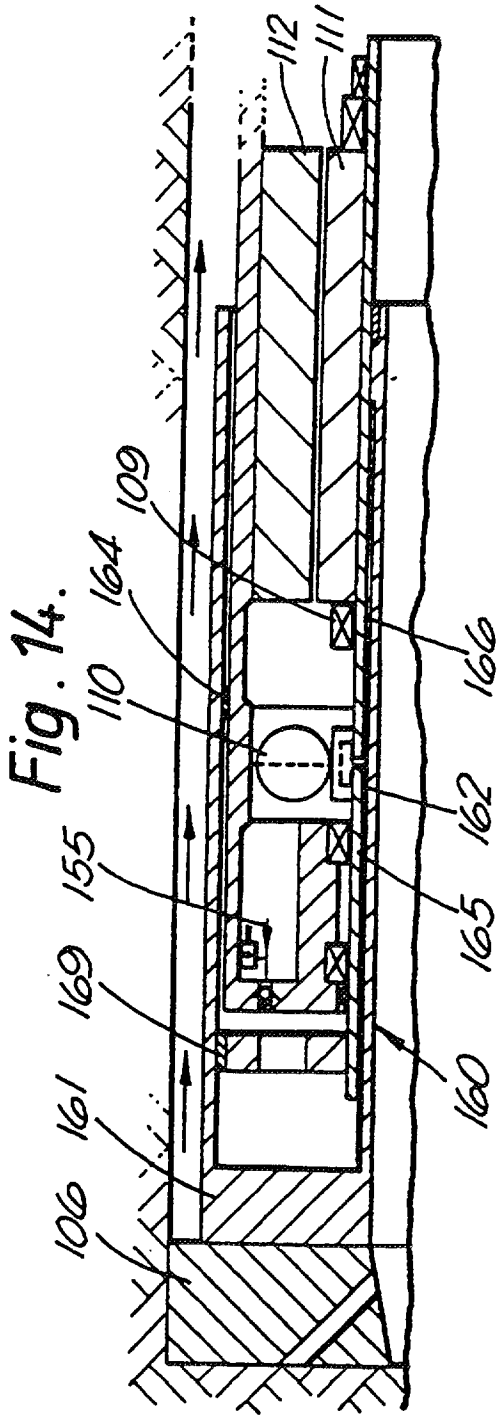
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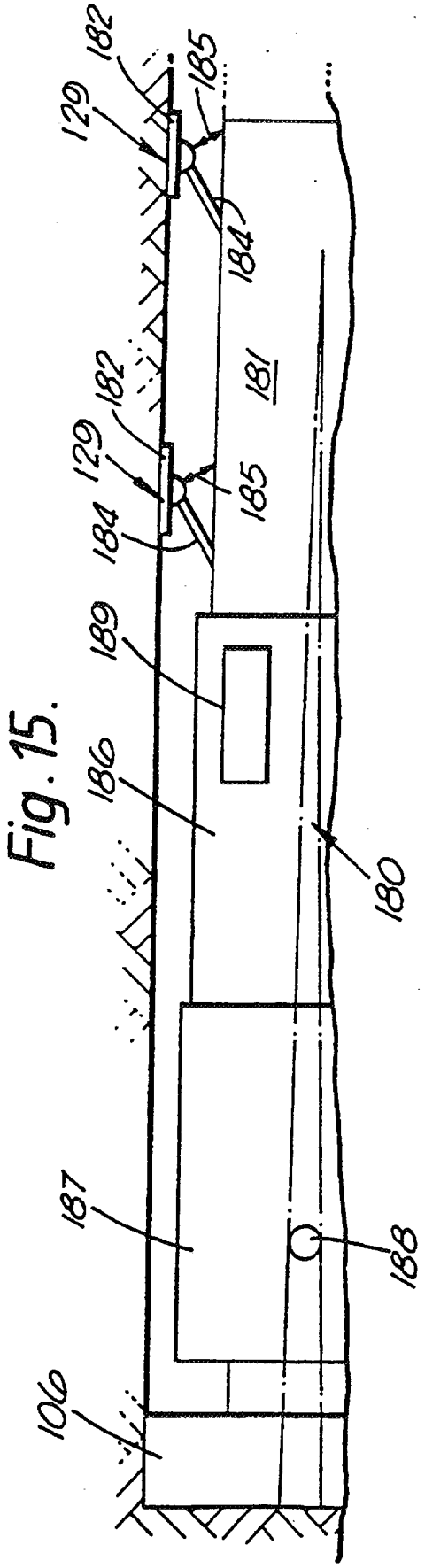
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Fig. 15.

DRILLING SYSTEM

This application is a continuation of application Ser. No. 07/068,227, filed Jun. 30, 1987, now abandoned.

FIELD OF THE INVENTION

The invention relates to a drilling system, more specifically to a drilling system of the kind in which a drill string extends from topside or stationary equipment to a drill bit for performing a drilling operation.

BACKGROUND OF THE INVENTION

In known drilling systems of this kind, the drill bit may be driven by a motor receiving power by way of the drilling mud supplied to the drilling site, or by an electric motor. Difficulties are encountered with electric motor drive arrangements because of the length of the necessary cable connection, and the adverse environment in which the electric motor has to operate. Further problems arise in connection with directional or horizontal drilling, because information relating to performance of the drill bit and to its position has to be conveyed along the drill string more or less continuously. Mud pulsing can be employed in the mud drilling systems but the speed of data transmission is low, as is the volume of data that can be transmitted.

It is accordingly an object of the present invention to provide a drill string for a drilling system which facilitates transmission of electric power supply and/or communication signals therealong.

It is also an object of the invention to provide a drill string structure providing inbuilt electrical conductor means, in sections which can be handled by conventional pipe handling equipment.

It is also an object of the invention to provide a drill string structure having facilities therein for transmission of electric power and/or communication signals, for supply of drilling mud and for supply and/or return of protective or other fluid.

It is also an object of the invention to provide a drill string for use in a drilling system having selectively operable means for advancing the drill string along a drill hole in particular, a non-vertical drill hole.

It is also an object of the invention to provide a drill string which can be moved relative to a drill hole wall.

It is also an object of the invention to provide a drill system in which drilling reaction forces can be transferred to the drill hole wall.

It is also an object of the invention to provide a drill system incorporating remotely controllable local power generators at desired positions within the system.

It is also an object of the invention to provide a drill unit of which the drill bit can be selectively loaded in the drilling direction.

It is also an object of the invention to provide a drill unit of which the drilling direction can be selectively angled with respect to a drill hole axis.

SUMMARY OF THE INVENTION

The invention accordingly provides a drilling system of the kind described including a drill string incorporating as an integral part thereof electric conductor means capable of power and/or communication transmission. The conductor means can comprise rigid conductors in fixed relation to a drill pipe, the conductors being conveniently of concentric tubular configuration and mounted within the drill pipe, with clearance, and protective inner or outer tubing to provide at least one passage for fluid as well as for movement of drilling mud along the drill string.

The drill string can be made up of relatively short sections, the conductor means and any protective tubing within each section being then arranged for ready coupling with adjacent sections, with continuity of the electric conductor paths and fluid channels along the drill string.

The electric conductor arrangements for a drill string in accordance with the invention can provide mechanical protection for the conductors and can employ simple connections means, for example, screw-threaded or slip-on couplings The arrangements facilitate the use of an electric motor, which can be either rotary or linear, to drive the drill bit and they moreover provide for prompt transmission of a large volume of data between the fixed or topside control equipment, from which the drill string extends, and sensing and/or control equipment associated with the drill unit. The conditions under which the drill bit is operating, and the direction in which drilling is being carried out, are consequently easily monitored and appropriate control signals readily supplied to the drill unit. Directional control of the drill unit during horizontal or directional drilling is facilitated.

The conductor means also facilitate the provision of electrically powered and/or controlled auxiliary equipment at one or more positions along the drill string and also the use of sensor or measurement devices at such positions, as well as the location on the drill string of one or more local power sources or generators, and power and data and control communication between such sources and between them and the topside equipment.

The fluid passage or passages provided can be employed for circulation of oil or other protective fluid for one or more of such purposes as cooling, lubrication, insulation, operation of ancillary equipment, and supply of oil or chemicals required for drilling or for connected operations. The fluid can be held static under pressure or can be circulated at a selected pressure either with a special return path or it can be returned mixed with the returning drilling mud, as when the fluid is leaked through labyrinth seals employed for sealing moving parts of the system.

Although the drill string is primarily intended for systems in which the drill string is not required to rotate, its use in systems in which rotation is required is not precluded. The drill string can moreover be used as a standard drill string for parts of the drilling process, and can then be equipped with a standard drill bit, the conductor means being used for signalling, for example to control equipment from sensors at the drill unit monitoring the drilling process.

The invention also provides a drilling system of the kind described with means for selective movement of the drill string and/or production piping and/or drill hole casings along the drill hole. Such means are of particular significance in the case of deviated, that is, non-vertical, drilling, where placement of production tubing or drill hole linings under gravity cannot be relied upon.

The drill string can thus be provided with one or more external piston elements to be acted upon by a flow of drilling mud in the required direction along the space between the drill string and the drill hole wall. The piston elements can be selectively inflatable, as by

means of fluid conveyed along the drill string where this has a structure as described above including one or more fluid passages besides the passage for drilling mud. Alternatively, the piston element can be a fixed configuration, with one or more passages containing check valves or selectively operable valves for permitting flow of the drilling mud during normal operation, the valves closing to render the piston element effective when the mud flow direction is reversed in order to advance the drill string.

Where production tubing or a casing for lining the drill hole wall is to be brought into position, the drill string can be clamped at its lower end to the drill hole wall, as by clamping means described below with particular reference to certain drill units embodying the invention, and the production tubing or the like can be moved by the action of drilling mud on one or more pistons extending inwardly from the tubing and sliding on the drill string, which can serve as a return path for the mud. After the placement operation has been completed, the drill string is unclamped and withdrawn.

The invention also provides a drilling system of the kind described having one or more electrically powered drive means for effecting movement of the drill string and/or production piping and/or drill hole casing along the drill hole. Such drive means can comprise a frame secured externally of the drill string and carrying electrically powered traction elements, for example, wheels, roller or drive belts, engageable with the drill hole wall. The drive means can instead comprise one or more electrical windings secured to the drill string so as to extend around it and to function when energized as an element of a linear electric motor, the other element of which is constituted by a drill hole casing. By suitable energization of the motor windings the drill string casing and the drill string can be relatively moved in either direction or rotationally.

This form of drive means in particular can be used also to assist or effect installation of the drill hole casing and/or of production piping after the drilling has been completed, with the leading end of the drill string clamped as described above in connection with the use of drilling mud to affect such placement. Both techniques can of course be used for movement relative to the drill string or other selectively campable core or guide member in either direction. Power can be supplied to these drive means by way of the conductors extending along a drill string in accordance with the invention as described above.

The invention also provides a drill unit for use in a drilling system of the kind described, the drill unit including a rotational or linear electric motor for applying a rotational and/or reciprocal drive to the drill bit directly or through a mechanical or hydraulic mechanism driven by the motor.

In a simple arrangement, the drill unit of the invention comprises a drill bit carried by a drill shaft rotatably driven by an electric motor which may be concentrically arranged around the drill shaft. The motor may be arranged to rotate the drill bit at a predetermined speed or the speed may be adjusted by a frequency control device. The motor can instead be coupled to the drill shaft not directly but by means of a speed/torque converter in the form of a gearbox, hydraulic coupling or hydrostatic transmission device or a combination of these.

The invention also provides a drill unit for use in a drilling system of the kind described, the unit having a percusive drill bit reciprocating by a linear electric motor. The linear electric motor can be arranged to drive the drill bit positively in both directions, but alternatively the motor can be arranged to effect movement in one direction only, movement in the other direction being effected by release of a spring which has been stressed during the electrically powered stroke.

The invention also provides a drill unit for use in a drilling system of the kind described in which a linear electric motor advances a plunger in an hydraulic system, the drill bit being reciprocated by the consequential movement of a piston within a hydraulic cylinder of the system. Again, both the operative and return stroke of the drill bit can be positively powered, or a spring loading means can be provided to power one of the strokes, as with the arrangement described above.

When the drill string extends generally vertically, its weight applies adequate axial loading to the drill bit, but the drill string cannot be used alone and with sufficient accuracy to apply such loading during horizontal drilling.

The invention accordingly provides a drill unit for use in a drilling system of the kind described which comprises a first portion carrying the drill bit, a second portion for connection to the drill string, and means for selectively advancing the first portion relative to the second portion.

The second portion can be provided with clamping means whereby it can be selectively clamped to the formation being drilled, that is, to the drill hole wall. The two drill unit portions are preferably telescopically related and are arranged to be relatively moved hydraulically. The drill string can be in accordance with the invention as described above and the fluid pressure can be applied by way of a fluid passage with which the drill string is provided, or can be generated locally, within the drill unit, as with fluid pressure used for operating the drill bit.

It is frequently of importance that the direction of drilling be controlled and the invention accordingly provides a drilling unit for use in a drilling system of the kind described having means for orientating the axis of the drill bit at a predetermined angle to the drill hole axis. The drill bit axis can be selectively adjustable relative to the drill unit axis or the drill unit itself can be adjustable relative to the drill hole or its casing, as by clamping means of the kind described above provided with selectively adjustable spacing between the drill unit and the drill hole and casing.

The invention also provides a drilling system of the kind described comprising means for clamping the drill string to the drill hole wall or to the drill hole casing at one or more appropriate positions, for example adjacent to the drill unit, so as to transfer the reaction force of the drilling from the drill string.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is further described below, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is a schematic general view of an entire drilling system embodying the invention;

FIG. 2 is a partial sectional side view of a drill string which can be incorporated in the system of FIG. 1;

FIG. 3 is a partial cross-sectional view of a first modified form of the drill string of FIG. 2;

FIG. 4 is a partial sectional side view of a second modified form of the drill string of FIG. 2;

FIG. 5 is a partial cross-sectional view of a conductor assembly only, of a third modified form of the drill string FIG. 2;

FIG. 6 is a schematic side view of a connector plug for the conductor assembly of FIG. 5;

FIG. 7 schematically illustrates a first traction unit for moving a drill string along a drill hole in accordance with the invention;

FIGS. 8, 9 and 10 schematically show respectively a second, third, and a fourth means in accordance with the invention for moving a drill string along a drill hole;

FIG. 11 is a partial sectional side view of a first drill unit which can be incorporated in the system of FIG. 1; and

FIGS. 12–15 are like views of second, third, fourth and fifth alternative drill units for use in the system of FIG. 1 respectively.

The drilling system schematically shown in FIG. 1 comprises a drill string 1 extending from topside control and supply equipment located on a platform 2 of a drilling frame or structure 4 resting on the seabed. The drill string 1 extends generally vertically downwardly from the platform 2 within tubing 6 into a drill hole 7 which curves from an upper vertical portion communicating with the tubing to a generally horizontal end portion in which a drill unit 10 at the end of the drill string is operating.

The drill string 1 incorporates electric conductors which can perform various functions. They can thus supply power to an electric motor in the drill unit 10 from a power supply unit 12 on the platform 2, the electric motor driving and/or advancing the drill bit either directly or by way of a hydraulic mechanism. Additionally, the conductors can be employed for communication between a system control unit 14 on the platform 2 and condition-sensing equipment and/or a local control unit for the drill unit 10. Multiplexing techniques can be employed to provide a plurality of communication channels on a single conductor, which can additionally supply power along the drill string 1. Drilling mud is circulated between a mud unit 15 on the platform 2 and the drill unit 10 by way of the drill string 1 and the generally annular passage between the drill string and the drill hole wall and pumping units 16 spaced along the drill string within the passage are powered by means of the conductors. Traction units 17 for advancing the drill string 1 along the drill hole are similarly powered and controlled.

The drill string 1 can also provide a fluid supply passage or fluid supply and return passages, for fluid communication between equipment 18 on the platform 2 and the drill unit 10 and/or other elements of the system. The fluid can perform a variety of functions, some in place of certain functions of the electrical arrangements described above. The drill string 1 is handled by pipe handling equipment 19 on the platform 2, and the drill string structure can be such that the equipment 19 is conventional.

The drill string 1 is suspended from the platform 2 by means of an adapter 20 for effecting the necessary connections between the equipment on the platform 2 and the various supply and communication channels of the drill string 1.

In the following more detailed description of various possible forms of certain elements of the system, parts which serve equivalent functions are given the same reference numerals throughout. It will be understood that certain features to be described can be combined in different ways, that is, certain features, for example of one of the drill units can be employed in one or more of the other drill units illustrated.

Turning now to the structure of the drill string 1, this is composed of sections of suitable length coupled together. Each section includes rigid electrical conductor means structurally integrated into the drill string section of which various forms are shown in FIGS. 2–6.

As shown in FIG. 2, the drill string 1 comprises a drill pipe 21 containing concentrically within it an inner pipe or mud liner 22, the interior of which guides the drilling mud to the drill unit, and conductor tubing 25 received between the mud liner and the drill pipe. The conductor tubing 25 comprises a plurality of concentric metal tubes, for example three such tubes for a 3-phase power supply, with sleeves of solid insulation material between them. A concentric tubular conductor assembly of this kind is described in EP-A-0 063 444, the contents of which are incorporated herein by reference. The conductor tubing 25 is spaced from both the drill pipe 21 and the mud liner 22 to define inner and outer annular passages 26,27 which can be employed as supply and return paths for fluid. The fluid has insulating properties where the conductor tube assembly is internally and externally free of insulation.

Suitable spacing means are provided to maintain the concentric relationship of the mud liner 22 the conductor assembly 25 and the drill pipe 21. For example, as shown in the lower part of FIG. 2, the conductor assembly 25 can be provided with externally projecting hangers 29 arranged to rest with suitable insulation, on an internal shoulder of the drill pipe.

Connection is made between the ends of adjacent sections of the drill pipe 21 in any suitable way, the lower end of the upper section being shown as provided with a downwardly and inwardly tapered end portion engageable with a mating tapered portion at the upper end of the lower section. The ends of the tubular conductors of the upper conductor tubing 25 are stepped back one from the other, and the conductors of the tubing in the lower section are stepped back in the contrary manner to provide for continuity of electrical connection and insulation between the two sections, in a way described in more detail in EP-A-0 063 444. The upper end of the mud liner 22 in the lower section has a stepped end portion for reception in the lower end of the liner of the upper section, with sealing rings operative between the two mud liner sections.

In the modified drillstring structure of FIG. 3, the conductor tubing is constituted as an assembly of separate arcuate portions or segments 30 of a tube, with insulation between them. The conductor segments 30 are held in position by an inner pipe 31 spaced outwardly of the mud liner 22 and provided with radially outwardly extending spacers 32 which engage the drill pipe 21. Insulation 34 is provided between each segment 30 and the inner pipe 31, and the insulation may extend also to the outer surface of the segment. Each segment 30 is spaced from the drill pipe to provide one of the supply and return passages 26,27 for a protective fluid, of which the other is formed between the inner pipe and the mud liner.

In the alternative conductor tubing arrangement shown in FIG. 4, the mud supply is by way of an annular passage between the drill pipe 21 and a protective pipe or mud liner 22 concentrically received therein and surrounding a tubular conductor 25 which corresponds generally to the tubular structure assembly of FIG. 2,

but is of course of smaller diameter. The supply and return passages 26,27 for the protective fluid are in this arrangement within the conductor tubing 25 and between it and the mud lines 22 respectively. As shown, connection arrangements at the ends of adjacent drill pipe sections are similar to those provided for in the arrangement of FIG. 2. Suitable spacers 40 and hangers 41 extend between the mud liner 22 and the drill pipe 21 to maintain the mud liner and conductor tubing in correct concentric relationship within the drill pipe.

In accordance with FIG. 5, the conductor tubing arrangement of FIG. 4 can be modified to include segmental conductors 30 similar to those of FIG. 3. Thus for example three segmental conductors 30, with insulation 34, surround an inner pipe 31 from which radial spacers 32 extend to the mud liner 22. The conductor segments 30 are spaced from the mud liner to define the outer passage 27 for protective fluid, and the interior of the inner pipe defines the inner passage 26.

Where segmental conductors are employed, as shown in FIGS. 3 and 5, and the drillstring sections are connected together by screw-threaded connections at their ends, so that the relative angular location is not predetermined, electrical continuity between respective segments 30 can be achieved by the coupling arrangement shown in FIG. 6. Here, each of the conductor segments at the end of a drillstring section is in electrical connection with a respective end contact ring 42. The end rings 42 are of successively larger diameter contact downwardly from the free end of the section to form a male coupling assembly. The co-operating female assembly (not shown) is formed as a socket with internal steps matching in diameter and axial spacing the external steps of the male assembly illustrated. At these steps, respective conductor segment ends are exposed, so that they can engage the contact rings of the male coupling assembly.

In any of the arrangements of FIGS. 2–6, one of the protective fluid passages can be omitted where the fluid is to be leaked into the drilling mud at the drill unit so that no return path is required. For example, as shown on the lefthand side of FIG. 3, the mud liner 22 can simply be omitted, so that its function is performed by the inner pipe 31.

The drill string 1 needs to be advanced along the drill hole 7 as drilling progresses and FIGS. 7, 8, 9 and 10 show different forms of drive means for achieving this advance, or for withdrawal of the drill string if required.

As appears from FIG. 7, the drill string 1 includes a section 50 of which the interior can correspond to any one of the drill string sections described in connection with FIGS. 2–6 but which carries externally an inflatable packer 51 which can be selectively inflatable, as by admission to its interior of the protective fluid conveyed along the drill string by way of an electrically controlled valve 52. When inflated, the inflatable packer 51 functions as a piston whereby the drill string 1 is moved along the drill hole by the pressure of drilling mud between the drill string and the wall of the drill hole 7 which acts as an hydraulic fluid. Drilling mud is normally circulated to the drilling unit 10 inside the drill string and returned between it and the drill hole wall, as indicated by the arrow 55, so that the inflatable packer would thus be urged to retract the drill string rather than advance it. To obtain the desired drill string advance, the direction of the mud flow is reversed to that indicated by the arrow 56.

The pressure on the near side of the inflated inflatable packer 51 must of course exceed that on the far side and an electrically controllable mud dump valve 57 can be provided in the wall of the drill string downstream of the inflatable packer, so that drilling mud pressure on the far side of the annulus is reduced by passage of mud on that side to the mud flowing within the drill string. When the inflatable packer 51 is deflated mud circulation in the usual direction can continue unobstructed.

The traction unit shown in FIG. 8 also employs the drilling mud as a hydraulic fluid, but instead of an inflatable annulus, the mud engages a piston element 60 of fixed form secured externally around a section of the drill string 1. The piston element 60 is sealed to the wall of the drill hole by annular flexible sealing members 61 which extend radially outwardly to the wall so that the pressure of drilling mud during traction enhances the seal. A plurality of passages 62 extend through the piston element 60 and each includes a non-return valve 64 which permits mud flow through the associated passage in the direction of the arrow 55 during drilling. When the drill string 1 is to be advanced, the direction of mud flow is reversed, so that the mud flows in the annular space between the drill string and the drill hole wall in the direction indicated by the arrow 56. The non-return valves 64 close the passages 62 through the piston element rendering this effective to achieve the desired drill string movement.

The non-return valve 64 can instead be a selectively operable valve controlled directly, by electrical means, or indirectly, as by electrohydraulic means, so that it can function as a deep set blow out preventer valve, when it is desired to close off the drill hole other than by the use of an X-mas tree valving arrangement.

The traction unit shown in FIG. 9 comprises a frame 70 permanently secured to the exterior of a drill string section, the frame being such as not to unduly obstruct the flow of mud between the drill string and the drill hole wall. The frame 70 rotatably mounts traction elements in the form of wheels or rollers 71 which may be spring urged to engage the wall, and are electrically driven so as to advance the drill string 1 as and when required. In an alternative arrangement, shown at the lower part of FIG. 9, the frame 70 mounts rollers 72 around which is entrained a traction belt 74 engageable with the drill hole wall, the rollers again being selectively driven by an electric motor taking its power from the conductors within the drill string.

The traction unit illustrated in FIG. 10 is also electrically driven and comprises an annular casing 81, which contains an electrical winding 82 and which is fixed to and surrounds the drill string 1, or is incorporated in the drill string as a separate drill string section. The winding 82 can be selectively energized by way of the conductors within the drill string so as to function as a component or "stator" of a linear electric motor, the other component or "rotor" being represented by a steel casing 84 lining the drill hole. By suitable control of the energization of the winding 82 the drill string 1 can be moved along the casing 84 in either direction, as desired.

It will be evident that the various means described above for advancing or withdrawing the drill string 1 can be employed for moving the casing 84, or other external piping, for example, production tubing, along the drill hole in either direction. Such movement can be effected relative to a core or guide member in place of the drill string. The member or drill string requires to be

held stationary, and its leading end may be selectively clamped to the drill hole wall by clamping means as described below.

The drill unit 100 of FIG. 11 comprises a cylindrical housing 101 having a rotatable drill shaft formed of aligned forward and rear portions 104, 105 concentrically received therein. The drill shaft is hollow to provide a passage for the supply of drilling mud to a drill bit 106 carried by the shaft portion 104, which is journalled in bearings 107. The rear shaft portion 105 is jounralled in bearing 109 and is connected to the forward portion by way of a selectively adjustable speed/-torque converter 110.

Between the bearings 109, the rear shaft portion 105 carries an annular rotor portion 111 of an electric motor which is concentrically surrounded by an annular stator portion 112 secured to the housing 101. The housing 101 is connected at its rear end to a drill string which has one of the forms shown in FIGS. 2–6, with conductor tubing extending to a connector box 114 connected to a distributor unit 115. The conductor tubing of the drill string 1 provides not only power for the electric motor 111,112 but also data communication between the control equipment 14 located on the platform 2 and a local control unit 117, for control of the electric motor, and also between the control equipment and sensor means 116 for monitoring motor operation and progress of the drilling.

The speed/torque converter 110 may be omitted where direct drive of the drill bit 106 by the electric motor 111,112 is satisfactory.

Instead of a rotary drill bit, the drill unit of the invention can mount a reciprocable drill bit which operates percusively. In the drill unit 120 of FIG. 12, the housing 121 has a hollow drill shaft 122 concentrically guided therein for reciprocating movement by slide bearings 124. At its forward end, the housing 121 includes the stator 125 of a linear electric motor, of which the drill shaft 122 functions as the "rotor". The housing 121 connects at its rearward end to a drill string 1 which can again be one of the kinds described with reference to FIGS. 2–6.

The linear electric motor constituted by the stator 125 and the drill shaft 122, can be operated so as to power both the forward and return strokes of the drill bit 106 by appropriate change of the phase sequence of the electrical supply, or alternatively, the motor could operate to effect only one of the strokes, for example the return stroke, the other stroke being then effected by release of energy stored during the powered stroke. The unit 120 can thus incorporate a plurality of compression springs 126 extending into respective bores opening from the rear end of the drill shaft 122, the outer ends of the springs being held by retaining members 127 secured to the housing 121, which contains also a local control system 116.

To better support the unit 120 against the cutting stroke of the drill bit, the housing 121 can be provided with clamping devices 129 engageable with the drill hole wall, whereby the housing is concentrically clamped within the drill hole. Such clamping devices can be provided additionally or instead on the drill string 1 at suitable positions, to transfer the drilling reaction forces experienced by the drill string, so as to resist any tendency for the drill string to buckle. The clamping devices 129 can be of the kind described below with reference to FIG. 12.

In a modification of the drill unit 120, schematically shown at the lower part of FIG. 12, the linear motor stator 135 operates a plunger 136 of a hydraulic system 137 to move a piston within a hydraulic cylinder of which the piston rod 139 carries the drill bit 106.

In the drill unit 140 of FIG. 13, the drill bit 106 and the motor for driving it are arranged for axial movement relative to a "stationary" portion of the unit connected to the drill string or constituted by the end thereof.

As shown, the drill bit 106 extends forwardly from a casing 141 containing a motor by which the drill bit is driven. Concentric inner and outer sleeves 142,144 extending rearwardly from the casing 141. The inner sleeve 142 serves for the conveyance of drilling mud to the drill bit and is sealed to an inner sleeve 145 of the stationary portion of the unit within which it slides. The stationary portion of the unit also has an outer sleeve 147 slidably received within the sleeve 144 and sealed thereto. A pin 149 on the sleeve 144 slides in a longitudinal slot of the sleeve 14 to prevent relative rotation of the two portions of the unit.

Between the two sets of inner and outer sleeves, sliding electric contacts or other means, for example flexible cables, are provided for transmission of electric power and/or communication signals. The stationary portion of the unit is thus provided with tubing 150 supporting a plurality of segmental conductors, suitably of the kind described in connection with FIGS. 3 and 5, which are in sliding contact relationship with corresponding conductor tubing 151 extending rearwardly from the casing 141.

Fluid pressure conveyed along the drillstring 1 to the space 152 between the outer sleeve 144 and the conductor tubing 151 acts on the casing 141 to apply axial loading to the drill bit. The annular space 154 within the conductor tubing provides a low pressure fluid return path, and the high pressure and low pressure fluid spaces are connected together through a pressure control valve 155 within the casing 141, the valve being adjustable so that the loading of the drill bit is in accordance with requirements.

The relatively sliding surfaces of the stationary and movable portions of the drill unit 140 are provided with stops which limit the relative movement corresponding to a certain advance of the drill bit. At this point, the drillstring 1 is advanced in the drill hole, as by the means described with reference to FIGS. 7–10, relative to the new stationary drill bit 106 and casing 141. Thereafter, drilling is recommenced under the axial drill bit loading applied by the fluid pressure.

The drill unit 160 shown in FIG. 14 is also telescopically constructed, so that the drill bit can be axially loaded under hydraulic pressure. The drill bit 106 is carried by a movable portion of the unit comprising a drill bit support 160 with rearwardly extending inner and outer concentric sleeves 162,164, of which the inner sleeve 162 serves to guide drilling mud to the drill bit. The "stationary" drilling unit portion is received between these two sleeves.

The inner sleeve 162 adjacent the support 161 is surrounded by a hollow drive shaft 165, which is splined to the inner sleeve so as to rotate therewith. Rearwardly from the shaft 165, a hollow motor shaft 166 also surrounds and is sealed to the inner sleeve 162 but is capable of rotation with respect to it. The motor shaft 166 is driven by an electric motor of the same form as the motor employed in the drilling unit 100 and drives the

drive shaft 164 by means of a torque converter or speed reducer 110 of the kind employed in the drilling unit 100.

The inner surface of the drill bit support 160 and adjacent surfaces of the inner and outer sleeves 162,164 provides a pressure chamber, sealed from the motor by sealing means 169, for fluid pressure conveyed along the drillstring 1, whereby the drill bit is subjected to axial loading adjustable by control means 155 as with the unit 140 of FIG. 13. The use and operation of the drilling unit 160 will be understood to be generally similar to that of the unit 140.

The fluid pressure axially loading the drill bit in the drill units of FIGS. 13 and 14 reacts against the stationary portions of the units and thus against the drill string to which they are attached. The stationary portions can however be clamped to the formation, by means of selectively actuable clamping devices 129 similar to those provided for the drilling unit 120.

A drilling unit 180 shown in FIG. 15 thus comprises a stationary portion 181 provided with clamping devices comprising pads 182 pivotably carried at the outer ends of levers 184 pivoted to the outer wall of the stationary portion so as to extend outwardly and rearwardly of the drilling direction. Selectively operable actuator devices 185, for example hydraulic cylinders, act between the outer ends of the levers 184 and the stationary portion wall to urge the pads 182 against the drill hole wall or to withdraw them inwardly.

An axial loading portion 186 of the drilling unit extends forwardly in the drilling direction from the portion 181 and a motor unit 187 having the drill bit 106 at its forward end can be advanced in the drilling direction under hydraulic pressure developed in the loading portion.

The clamping devices 181,182 are preferably independently controllable, so that the drill bit axis can be orientated at a desired angle to the drill hole axis within an angular range, as indicated by the circle 188. Thus, in operation of the drill unit 180, the clamping devices 129 are released at the conclusion of a drilling stage to effect withdrawal of the pads 182 from the drill hole wall, and the drill string and stationary drilling unit portions are then advanced relative to the drill bit and motor unit 187, so that the drilling unit takes up a contracted condition. In accordance with command signals designating a desired drilling direction, or a direction indicated by information obtained by appropriate sensors associated with the drilling unit, the clamping devices 129 are actuated to apply a directional influence to the unit whereby a new drilling direction is determined. Drilling is then recommenced, with axial loading applied to the drill bit 106 so that this and the motor unit 187 advance relative to the stationary portion 181.

In the drill unit 180, and in the other drill units in which pressure fluid is used to load the drill bit, the fluid pressure can be generated within the unit, as by a motor driven pump unit 189. The pressure fluid from this source can be applied also to operation of the actuators 184. A power distributor or a power generator such as the unit 189 can be located at any appropriate position or positions along the drill string 1, and in the drill unit, wherever power is required for a specific operation, for example to activate local control mechanisms or sensing or measuring equipment. Such local power generators can be controlled remotely as by electrical control signals from the control equipment 14 and can themselves be powered electrically or from pressure fluid or the flow of drilling mud.

Although the functions of the various drill units described with references to FIGS. 11-15 can be controlled from the platform 2, provision can be made for a degree of local control at the drilling unit itself in response to locally sensed conditions. Also, if the hydraulic pressure required for axial drill bit loading and/or for clamp operation is generated locally, within the drill unit, the pressure fluid source can be controlled from the equipment on the platform 2 or in response to locally sensed conditions.

Although the invention has been described with reference to fixed offshore platform it will be evident that it can be employed also with floating drilling rigs or vessels and onshore drilling installations.

It is evident that those skilled in the art may make numerous modifications of the specific embodiment described above without departing from the present inventive concepts. It is accordingly intended that the invention shall be construed as embracing each and every novel feature and novel combination of features present in or possessed by the apparatus herein described and that the foregoing disclosure shall be read as illustrative and not as limiting except to the extent set forth in the claims appended hereto.

I claim:

1. A drilling system comprising topside equipment, a drilling unit, and a drill string extending between said topside equipment and said drilling unit, wherein said drill string comprises:

a drill pipe,

a mud pipe concentrically received within said drill pipe and defining a mud passage for supply of drilling mud from said topside equipment to said drilling unit,

electrical conductor means providing electrical communication between said topside equipment and said drilling unit and comprising three concentric angularly spaced arcuate conductors of equal radii, said mud pipe being received within said conductors, an inner pipe received concentrically between said mud pipe and said arcuate conductors,

spacer portions on said inner pipe extending radially outwardly between said arcuate conductors to engage said drill pipe, and

wherein a first and a second fluid passage each extending between said topside equipment and said drilling unit are provided between said mud pipe and said inner pipe and between said conductors and said drill pipe respectively.

2. The drilling system of claim 1 further comprising electrically insulating material around each of said arcuate conductors.

3. A drilling system comprising topside equipment, a drilling unit and a drill string extending between said topside equipment and said drilling unit, wherein said drill string comprises:

a drill pipe,

a mud pipe concentrically received within said drill pipe and defining a mud passage for supply of drilling mud from said topside equipment to said drilling unit,

electrical conductor means providing electrical communication between said topside equipment and said drilling unit and comprising three concentric angularly spaced arcuate conductors of equal radii received within said mud pipe,

an inner pipe received concentrically in said mud pipe and said arcuate conductors,

three spacer portions on said inner pipe extending radially outwardly between said arcuate conductors to engage said mud pipe, and

wherein a first and a second fluid passage extending between said topside equipment and said drilling unit are provided between said conductors and said mud pipe and within said inner pipe respectively.

4. The drilling system of claim 3 further comprising insulating material around each of said arcuate conductors.

5. In a drilling system comprising a drill pipe extending between topside equipment and a drilling unit, electrical conductor means extending within said drill pipe comprising:

three arcuate electrical conductors of equal radii,

an outer pipe concentrically received within said drill pipe,

an inner pipe received within said outer pipe for conveyance of drilling mud to said drilling unit, said inner and outer pipes being spaced to provide therebetween a further passage for fluid communication between said topside equipment and said drilling unit,

three angularly spaced spacer means extending between said outer pipe and said drill pipe, a respective one of said arcuate conductors being received between each adjacent pair of said spacer means with spacing to define fluid passage means for fluid communication between said topside equipment and said drilling unit.

6. A drill pipe assembly for use in a drilling system, the assembly comprising:

a drill pipe,

an intermediate pipe concentrically received within said drill pipe with spacing to define a first conduit of annular cross-section therebetween,

an inner pipe concentrically received within said intermediate pipe with spacing to define a second conduit of annular cross-section therebetween,

a plurality of spacers extending radially between said intermediate pipe and one of said drill pipe and said inner pipe to divide one of said first and second conduits into a plurality of arcuate conduit portions of generally arcuate cross-section, and

a plurality of electrical conductor means of generally arcuate cross-section, each of said electrical conductor means being located within a respective one of said arcuate conduit portions.

7. The drill pipe assembly of claim 6 wherein said spacers extend radially between said intermediate pipe and said drill pipe, and wherein each of said conductor means occupies part only of the arcuate conduit portion in which the conductor means is located.

8. The drill pipe assembly of claim 7 wherein said spacers are integrally formed portions of said intermediate pipe.

9. The drill pipe assembly of claim 6 wherein said spacers are three in number and are equiangularly distributed around said intermediate pipe.

10. The drill pipe assembly of claim 7 wherein each of said generally arcuate conductor means engages the outer surface of said intermediate pipe and the spacers defining the arcuate conduit portion within which said conductor means is located.

11. In a drilling system including topside equipment, and a drilling unit;

a drill string comprising the drill pipe assembly of claim 7 extending between said topside equipment and said drilling unit,

means supplying drilling mud to said drill unit through the interior of said inner pipe,

means effecting electrical communication between said topside equipment and said drilling unit by way of said plurality of electrical conductor means, and

means for supplying fluid from said topside equipment along at least one of said first and second conduits.

12. The drill pipe assembly of claim 6 wherein said spacers extend radially between said intermediate pipe and said inner pipe and wherein each of said conductor means occupies part only of the arcuate conduit portion in which the conductor means is located.

13. The drill pipe assembly of claim 12 wherein said plurality of conductor means forms a ring of conductor means, the conductor means of said ring being separated only by said spacers.

14. The drill pipe assembly of claim 12 wherein each of said generally arcuate conductor means has an inner curved surface engaging said inner pipe and an outer curved surface spaced from said intermediate pipe.

15. In a drilling system including topside equipment and a drilling unit;

a drill string comprising the drill pipe assembly of claim 12 extending between said topside equipment and said drilling unit,

means supplying drilling mud to said drill unit by way of said first conduit,

means effecting electrical communication between said topside equipment and said drilling unit by way of said plurality of electrical conductor means, and

means for supplying fluid from said topside equipment along at least one of said second conduit and the interior of said inner pipe.

16. In a drilling apparatus including topside equipment and a drill unit;

a drill string extending between said topside equipment and said drill comprising the drill pipe assembly of claim 6;

at least one remotely controllable power generating unit in at least one of said drill unit and said drill pipe, said power generating unit generating power for effecting at least one of local control and local sensor operations.

17. A drilling system comprising a drill string extending between topside and downhole equipment, said drill string comprising:

plural concentric pipes spaced to provide at least one annular passage,

spacers extending radially of said pipes to divide said annular passage into arcuate passage portions,

plural electrical conductor means each of arcuate cross-section, the conductor means being concentrically located each in a respective one of said arcuate passage portions with radial spacing from one of said concentric pipes to provide fluid conduits within said passage portions.

18. The drilling system of claim 17 wherein each of said conductor means has an arcuate extent substantially equal to that of the said arcuate passage portion in which it is located.

19. The drilling system of claim 17 wherein said conductor means are three in number and are uniformly spaced around said drill string.

20. The drilling system of claim 17 wherein each of said conductor means engages one of the said concentric pipes and extends between said spacers defining said passage portion within which the conductor means is located.

21. The drilling system of claim 17 further comprising, at at least one position along said drill string, a drive unit selectively operable to move said drill string within a drill hole in response to power supplied and/or control signals transmitted by the conductor means.

22. The drilling system of claim 21 wherein said drive means comprises at least one piston element carried externally by said drill string and selectively responsive to the flow of fluid within the system to effect said movement.

23. The drilling system of claim 22, wherein said fluid comprises drilling mud.

24. A drilling system comprising topside equipment, a drill unit, and a drill string extending from said topside equipment to said drill unit, wherein:

said drill string comprising:

a drill pipe,

a mud pipe,

a tubular conductor assembly, said conductor assembly comprising a plurality of conductor elements each having the form of at least part of a tube; and each of said drill pipe, said mud pipe and said plurality of conductor elements extending from said topside equipment to said drill unit,

means mounting said mud pipe and said conductor assembly substantially concentrically within and spaced from said drill pipe, and spaced apart from each other, thereby to provide within said drill pipe a mud passage for supply of drilling mud from said topside equipment to said drill unit, and a first and a second fluid passage each providing fluid communication between said topside equipment and said drill unit, said first and said second fluid passages being at least in part defined by said conductor assembly,

said drill unit comprising:

a drill bit,

an electric motor for driving said drill bit, said electric conductor elements being connected to said electric motor for supplying power thereto from said topside equipment, and

fluid passage means extending through said electric motor and communicating with said first and said second fluid passages,

said topside equipment comprising:

means for supplying drilling mud through said mud passage to said drill unit, and

means for circulating fluid downwardly through one of said first and second fluid passages to said drill unit, through said fluid passage means, and upwardly from said drill unit to said topside equipment through the other of said first and second passages.

25. The drilling system of claim 24, wherein said conductor elements comprise tubular conductor elements and said conductor assembly further comprises solid insulation between said tubular conductor elements.

26. The drilling system of claim 24, wherein said conductor elements comprise part-tubular conductor elements of equal radii centered on a common axis, and said conductor assembly further comprises a support ring having radially projecting spacer means, a respective on of said conductor elements being received between each adjacent pair of said spacer means.

* * * * *

United States Patent [19]

Jurgens et al.

[11] **Patent Number: 4,732,225**

[45] **Date of Patent: Mar. 22, 1988**

[54] **DEEP-BOREHOLE DRILLING DEVICE WITH MAGNETIC COUPLING**

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[21] Appl. No.: **10,750**

[22] Filed: **Feb. 4, 1987**

[30] **Foreign Application Priority Data**

Feb. 12, 1986 [DE] Fed. Rep. of Germany 3604270

[51] **Int. Cl.**[4] **E21B 4/02; E21B 4/04**

[52] **U.S. Cl.** **175/92; 175/104; 175/107; 166/66.5; 464/29**

[58] **Field of Search** 175/92, 104, 107; 166/65.1, 66.4, 66.5; 464/29

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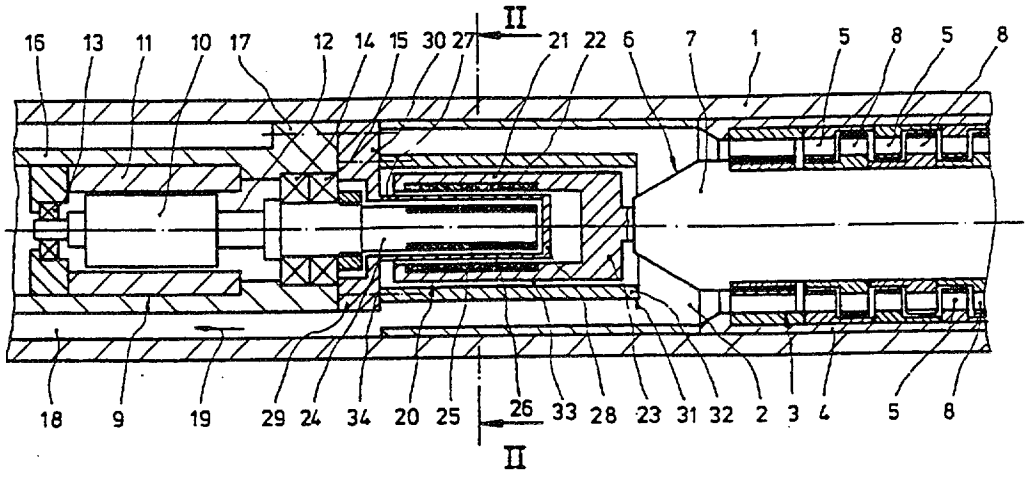
Primary Examiner—James A. Leppink
Assistant Examiner—Terry Lee Melius

[57] **ABSTRACT**

A deep-borehole drilling device comprising a drive unit such as a downhole motor and a driven unit such as a generator in which a drive transmission coupling is provided in the form of a contact-free magnetic coupling. The magnetic coupling may be a permanent magnet coupling with the magnets arranged coaxially and is preferably a can-tube coupling comprising an outer magnet carrier and a can-tube disposed coaxially within said outer magnet carrier.

8 Claims, 2 Drawing Figures



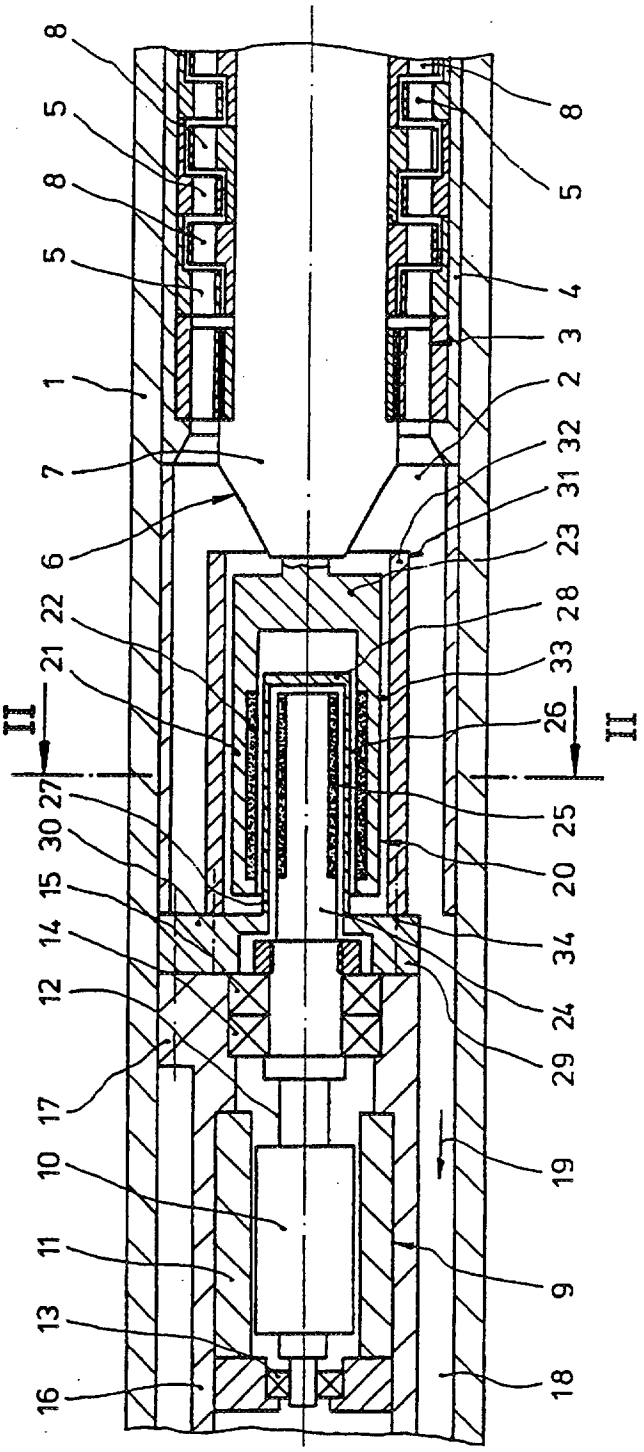

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Fig. 1

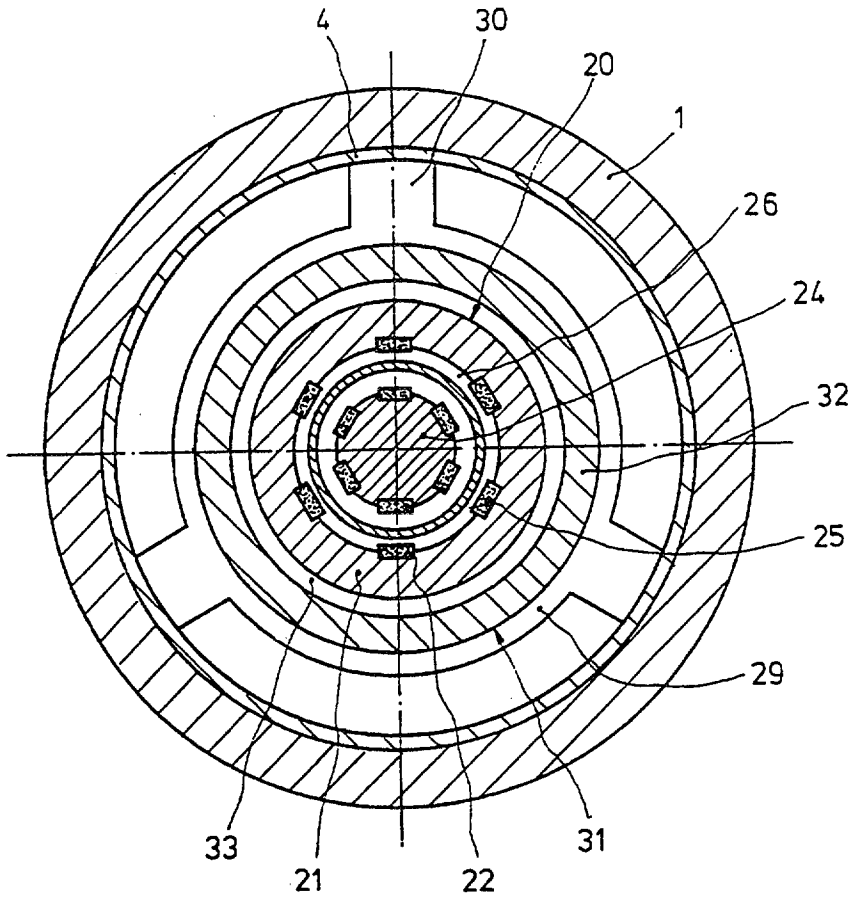

Fig. 2

DEEP-BOREHOLE DRILLING DEVICE WITH MAGNETIC COUPLING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a deep-borehole drilling device and more particularly concerns such devices which include a drive unit coupled to drive a driven unit by drive transmission coupling means.

2. Description of the Prior Art

In deep-borehole drilling devices, mechanical drive transmission couplings are generally used to couple drive units to driven units as these couplings exhibit no temperature dependence, function with very little wear, and establish a direct physical connection between driving parts and driven parts. Such an arrangement is described in German Pat. No. 26 20 801.

The object underlying the invention is to provide a drilling tool with contact-free drive transmission coupling between the drive unit and the driven unit.

SUMMARY OF THE INVENTION

According to the present invention there is provided a deep-borehole drilling device comprising a casing, a drive unit supported inside said casing, and with at least one driven unit, which is adapted to be driven by the drive unit, a drive transmision coupling enabling said driven unit to be driven by said drive unit, said coupling being a contact-free magnetic coupling.

Preferably the coupling is a coaxial permanent magnet coupling and is desirably a can-tube coupling, comprising an outer magnet carrier and a can-tube disposed coaxially within said outer magnet carrier with a clearance therebetween.

The clearance between the outer magnet carrier and the can-tube is preferably sealed by a sealing device. A labyrinth seal is particularly suitable, preferably a labyrinth seal which comprises a sleeve with coaxially surrounds the outer magnet carrier leaving a small clearance.

In the drilling device of the invention, rotary motion is transmitted from the drive unit to a driven unit in a manner involving no contact thus enabling the drive units and driven units to belong to separate systems. This is particularly important in applications where the drive unit is a downhole motor which is operated by drilling mud, and where there is a requirement to drive driven units in the form of sensors, generators or similar functional units which need to be encapsulated or otherwise sealed from the drilling mud.

BRIEF DESCRIPTION OF THE DRAWING

A more detailed representation of an illustrative embodiment of the subject matter of the invention is presented in the drawing, wherein

FIG. 1 is a truncated longitudinal section through a deep-borehole drilling device according to the invention; and

FIG. 2 is a section along line II—II in FIG. 1.

In detail, the deep-borehole drilling device, as diagrammatically illustrated in FIG. 1, comprises a tubular casing 1 which can form a portion of a borehole pipe string. A drive unit 2 is supported inside the casing 1. The drive unit may be of any known suitable design, but is preferably a downhole motor which is operated by the drilling mud, such as, for example, a turbine as shown in the drawing, or a displacement motor operating on the Moineau principle. As shown, the turbine comprises a stator 3, supported inside a tubular stator housing 4 and having stationary blade rings 5, and a rotor 6, having a rotor shaft 7 carrying blade rings 8 which revolve with it.

The drive unit 2 drives a driven unit 9 which may be any unit for which there is a need when drilling deep boreholes and which requires a rotary drive. Drive units which are of primary interest include generators, sensors and measuring instruments of all types and pumps although other driven units can be driven if required.

As shown in the drawing, the driven unit 9 is a generator, having a rotor 10 which can be rotated inside and coaxially with a stator assembly 11. The rotor shaft 12 is supported in an encapsulating housing 16, by means of bearings 13, 14, 15, while the housing 16 is supported in the casing 1, by means of radial projections 17, so as to leave a circumferential clearance 18 for the through-passage of drilling mud in the direction of the arrow 19.

So that the drive unit 2 may drive the driven unit 9, a contact-free permanent-magnet drive transmission coupling 20 is provided, which is preferably designed as a coaxial-magnet coupling, as in the illustrative embodiment shown. The drive transmission coupling 20 can be designed as a face-magnet coupling if desired.

In detail, the drive transmission coupling 20 consists of an outer magnet-carrier 21, in the form of a circular-profile tube, supporting permanent magnets 22 which are inset into its inner surface, so that they are located on a circular arc. On its end facing the rotor 6, the outer magnet-carrier 21 is closed-off by a blanking wall 23 and is connected, in the region of this wall, to the shaft 7 of the rotor 6 of the drive unit 2.

The drive transmission coupling 20 further comprises an inner magnet-carrier 24, which is designed in the form of a shaft extension and, in the example presented here, is a portion of the shaft 12 of the driven unit 9. Permanent magnets 25 are inset into the outer surface of the inner magnet-carrier 24, so that they, in their turn, are located on a circular arc. The number, size and shape of the magnets are governed by the torque which has to be transmitted in the particular drilling device. The arrangement of the magnets is governed by the geometric design of the drive transmission coupling 20, which depends on parameters such as the available inside diameter of the casing 1, etc.

In the embodiment shown, the drive transmission coupling 20 is a coaxial magnet coupling designed as a can-tube coupling. A can tube 27 is provided in the clearance 26, is closed-off by an end wall 28, and completely covers the inner magnet-carrier 24. The can tube 27 blends into a connecting flange 29 which is fixedly and sealingly connected to the encapsulating housing 16 of the driven unit 9, for example by means of screws. These screw-connections can be provided inside radial projections 30 which correspond to the projections 17 and are flush-located opposite and in axial alignment with them.

In order to prevent drilling mud from flowing through the clearance 26, between the can tube 27 and the outer magnet-carrier 21, carrying abrasive particles with it and entailing the possibility of wear or deposits which could cause malfunctions, the clearance 26 is preferably sealed-off from the surroundings by means of a sealing device. Any known or suitable sealing device may be used for this purpose, but a labyrinth seal 31 is

preferred, the seal being formed by a sleeve 32 which coaxially surrounds the outer magnet-carrier 21 of the central-magnet coupling 20, leaving a small clearance. The sleeve 32 forms a labyrinth clearance 33 with the outer surface of the outer magnet-carrier 21, this clearance 33 being designed to be sufficiently narrow to prevent flow through the clearance 26. In the embodiment shown, the sleeve 32 is fixedly connected to the connecting flange 29, for example by means of screws at the position 34.

The rotor 6 of the drive unit 2 drives the shaft 12 of the driven unit 9 via the drive transmission coupling 20 in a manner which involves no contact, and thus facilitates the installation of the driven unit 9 in a fully encapsulated, separate system or section of the deep-borehole drilling device, and provides it with reliable protection against the ingress of drilling mud or other extraneous material.

We claim:

1. In a deep-borehole drilling device including a casing, at least one driven unit and a drive unit supported inside said casing to drive said at least one driven unit, and wherein mud flows through said casing to drive said driven unit, the improvement comprising:

a drive transmission coupling for effecting a driving relation between said at least one driven unit and said drive unit,

said drive transmission being a contact-free magnetic coupling supported within said casing and including first magnetic means rotatingly driven by said drive unit and second magnetic means spaced from said first magnetic means and rotatingly driven thereby,

said at least one driven unit being supported in said casing in sealed relation with respect to entrance of said mud into said at least one driven unit,

said second magnetic means being sealingly connected to drive said at least one driven means,

non-rotating means supported in said casing in spaced relation to said said first magnetic means, and

seal means cooperating with said non-rotating means to prevent flow of mud into the space between said first and said second magnetic means.

2. In a deep-borehole drilling device as set forth in claim 1 wherein said contact-free magnetic coupling is a coaxial permanent-magnetic coupling.

3. In a deep-borehole drilling device as set forth in claim 2 in which the drive transmission coupling is a can-tube coupling, and

said can-tube coupling including can-tube means disposed between and spaced from each of said first and second magnetic means.

4. In a deep-borehole drilling device as set forth in claim 3 wherein said means to prevent flow into said space includes seal means between said first magnetic means and said can tube means.

5. In a deep-borehole drilling device as set forth in claim 4 wherein said seal means is a labyrinth seal.

6. In a deep-borehole drilling device as set forth in claim 1 wherein each of said first and second magnetic means includes a plurality of spaced permanent magnets, the permanent magnets of said first magnetic means being concentrically disposed with respect to the permanent magnets of said second magnetic means.

7. In a deep-borehole drilling device as set forth in claim 1 wherein said drive means is a turbine.

8. In a deep-borehole drilling device as set forth in claim 1 wherein said drive means is a downhole motor.

* * * * *

United States Patent [19]

Rinaldi

[11] **Patent Number: 4,544,041**

[45] **Date of Patent: Oct. 1, 1985**

[54] **WELL CASING INSERTING AND WELL BORE DRILLING METHOD AND MEANS**

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[21] Appl. No.: **545,222**

[22] Filed: **Oct. 25, 1983**

[51] Int. Cl.[4] **E21B 7/20**

[52] U.S. Cl. **175/57**; 175/104; 175/171; 175/203

[58] Field of Search 175/57, 92, 104, 162, 175/171, 203, 257

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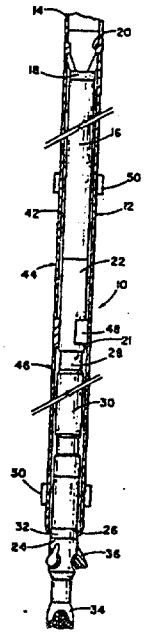
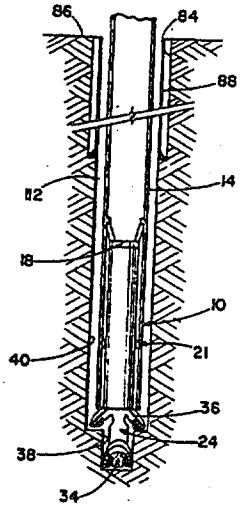
Primary Examiner—Stephen J. Novosad
Assistant Examiner—William P. Neuder
Attorney, Agent, or Firm—Head, Johnson & Stevenson

[57] **ABSTRACT**

A well bore casing inserting and drilling method and apparatus comprising the simultaneous drilling and casing setting of an oil and/or gas well bore by supporting a drill bit and actuating motor therefor from the lower end of the well casing whereby the well casing is lowered into the well bore simultaneously with the penetration of the earth by the drill bit assembly, the motor and drill bit being releasably secured within a housing whereby the motor and drill bit may be retrieved through the internal bore of the casing for repair or replacement of the drill bit or other operational components of the apparatus.

9 Claims, 5 Drawing Figures





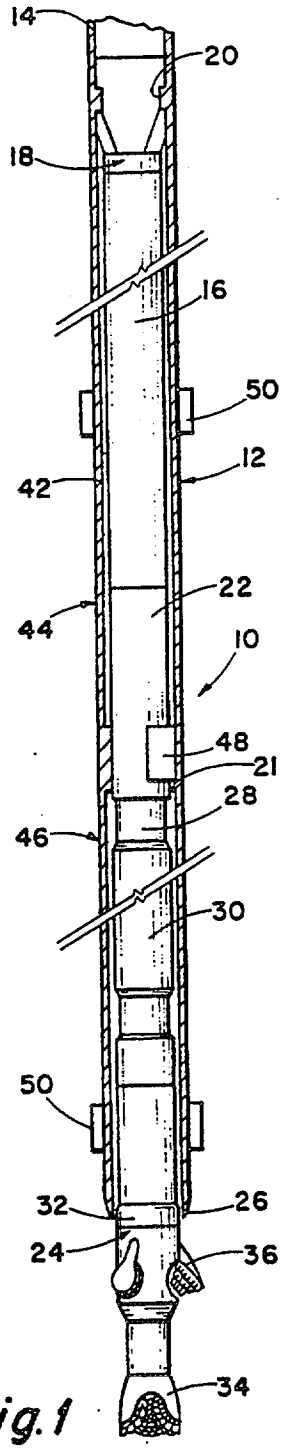

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Fig. 1

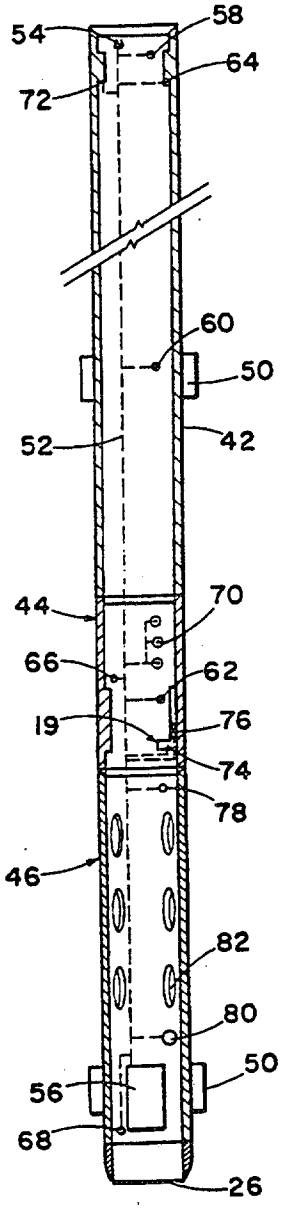
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Fig. 2

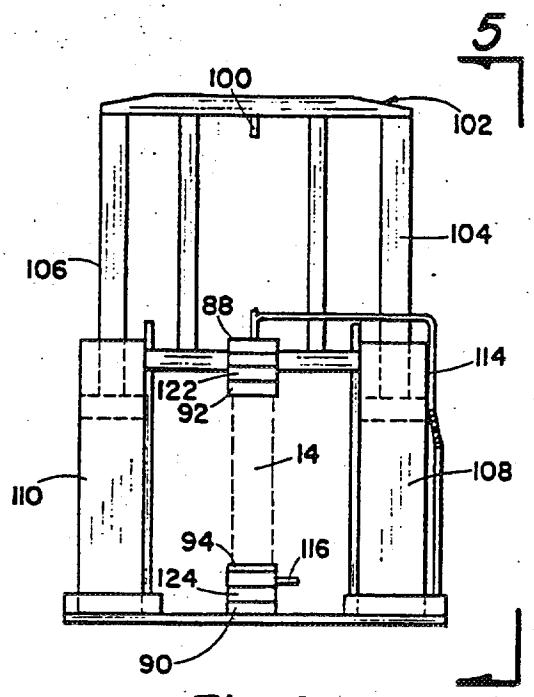

Fig. 4

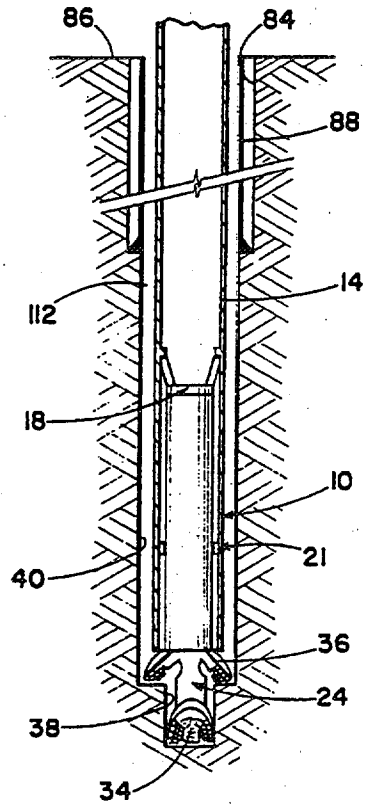

Fig. 3

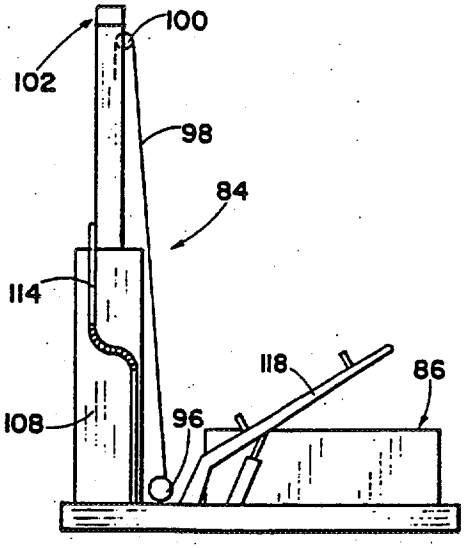

Fig. 5

WELL CASING INSERTING AND WELL BORE DRILLING METHOD AND MEANS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in well bore drilling operations and more particularly, but not way of limitation to a method and means for simultaneously inserting well casing into and drilling a well bore.

2. Description of the Prior Art

In the present day drilling of an oil and/or gas well bore it is the usual practice to suspend a string of drill pipe from a supporting structure, commonly called a derrick, and connect a drill bit to the lower end of the pipe. The drill pipe is rotated about its own axis by surface equipment commonly known as a kelly, and the rotation of the drill string is transmitted to the drill bit. As the drill bit cuts through or penetrates the earth, the well bore is formed and the weight of the drill string on the bit facilitates the penetration of the bit into the earth for deepening of the well bore. As the depth of the well exceeds the overall lenght of the drill string, it is necessary to add sections of drill pipe to the drill pipe string in order to assure that the drill bit will remain disposed against the bottom of the well bore during the drilling operation. Of course, in the event the drill bit becomes worn or otherwise damaged, it is necessary to elevate the entire drill string within the well bore in order to raise the drill bit to the surface of the ground for repair or replacement. This operation requires considerable time and expensive equipment since the drill string is usually several thousand feet long and quite heavy.

Subsequent to the penetration of the earth by the drill bit through a sufficient depth to drill the well bore to the desired well completion depth, it is necessary to remove the drill string and drill bit from the well bore and lower a string of well casing into the well bore for lining thereof and for receiving the production tubing therethrough. The pulling of the drill string as well as the lowering of the well casing is another time consuming and difficult task, requiring expensive labor and equipment to accomplish.

Another problem encountered in the usual present day well bore drilling method and means is establishment of communication between the surface of the ground and the bottom of the well bore in order to determine certain conditions existing at the bottom of the bore which may be relevant to the overall drilling operation. The most advanced method in use today for determining the conditions within the bore, particularly at the bottom of the bore is a slow, non-continuous, one-way communication system comprising a mud pulse telemetry. This involves the application of a pulse in the drilling mud, or the like, at the bottom of the well bore in order that the pulse may be transmitted upwardly through or by the mud. It will be apparent that some of the pulse is absorbed by the mud, resulting in relatively inaccurate and inefficient returns at the surface of the well.

SUMMARY OF THE INVENTION

The present invention contemplates a novel well bore drilling and well casing system and means wherein the well bore is cased simultaneously with the drilling of the bore without the use of a drill string and the attendant or auxiliary equipment normally used therewith. A retractable bit of the type known as a "drilling hole opener" and readily available at the marketplace, is operably connected with a downhole motor of any suitable or well known type, and the motor is secured or attached to a movable casing string. As the drill bit engages the earth for penetrating the earth during the drilling operation, the well casing moves concurrently or simultaneously downward through the bore therewith. When the drill bit becomes worn or damaged, the motor and bit carried thereby may be released from engagement with the well casing and elevated through the well casing to the surface of the ground by means of a cable and winch means operable from the surface. The well casing remains in position within the bore hole during the releasing or tripping operation of the motor and bit therefrom. The drill bit may then be repaired or replaced, and the motor and drill bit may be lowered through the well casing by the cable and winch means and reconnected at the bottom of the well casing for continuing the drilling operation.

Since the well casing is installed within the well bore as the bore is being drilled, a flat wire, closed loop, electrical communication and control system of any well known type may be installed in or secured on the wall of the casing. This provides a closed loop system between the surface of the well and the bottom of the well bore which permits the development and use of a down hole sensing means and system for guidance of the bit since the system may be monitored and controlled from the surface of the ground on a real time, continuous basis.

It is estimated that the complete elimination of the drill string and its associated surface equipment and labor required for the operation thereof will reduce the cost of well bore drilling operations by approximately ten to fifteen percent, which is significant when the overall cost of drilling the usual oil and/or gas well is considered. The development and the use of a closed loop electrical control system for establishing downhole communication may provide an even further cost saving in the drilling of well bores. The novel method and means of setting well casing simultaneously with the drilling of a well bore is simple and efficient in operation and economical and durable in construction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational view of a well casing inserting and well bore drilling apparatus embodying the invention, with portions shown in section for purposes of illustration.

FIG. 2 is an elevational view of a control sub which may be utilized in the practice of the invention, with portions shown in section for purposes of illust- ration.

FIG. 3 is a sectional elevational view of a well casing inserting and well bore drilling apparatus embodying the invention in use for the drilling of a well bore.

FIG. 4 is a front elevational view of surface equipment which may be utilized in combination with the well casing inserting and well bore drilling apparatus embodying the invention.

FIG. 5 is a view taken on line 5—5 of FIG. 4.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings in detail, and particularly FIGS. 1 and 3, reference character 10 generally indicates a well casing inserting or lowering and well bore drilling apparatus or control sub comprising a housing

or tube 12 adapted to be secured to the lower end of a suitable well bore casing 14 in any suitable manner (not shown) for encasing or housing and supporting a down hole motor 16. There are many types of downhole motors available today, and the motor 16 may be of any suitable "off-the-shelf" type readily available at the marketplace. The motor 16 may be removably secured to or locked within the housing 12 in any suitable well known manner, such as by a motor lock assembly generally indicated at 18 and which may cooperate with longitudinally spaced inwardly directed annular shoulders or flange means 20 and 21 provided on the inner periphery of the housing 12. The motor 16 is preferably suspended or supported concentrically within the housing 12.

A transmission assembly 22 of any suitable or well known type may be operably connected to the lower end of the motor and transmits operational power from the motor 16 to a suitable drill bit 24 suspended therebelow and extending beyond the open lower end 26 of the housing or tube 12. It is preferably to interpose a saver sub assembly 28 and shock sub assembly 30 between the transmission 22 and bit assembly 24 for increasing the overall operating efficiency of the apparatus 10. Similarly, it is preferably to provide a suitable wear sleeve means 32 on the bit assembly 24 for protection thereof during a well bore drilling operation with the assembly 10.

The drill bit assembly 24 may be of any well known retractable type commonly known in the industry as a rock drilling hole opener, and usually comprises rotary or roller bit drill means 34 at the extreme outer or lower end thereof and a plurality of circumferentially spaced bits or cutters 36 spaced thereabove but is not limited thereto. In this manner, a well bore may be initially opened by the roller or rotary bit 34, as shown at 38 in FIG. 3, and enlarged to a diameter greater than the outer diameter of the housing 12 by the cutters 36, as shown at 40 in FIG. 3.

The housing 12 is preferably tubular, but not limited thereto, and is preferably of a longitudinally sectional construction including an upper pipe or motor lock tube section 42 secured in axial alignment with a torque tube means 44 and instrument probe means 46, all of which may be threadedly secured in tandem relation, or otherwise secured in longitudinally aligned relationship. In addition, it is desirable to provide a suitable torque pad means 48 cooperating between the torque tube means 44 and the transmission 22 or other appropriate part of the motor bit assembly so as to transmit the reactive torque of the drilling bit 24 to the housing 12 during a well bore casing lowering and drilling operation. It may also be preferable to provide a plurality of suitable circumferentially and longitudinally spaced reamers 50 on the outer periphery of the housing 12, as is well known, for facilitating the penetration of the well bore 40 by the housing 12 during the casing setting well bore drilling operation.

Referring now to FIG. 2, numerous control systems may be designed for control sub 10 depending upon the needs of the user. A typical system is schematically illustrated in FIG. 2. A suitable wire harness means 52 extends longitudinally through the sub 10, providing connection between a suitable harness electrical connector means 54 provided in the proximity of the upper end of the sub 10 and an electronic/nuclear sensor module 56 provided in the proximity of the lower end thereof. In addition, an upper position sensor means 58, a mid position sensor means 60 and a lower position sensor means 62 are disposed within the sub 10 and operably or electrically connected with the wiring harness 52 in any suitable or well known manner. A sensor means 64 is also operably connected with the wire harness means 52, and is preferably disposed in the proximity of the shoulder or flange 20 for sensing the weight on the bit 34 or assembly 24. An upper vibration and shock sensor means 66 and a lower vibration and shock means 68 are installed within the sub means 10 in any well known manner, and are operably connected with the wiring harness. A suitable transmission control means 70, preferably of a magnetic type, but not limited thereto, is operably connected with the wiring harness means 52 and the transmission 22 for controlled actuation thereof, as is well known. An upper motor lock sensor means 72 is operably connected with the wiring harness means 52 in the proximity of the locking means 18, and a lower motor lock sensor means 74 is operably connected with the wiring harness means 52 in the proximity of a lower motor locking means 19. In addition, a suitable torque sensor means 76 is operably connected with the wiring harness means 52 is disposed between the torque pad means 48 and the torque tube means 44.

A suitable RPM sensor means 78 and a gas sensor means 80 are preferably provided in the instrument probe means 46 and are operably connected with the wiring harness means 52. In addition, it is desirable to provide a plurality of circumferentially and longitudinally spaced mud flow ports 82 in the sidewall of the instrument probe means 46.

Referring now to FIG. 3, a simultaneous well bore casing inserting and drilling operation of the present invention may be accomplished in the following manner: The usual practice of initially opening the earth or drilling a relatively large diameter bore at the surface 86 of the earth and the installation and/or setting of the conductor casing and/or surface casing 88 therein may be performed in any well known manner. The normal purpose of setting the casing 88 is to protect the upper subsurface formations from contamination by the well fluids (not shown) which may ultimately be elevated to the surface 86 through the well bore 40. In this manner, ground water, and the like may be protected from contamination and the well bore may be stabilized for further operations.

Subsequent to the lowering or inserting of the casing 88, the sub means 10 carrying the retractable drilling hole opener or drill bit assembly 24 may be suspended in substantial axial alignment with the internal bore of the surface casing 88 and lowered therethrough in substantially concentric relation with respect thereto until the drilling hole opener 24 is brought into engagement with the bottom of the well bore. Of course, the upper end of the control sub assembly 10 is secured in any suitable or well known manner to the lower end of a well casing section 14, and the wiring harness means 52 may be electrically or operably connected with a source of electrical current, such as a signal and/or power cable which may extend longitudinally through or on the outer periphery of the casing section 14. This operably connects the wiring harness and electrical component operably connected therewith to the usual surface recording equipment (now shown) whereby a visual indication of the subsurface conditions may be constantly viewed.

When the drill bit assembly 24 has been positioned against or in contact with the bottom of the well bore 40, the motor 16 and transmission 22 may be activated for initiation of the operation of the drilling bit assembly 24. As the bit 34 penetrates the earth at the bottom 38 of the well bore, the side bits or cutters 36 engage the sidewalls of the bore above the bit 34 and increases the diameter of the bore as shown at 40. The bore 40 opened by the side bits or cutters 36 is preferably of a diameter greater than the outer diameter of the housing 12 and well casing 14 thus facilitating the downward movement of the housing 12 and casing 14 simultaneously with the downward penetration of the earth by the bit assembly 24. Of course, the reamers 50 function in the usual or well known manner for facilitating the downward movement of the housing 12 in the well bore, particularly in instances wherein the well bore does not extend vertically downwardly from the surface 86 of the earth, but veers at an angle with respect thereto.

In the event the bit 34 or cutters 36 become worn, or require repair or replacing for any reason, the locking means 18 and 19 may be released by remote actuation thereof from the surface of the well bore in any suitable or well known manner, and motor 16, transmission 22, subs 28 and 30 and drill bit assembly 24 may be pulled upwardly through the housing 12 and casing 14 by the usual cables (not shown) normally used in well bore drilling operations, and the like. Of course, as hereinbefore set forth, the drill bit assembly 24 is of a retractable type wherein the cutters 37 may be moved radially inwardly to preclude interference therefrom as the drill assembly is elevated to the surface of the ground. The drill assembly 24 may be removed from its connection with the motor 16 and associated elements, and repaired or replaced, as required, whereupon the bit assembly 24 may again be lowered into the bore 40 until the bit 34 is in engagement with the bottom of the bore, and the casing setting and drilling operation may be continued. Of course, as the depth of the well bore 40 increases, it may be necessary to add additional sections of casing 14 at the surface of the well, as is well known in the well drilling industry.

When the well bore has been drilled to the desired completion depth therefor, the motor 16, transmission 22, subs 28 and 30 and drill bit assembly 24 may be removed from the well bore as hereinbefore set forth, and the casing inserting operation may be completed in the usual manner for securing the casing efficiently within the well bore. The well bore has thus been drilled and the casing inserted therein in a simultaneous operation, and the cased well bore is ready for the usual installation of the production tubing, downhole pumping means and the like normally required for the production of oil and/or gas therefrom.

Referring now to FIGS. 4 and 5, reference character 84 generally indicates a typical arrangement for the surface equipment which may be utilized with the well bore casing inserting and drilling operation of the invention. Of course, as hereinbefore set forth, the usual drill string (not shown) and all of the equipment associated therewith is eliminated by the present well bore casing inserting and drilling method and means. A simple casing dispenser rack means 86 may be provided in lieu of the usual pipe racks normally in use in the present day well bore drilling operations. A suitable blow out preventor 88 may be provided in the proximity of the top of the casing in addition to a lower blow out preventor 90. Of course, suitable upper slip means 92 and lower slip means 94 are provided for receiving the casing 14 therethrough and supporting the casing in the usual or well known manner. A power swivel 122 and a simple and slow rotary mechanism or rotary drive means 124 may be used for transmitting rotation to the well casing 14.

A suitable winch means 96 may be provided at the surface of the well bore, and a bottom hole assembly retrieval line 98 may extend from the winch 96 over a pulley means 100, and downwardly through the well casing 14 for connection with the downhole motor bit assembly in any well known manner for facilitating the raising and lowering thereof as hereinbefore set forth, In addition, it may be desirable to support the pulley means 100 from a frame means 102 having the support members 104 and 106 thereof operably connected with or supported by hydraulic ram assemblies 108 and 110, respectively. The hydraulic ram assemblies 108 and 110 are used to lower the casing 14 into the well bore.

The drilling mud circulation system used during the well bore casing inserting and drilling operation is substantially the same as in present day drilling operations, with the drilling mud being circulated downwardly through the central bore of the casing 14 and housing 12 and upwardly through the annulus 112 (FIG. 3) between the outer periphery of the well casing 14 and bore 40. The usual stand pipe mud line 114 may be provided in communication with the drilling mud source or supply (not shown) and directs the mud into the upper portion of the casing through the power swivel 122 in the usual manner. A suitable return mud line 116 is also provided in communication with the annulus 112 for receiving the returning or recirculated mud supply and returning the mud to a mud pit or the like (not shown) as is well known.

With regard to the pipe or casing rack 86, it may be desirable to provide a transfer arm means generally indicated at 118 in FIG. 5 for facilitating the transfer of individual sections of casing from the rack 86 to a position for connection with the uppermost casing section as the length of the casing string must be increased during the well drilling and casing setting operation.

By way of summary, the main components of the well bore casing and drilling system of the present invention include the casing string 14 having the control sub 10 secured to the lowermost end thereof, the control sub comprising a motor 16, transmission 22, shock sub 30 and retractable bit assembly 24. The casing string 14 is preferably a standard API casing modified to incorporate flat wire electric cables (not shown) covered by a protective coating, and operably connectable with the wire harness 52 of the control sub.

The motor 16 is a standard, off-the-shelf motor; the transmission 22 is preferably a speed reducing unit that is controlled from the surface 86 and permits a speed control similar to that in an automobile in the sense that gear ratios may be changed. This permits the selection of different speeds and torques during the drilling operation, depending upon the type of subsurface formation being penetrated by the bit assembly 24. The shock sub may be a standard, off-the-shelf item incorporated into the power system of the apparatus 10 to protect the motor and transmission from shock and vibration loads, and to permit a better overall system control. The retractable bit assembly 24 may also be an off-the-shelf item, which may be modified, if desired, to incorporate mud jet components (not shown) around the cutting

elements 36, for facilitating the efficient operation of the bit assembly 24.

As hereinbefore set forth, the flow of the mud stream is downwardly through the internal bore of the casing 14 and housing 12, and up the annulus 112 between the casing and well bore. The down hole equipment may be lowered into operating position by the wire line or cable 98 which incorporates an integral power cable for powering or supplying power to a downhole electric motor (not shown). Thus, all of the downhole equipment may be electrically powered and controlled. The novel assembly of elements permits the use of a downhole, closed loop, electrical system which will provide a real time communication in both the downward and upward directions in the bore hole, thus providing a more efficient determination of the downhole conditions than is presently available with the normal mud pulse systems.

From the foregoing, it will be apparent that the present invention provides a method and means of inserting well bore casing simultaneously with the drilling of the well bore, thus eliminating the necessity for a drill string and the associated equipment required for the use thereof. The novel casing inserting and well bore drilling method and means permits the completion of a well bore with considerably less expense and time involvment than with present day method and apparatus.

Whereas the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifications, apart from those shown or suggested herein may be made within the spirit and scope of this invention.

What is claimed is:

1. An apparatus for simultaneously inserting a well bore casing and drilling a well bore, comprising:
- a control sub means operably connected to the lowermost end of the well bore casing;
- motor means suspended within the control sub;
- a drilling bit means operably connected with the motor means;
- releasable locking means cooperating between the motor means and the control sub means for selective releasing of the motor means and drilling bit means through the well casing; and
- power means operably connecting the motor means with the surface of the well bore for controlled operation thereof.

2. An apparatus as set forth in claim 1 wherein said drilling bit means is a retractable drilling hole opening means.

3. An apparatus as set forth in claim 1 and including transmission means disposed within the control sub and operably connected with the motor means.

4. An apparatus as set forth in claim 1 wherein the motor means is a down hole motor.

5. An apparatus as set forth in claim 1 and including a reactive torque absorption means for transferring torque to the well casing.

6. An apparatus as set forth in claim 5 wherein said reactive torque absorption means includes a torque transfer means for transferring any reactive torque present in the apparatus during the drilling of the well bore to the casing.

7. A method of drilling a well bore and simultaneously inserting well casing therein, comprising:
- initially opening the earth to provide a bore therein;
- positioning a well bore casing in the opening in the earth, the casing having a control sub on the lower end thereof;
- positioning a motor driven drill bit means within the control sub;
- releasably locking the motor driven drill bit means to the control sub;
- selectably releasing the motor driven drill bit means from the control sub for retrieval of the motor driven drill bit means through the well bore casing;
- actuating the drill bit means for deepening the bore and simultaneously moving the housing and casing downwardly in the bore until the desired well bore competion depth is achieved.

8. A method of drilling a well bore and simultaneously inserting well casing therein as set forth in claim 7 including the step of circulating a drilling mud downwardly through the casing and housing to the bottom of the bore and recirculating the mud upwardly through the annulus between the well casing and the bore.

9. A method of drilling a well bore and simultaneously inserting well casing therein as set forth in claim 7 including the step of providing electrical communication between the surface of the well bore the bottom of the bore through a closed loop electrical system.

* * * * *

United States Patent [19]

Driver

[11] **4,227,584**

[45] **Oct. 14, 1980**

[54] **DOWNHOLE FLEXIBLE DRIVE SYSTEM**

[76] Inventor: **W. B. Driver**, 19 Sheridan Rd., Arnold, Md. 21012

[21] Appl. No.: **970,919**

[22] Filed: **Dec. 19, 1978**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 827,689, Aug. 25, 1977, Pat. No. 4,143,722.

[51] **Int. Cl.**[2] **E21B 7/04; E21B 1/06**

[52] **U.S. Cl.** **175/95**; 175/61; 175/104; 175/325

[58] **Field of Search** 175/61, 73, 74, 75, 175/76, 79, 81, 104, 107, 95, 320, 325

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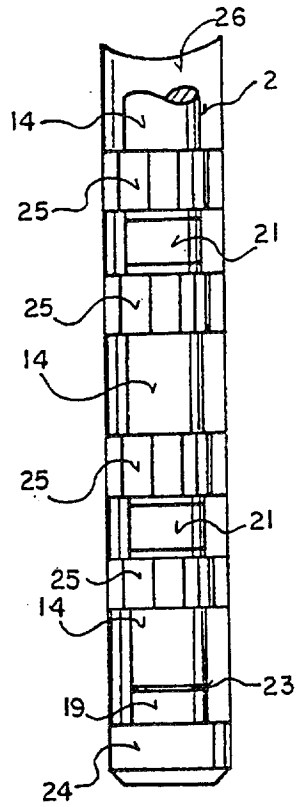
Primary Examiner—Ernest R. Purser
Assistant Examiner—Richard E. Favreau

[57] **ABSTRACT**

An improved downhole system for operating a drill bit around a small radius of bend in the directional drilling of curved holes from a vertical well hole in an oil or gas formation. The system is comprised of a plurality of double shaft downhole motors assembled in line and their shafts are connected by a flexible coupling. A flexible assembly encloses the area between the motors and provides a means for drilling fluids to be pumped through the system to a drill bit. The system can be constructed of either electrical motors or fluid turbine motors which can operate from drilling fluids pumped down a drill pipe string.

3 Claims, 7 Drawing Figures



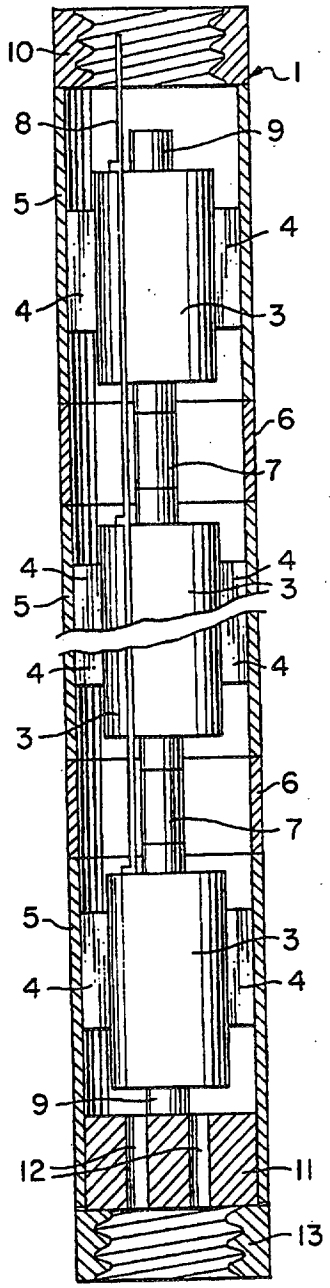

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FIG. 1

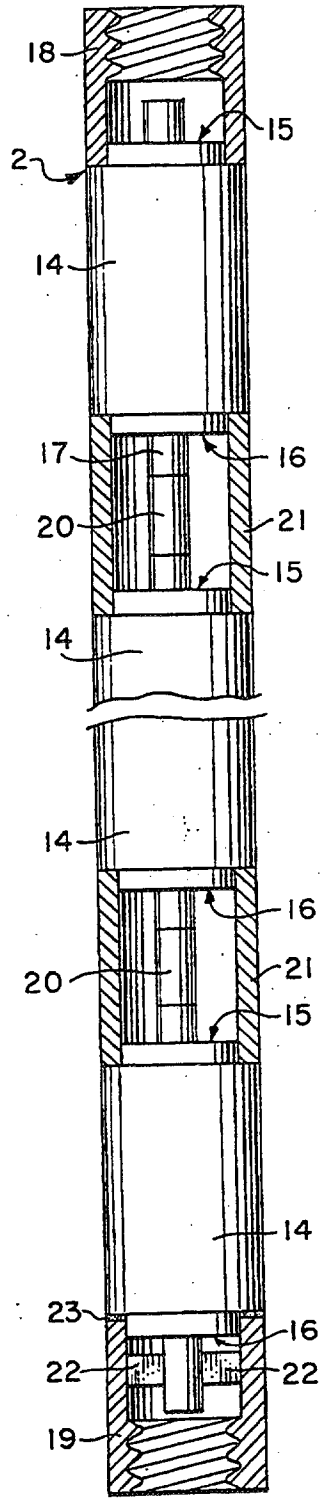
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FIG. 2

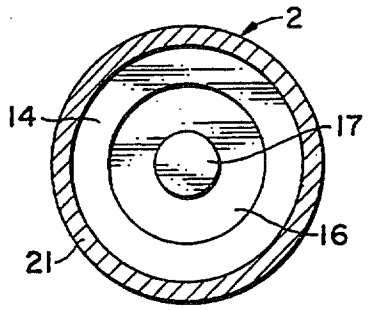


FIG. 3

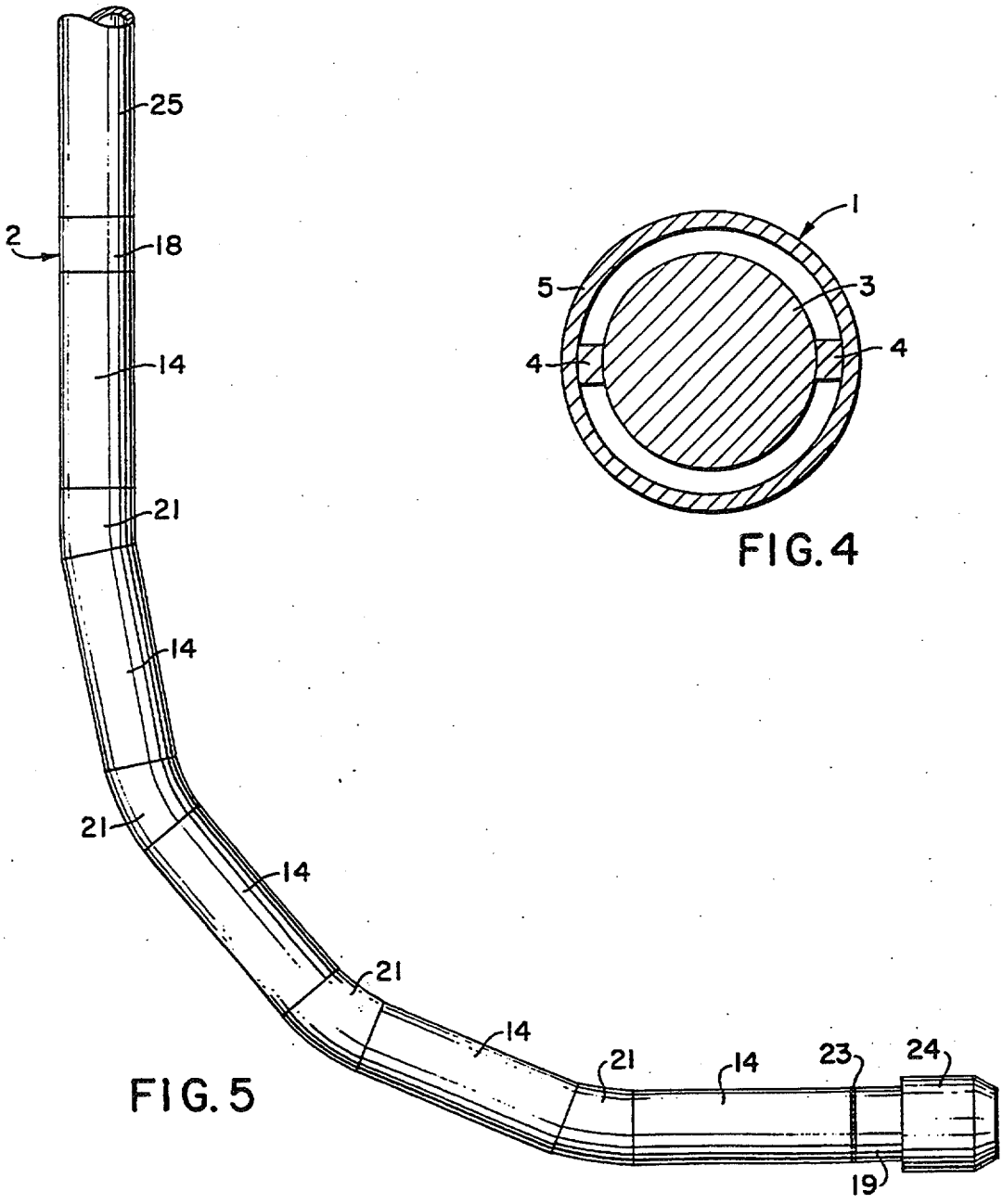


FIG. 5

FIG. 4

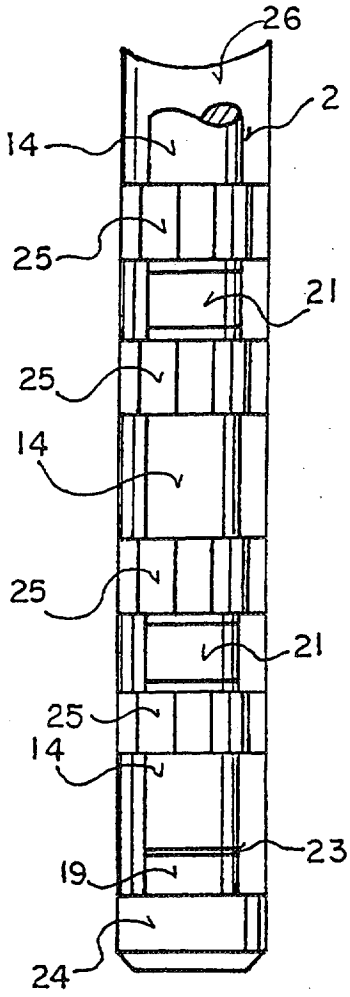
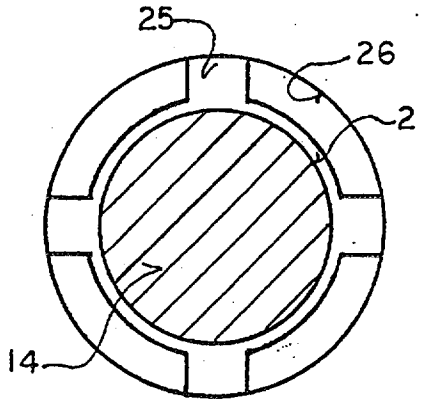


FIG. 6

FIG. 7



DOWNHOLE FLEXIBLE DRIVE SYSTEM

This application is a continuation-in-part of my application titled: Downhole Flexible Drive System, filing date 8/25/77, Serial No. 827,689 and now Patent No. 4,143,722 issued Mar. 13, 1979.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to downhole motors or other downhole driving means for drill bits.

2. Prior Art

Present directional drilling systems when used for drilling of horizontal holes or angle holes from a vertical well can only deviate from the vertical a few degrees per hundred feet and to drill a curved hole from the vertical to a horizontal position requires the radius of bend of the curved hole to be several hundred feet. This means that a considerable amount of formation in the immediate vicinity of the vertical well hole is not affected by directional drilling. The use of downhole motors has reduced the radius of bend of a curved hole from the vertical to the horizontal but they are not as effective as they should be because of their long length which restricts their uses around curved holes with small radius of bends. So a flexible drive system is needed that can operate a drill bit in the drilling of a curved hole with a small radius of bend.

Downhole motors have to be very long in length to develop the horse power required to drive a drill bit because they can only be a few inches in diameter. Also present downhole motors can only operate in curved holes with a radius of bend much greater than the length of the motor, whereas the downhole flexible drive system will be able to operate in curved holes with radius of bends equal to or less than the length of the downhole flexible drive system.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a downhole flexible drive system which cn be attached to the downhole end of a drill pipe string and operate a drill bit in the drilling of a curved hole with a small radius of bend.

It is an object of the invention to provide a downhole flexible drive system that uses a plurality of double shaft downhole motors assembled in line and their shafts connected by flexible couplings.

It is an object of the invention to provide a downhole flexible drive system with a flexible assembly that can support a plurality of downhole motors in line and provide a flexible connection between the downhole motors so drilling fluids can be pumped through the system.

It is an object of the invention to provide a downhole flexible drive system that is operated by a plurality of double shaft downhole electrical motors.

It is an object of the invention to provide a downhole flexible drive system that utilizes a plurality of double shaft downhole fluid motors which can be operated by drilling fluids.

It is an object of the invention to provide a downhole flexible drive system with a length long enough to provide the horse power to drive a drill bit but still be able to operate around a small radius of bend of a curved hole.

It is an object of the invention to provide a downhole flexible drive system that can operate around a radius of bend of a curved hole equal to or less than the length of the downhole flexible drive system.

It is an object of the invention to provide a downhole flexible drive system with a flexible assembly that attaches a plurality of downhole motors end to end in line forming an assembly of motors and provides a three hundred and sixty degree flexible connection between the downhole motors so the downhole flexible drive system can be rotated while operating around the radius of bend of a curved hole.

DESCRIPTION OF THE DRAWINGS

In the accompanying drawings;

FIG. 1 illustrates a downhole flexible drive system that utilizes electrical motors. Sections of the system are shown with partial cross-sections.

FIG. 2 illustrates a downhole flexible drive system that utilizes fluid motors. Sections of the system are shown with partial cross-sections.

FIG. 3 illustrates a horizontal cross-sectional of a downhole flexible drive system which uses fluid motors. The downhole end of a fluid motor is shown.

FIG. 4 illustrates a horizontal cross-section of a downhole flexible drive system which uses downhole electrical motors.

FIG. 5 illustrates how a downhole flexible drive system would be flexed when operating a drill bit around the radius of bend of a curved hole.

FIG. 6 illustrates how centralizers are used near the flexible connections between downhole motors so the system will not be flexible in different directions when drilling weight is applied to the system while operating in a vertical well hole.

FIG. 7 illustrates how the centralizers connect to the system and maintain contact with the wall of a well hole.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 a downhole flexible drive system 1 is shown and is powered by double shaft downhole electrical motors 3. The electrical motors 3 are assembled in line and the double shafts 9 of the electrical motors 3 are connected by flexible shafts 7 forming a flexible coupling between the electrical motors 3. Each electrical motor 3 housing is enclosed by a tube section 5. The electrical motors 3 are supported by a plurality of supports 4 so the axial center of the electrical motors 3 and the axial center of the tube sections 5 are the same. The supports 4 attach to the inside wall of the tube sections 5 and to the side of the electrical motors 3. The inside diameter of the tube sections 5 is larger than the outside diameter of the electrical motors 3 so drilling fluids can be pumped through the tube sections 5 and electrical power line 8 can be laid through the tube sections 5 to provide electrical power to the electrical motors 3. Flexible tubes 6 are attached to the respective ends of tube sections 5 between the electrical motors 3 forming a flexible connection between the electrical motors 3 to support the structure of the drive system 1 and provide a means for driling fluids to be pumped through the drive system 1. The flexible shafts 7 and flexible tubes 6 together form a flexible section in the drive system 1 so the drive system 1 can bend around a radius of bend of a curved hole and still provide power to a drill bit, see FIG. 5. The downhole end of the double shaft 9 of the electrical motor 3 at the downhole end of the assembled electrical motors 3 is attached to drive shaft 11. A plurality of holes 12 are constructed through the length of the drive shaft 11 so drilling fluids can be pumped through the drive shaft 11. The tube section 5 which encloses the housing of the electrical motor 3 whose

double shaft 9 is attached to drive shaft 11 is long enough in length to enclose most of the length of drive shaft 11. The downhole end of drive shaft 11 is attached to downhole tool joint 13 so the drive system 1 can be attached to a drill bit or other tools.

The diameter of drive shaft 11 is large enough to be in contact with the inside wall of the tube section 4 but still be able to turn and operate. Uphole tool joint 10 is attached to the uphole end of the tube section 5 at the uphole end of drive system 1 so drive system 1 can be attached to the downhole end of a drill pipe string similar to the illustration as shown in FIG. 5. In FIG. 2 downhole flexible drive system 2 is shown. The drive system 2 utilizes a plurality of double shaft downhole fluid motors 14 which are operated by drilling fluids pumped through the fluid motors 14. The fluid motors 14 are constructed so the double shafts 17 of fluid motors 14 extend outside the fluid motors 14 through the intake port 15 and output port 16 of each fluid motor 14. The plurality of fluid motors 14 are assembled in line with the downhole end of the double shafts 17 being connected by a flexible shaft 20 to the respective uphole end of the double shaft of the next fluid motor 14. The flexible shaft 20 provides a flexible coupling between each fluid motor 14. Flexible tubes 21 connect the respective uphole and downhole ends of the fluids motors together forming a flexible connection between fluid motors 14 that enclose the flexible shafts 20 and the respective output ports 16 and intake ports 15. The flexible tubes 21 support the structure of the drive system 2 and provides a way for drilling fluids to be pumped through the assembly of fluid motors 14. The uphole end of the fluid motor 14 at the uphole end of the assembled fluids motors is attached to an uphole tool joint 18 so the uphole end of the drive system 2 can be connected to the downhole end of drill pipe string 25 as shown in FIG. 5 and drilling fluids can be pumped through the drive system 2. FIG. 3 is a horizontal cross-section of a flexible tube 21 and drive system 2 showing the downhole end of a fluid motor 14 and how the flexible tube 21 encloses the output port 16. The downhole end portion of the double shaft 17 of the fluid motor 14 at the downhole end of the assembly of fluid motors is connected by connecting supports 22 to the inside wall of downhole tool joint 19 which is used to attach the drive system 2 to drill bit 24 as shown in FIG. 5.

Connecting supports 22 support downhole tool joint 19 so the axial center of downhole tool joint 19 and the axial center of the respective double shaft 17 will be the same. The inside diameter of downhole tool joint 19 is large enough to enclose the output port 16 of the respective fluid motor 14 but smaller than the overall diameter of the fluid motor 14. The uphole end of downhole tool joint 19 is interfaced with the downhole end of the respective fluid motor 14 through seal 23 which is in contact with the downhole end of the respective fluid motor 14 and the uphole end of downhole tool joint 19 and keeps drilling fluids from flowing between the downhole end of the respective fluid motor 14 and the uphole end of the downhole tool joint 19 when drilling fluids are being pumped through drive system 2 and downhole tool joint 19 is rotating.

The drive system 2 would have an advantage over drive system 1 in being more simple in construction and operation in shallow depths. For drilling at deep depths drive system 1 would have an advantage over drive system 2 because drive system 1 could provide more power and would not lose efficiency due to high pressure in the well hole.

For stability of downhole flexible drive system 1 and downhole flexible drive system 2, centralizers 25 will be used with flexible drive systems 1 and 2. See FIG. 6 and FIG. 7. As shown centralizers 25 are placed on each side of flexible tube 21 near flexible tube 21 so flexible downhole system 2 will not buckle in different directions when drilling weight is applied particularly as shown in a vertical well hole 26. Centralizers 25 would make contact with the wall of well hole 26 and hold flexible drive system 2 in the center of well hole 26. A centralizer 25 would be placed on the uphole side and downhole side of each flexible tube 21 near the respective flexible tube 21, except for the downhole side of the flexible tube 21 on the last downhole flexible tube 21 so the drill bit 24 can be more readily deflected by a curved hole or deflecting tool. Though not shown centralizers 25 will be used on the uphole and downhole side of flexible tube 6 near flexible tube 6 in flexible drive system 1 the same way they are used with flexible drive system 2.

The flexible shaft 7 and flexible tube 6 of flexible drive system 1 and the flexible shaft 20 and flexible tube 21 of flexible drive system 2 provides three hundred and sixty degrees flexible connections between their respective electrical motors 3 and fluid motors 14 so flexible drive system 1 and flexible drive system 2 can be rotated while operating around a curved hole to increase drilling capability and flexibility and be spin stabilized.

The flexible drive system 2 can also be operated to drill a curved hole from a vertical well hole by using a whipstock or other related deflecting tool common to the petroleum industry to deflect the flexible drive system 2 in the direction the curved hole is to be drilled. Drilling weight applied to flexible drive system 2 would force flexible drive system 2 against the deflecting tool since the deflecting tool would be at an angle to the vertical. As the curved hole is being drilled, drilling weight applied to flexible drive system 2 would force flexible drive system 2 against the outside radius of bend of the curved hole, so flexible drive system 2 would follow through a curved hole being drilled without flexing. For drilling curved holes with small radius of bends, the diameter of drill bit 24 would be considerably larger than the diameter of flexible drive system 2 so the fluid motors 14 can move through the curved hole. Also the drill pipe string 25 would rotate and spin stabilize flexible drive system 2 which would also keep flexible drive system 2 from flexing.

For drilling straight horizontal holes from a curved hole the diameter of drill bit 24 would only be slightly larger than the diameter of flexible drive system 2 and the horizontal hole being drilled would act as a casing and eliminate any serious flexing of flexible drive system 2. Also the drill pipe 25 would rotate and spin stabilize flexible drive system 2 to eliminate the flexing effects. Flexible drive system 1 would operate the same as flexible drill system 2.

I claim:

1. A downhole flexible drive system which attaches to the downhole end of a drill pipe string and operates a drill bit for the drilling of a curved hole in earth formations and drilling fluids can be pumped through the downhole flexible drive system and the downhole flexible drive system comprises: an assembly of motors comprising a plurality of double shaft downhole motors assembled in line a three hundred and sixty degree flexi-

ble connection connects the respective ends of said double shafts of said motors forming a flexible joint between said motors, a three hundred and sixty degree flexible assembly constructed to said motors and encloses said flexible connection forming a flex point in said drive system and supports the structure of said drive system and providing a means for drilling fluids to be pumped through said system, an uphole tool joint attached to the uphole end of said system so said drive system can be attached to said drill pipe string and receive drilling fluids from said drill pipe string, a downhole tool joint, a connecting mechanism for connecting said downhole tool joint to the downhole end of said drive system so said drive system can be attached to said drill bit and said motors can operate said drill bit, a plurality of centralizers, a centralizer attached around said system on the uphole side and downhole side of each said flexible connection near said flexible connection.

2. In claim 1 said assembly of motors being comprised of a plurality of double shaft downhole electrical motors, a flexible shaft connecting the respective downhole ends and uphole ends of said double shafts of said electrical motors providing said three hundred and sixty degree flexible connection between said electrical motors, said flexible assembly comprising a plurality of tube sections each said tube section enclosing a housing of said electrical motor, inside diameter of said tube sections being larger than the outside diameter of said electrical motors, a plurality of supports attached to the inside wall of each said tube sections connects to the respective electrical motor and supports said electrical motors so the axial center of said tube sections and said electrical motors will be the same, a plurality of flexible tubes, each said flexible tube connecting the respective ends of said tube sections between said electrical motors enclosing said flexible shaft and providing a means for drilling fluids to be pumped through said system and with said flexible shaft providing a three hundred and sixty degree flexible point in said system between said electrical motors, a drive shaft, uphole end of said drive shaft connected to the downhole end of said double shaft of the electrical motor located at the downhole end of said assembly of motors, said tube section which encloses said housing of said electrical motor located at the downhole end of said assembly of motors being long enough in length to enclose all but the downhole end portion of said drive shaft, diameter of said drive shaft being large enough to be in contact with the inside wall of said tube section and still turn, downhole end of said drive shaft connected to the uphole end of said downhole tool joint, a plurality of holes constructed through the length of said drive shaft so said drilling fluids can be pumped through said drive shaft, uphole end of said tube section enclosing said electrical motor located at the uphole end of said assembly of motors connected to the downhole end of said uphole tool joint, an electrical power line extending down through said uphole tool joint between said electrical motors and the inside wall of said tube sections attaching to each said electrical motor and providing electrical power to each said electrical motor.

3. In claim 1 said assembly of motors being comprised of a plurality of double shaft downhole fluid motors, input port of said fluid motors constructed on the uphole end of said fluid motors, output port of said fluid motors being constructed on the downhole end of said fluid motors, double shaft of said fluid motors constructed to extend through the input port and output port of said fluid motors, a plurality of flexible shafts, each flexible shaft connecting the respective downhole end and uphole end of said fluid motor assembled in line providing said three hundred and sixty degree flexible connection between said fluid motors, said flexible assembly comprising a plurality of flexible tubes, each flexible tube connecting the interfacing ends of respective fluid motors assembled in line and enclosing said flexible shaft and the respective output port and input port of said fluid motors so drilling fluid can be pumped through said system and with said flexible shaft provide a three hundred and sixty degree flexible point between said fluids motors so said system will be flexible between said fluid motors, downhole end of said uphole tool joint being attached to the uphole end of said fluid motor located at the uphole end of said assembly of motors, a plurality of supports attached to the inside wall of said downhole tool joint attaches to the downhole end portion of the double shaft of the fluid motor located on the downhole end of said assembly of motors so the axial center of said double shaft and said downhole tool joint will be the same, inside diameter of said downhole tool joint being less than the overall diameter of said fluid motors, a seal interfaces the uphole end of said downhole tool joint with the downhole end of said fluid motor located at the downhole end of said assembly of motors so said drilling fluids will not flow through said interface when said downhole tool joint is turning.

* * * * *

United States Patent [19]

Bechem et al.

[11] **Patent Number: 4,796,713**

[45] **Date of Patent: Jan. 10, 1989**

[54] **ACTIVATED EARTH DRILL**

[76] Inventors: **Ulrich W. Bechem; Klaus Bechem; Philip C. Bechem**, all of Tiefendorfer Str. 87, D-5800 Hagen, Fed. Rep. of Germany

[21] Appl. No.: **38,212**

[22] Filed: **Apr. 14, 1987**

[30] **Foreign Application Priority Data**

Apr. 15, 1986 [CH] Switzerland 1465/86

[51] **Int. Cl.**[4] **E21B 4/04**; E21B 4/16

[52] **U.S. Cl.** **175/96**; 175/101; 175/104; 175/106; 175/343; 175/365; 175/376

[58] **Field of Search** 175/101, 104, 106, 57, 175/55, 343, 365, 331, 344, 350, 351, 353, 354, 356, 376, 95, 96

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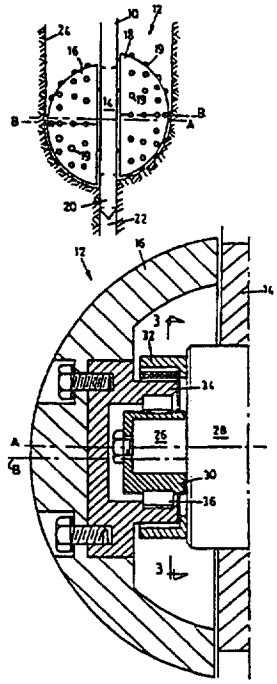
Primary Examiner—Hoang C. Dang

Attorney, Agent, or Firm—Barnes & Thornburg

[57] **ABSTRACT**

The invention relates to a drill bit which includes a drive arrangement having two opposed drive shafts which are transverse to the drill rod axis, mechanism for driving the shafts and a rock comminuting cutter which is eccentrically mounted on each of the shafts.

10 Claims, 2 Drawing Sheets



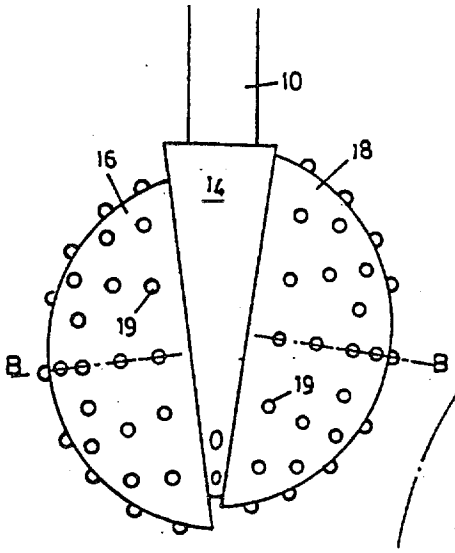


FIG_5

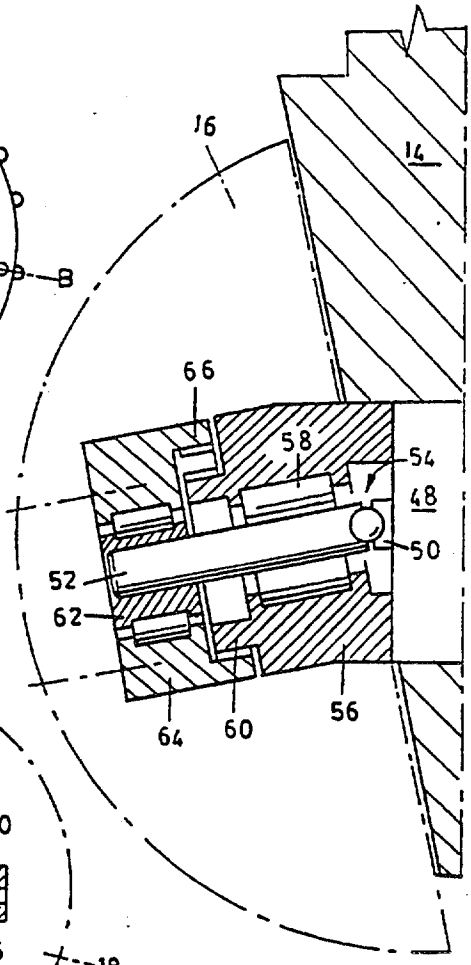


FIG_6

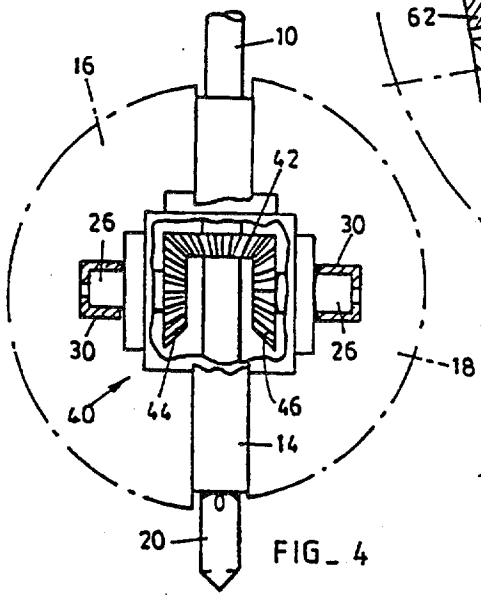


FIG_4

ACTIVATED EARTH DRILL

FIELD OF THE INVENTION

This invention relates to a method of earth drilling and to an activated earth or borehole drill for carrying out the method.

SUMMARY OF THE INVENTION

An activated earth drill according to the invention includes a drill rod, a drill bit which is attached to the rod with the drill bit including a drive arrangement having two opposed drive shafts which are substantially transverse to the axis of the drill rod, means to drive the shafts and a rock comminuting cutter which is eccentrically mounted on each of the drive shafts. Conveniently the rock cutters are of substantially the same mass and are eccentrically located on the drive shafts 180° out of phase with each other so that the drill bit is balanced in use.

In one form of the invention the drive shafts of the drive arrangement are in axial register with each other and normal to the axis of the drill rod.

In another form of the invention the axis of the drive shafts are each downwardly inclined relatively to the drill rod axis so that the rock cutters which are mounted on them converge towards each other and the forward end of the bit.

Further according to the invention the drive shaft means is a gearbox which is driven from surface through the drill rod.

Still further according to the invention the drive means is a motor which is located in the bit for driving the drive shafts and includes means which passes through the drill rod for energising the motor.

In a preferred form of the invention the bit is spheroidal in shape with each of the rock cutters being a substantially hemispherical body which carries on its outer surface hard metal inserts, picks, blades or like rock cutting or comminuting formations.

For flushing rock cuttings and earth from the hole being drilled by the bit, the drill rod carries a conduit through which flushing liquid may be fed to and from the drill bit in use.

A method of earth drilling according to the invention includes the steps of causing a drill bit on the end of a drill rod to be rotated about the axis of the drill rod and rotating an eccentric weight by means in the bit to impart a hammer action to the bit in its drilling direction.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is now described by way of example only with reference to the drawings in which:

FIG. 1 is an end elevation of the lower end of one embodiment of the drill of the invention in a hole;

FIG. 2 is a sectioned end elevation of one half of the drill bit of FIG. 1;

FIG. 3 is a side elevation of the bit drive arrangement shown sectioned on the line 3—3 in FIG. 2;

FIG. 4 is a partially schematic view of an alternative drive arrangement for the FIG. 1 drill bit;

FIG. 5 is an end elevation of a second embodiment of the drill bit of the invention; and

FIG. 6 is a partially schematic sectioned end elevation of one half of the bit of FIG. 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The drill of FIG. 1 is shown to include a drill rod 10 and an activated drill bit 12.

The drill bit 12 is spheroidal in shape and includes a disc 14 which is fixed at its upper end to the drill rod 10 and two substantially hemispherical rock comminuting cutters 16 and 18 which carry hard metal rock cutting inserts 19 on their domed outer surfaces. The underside of the disc 14 carries a guide rod 20 which extends forwardly from the bit 12 to be located, in use, in a predrilled pilot hole 22 for guiding the drilling direction of the bit 12.

The rock cutters 16 and 18 are rotated by a drive arrangement which is located in the bit. The drive arrangement includes a drive shaft 26 for each of the cutters. The drive shafts, in this embodiment of the invention, are in axial register on an axis A which is normal to the axis of the drill rod 10. The rock cutters are, however, eccentrically mounted on the drive shafts for rotation about the shafts. The eccentric axes B of the cutters are displaced by equal distances from and on opposite sides of the drive shaft axis A so that the bit is balanced as the cutters 16 and 18 are rotated.

FIGS. 2 and 3 illustrate a cutter drive arrangement in which the drive shafts 26 are driven by an electric motor 28 which is located in the bit by being secured to the bit disc 14. The motor is activated by an electric cable which passes from surface to the bit in the drill rod 10.

The drive arrangement includes an eccentric sleeve 30 which is fixed and keyed to the motor drive shaft 26. The key is shown only in FIG. 3. The drive arrangement for the cutter 18 is the same as that for the cutter 16 save that the sleeve 30 of the cutter 18 is fixed to its shaft 26 180° out of phase with that of the illustrated cutter 16. The drive arrangement further includes a ring gear 32 which is fixed to the casing of the motor 28 concentric with the axis of the drive shaft 26, a smaller diameter pinion gear 34 which is fixed on the rock cutter 16 and rotatable concentrically about the eccentric sleeve 30 and its eccentric axis B on roller bearings 36, only four of which are shown in the drawing. Because of the eccentricity of the sleeve 30 and the pinion gear 34 relatively to the axis of the shaft 26 and the ring gear 32 the pinion, by design, is only partially in mesh with the ring gear 32 as is more clearly seen in FIG. 3. It is self evident that the stroke or throw of the eccentric sleeve 30 must be co-ordinated with the difference in diameter of the ring and pinion gears to hold the gears, in their mesh zone, in positive contact as the shaft 26 is rotated.

As the shaft 26 is rotated in a clockwise direction by the motor 28 the mesh zone of the two gears is caused, by the radial pressure of the eccentric sleeve, to rotate with the shaft in a clockwise direction and the cutter 16 will merely wobble eccentrically about the drive axis A until a braking load is imposed on the cutter 16 by engaging the cutter inserts 19 with the ground to be drilled. With the cutters of the drill braked against the material to be drilled the cutters 16 and 18 are caused to rotate, as indicated by the arrows in FIG. 3, in the opposite direction to that of the shafts 26 by the reaction forces acting on the gear teeth in the meshed zone of the gears 32 and 34. Obviously the cutters 16 and 18 which are carried by the pinion gears 34 will rotate at a significantly lower speed than the drive shafts 26. The rota-

tional speed of the cutters may be varied by varying the ratios of the gears 32 and 34.

In use, for example using an eccentric throw of 3 mm, a shaft speed of 4,000 r.p.m. and suitably matched gear ratios the cutters will rotate at a cutting or milling speed of 200 r.p.m. with the two eccentrics providing 8000 hammer stroke per minute. The hammer and cutting action of the drill is further improved by rotating the drill rod 10 and so the bit 12 from the surface.

The hammer blows of the drill bit may be amplified by enlarging the eccentric throw of the drive arrangements or by applying timed hammer blow pulses to the drill rod 20.

The motor drive arrangement of FIGS. 2 and 3 may be replaced by an external drive such as that illustrated in FIG. 4. In the FIG. 4 arrangement the drive shafts 26 are driven through a gearbox 40 which is held in the bit by the disc 14. The gearbox includes three bevel gears 42, 44 and 46 the gear ratios of which are selected to provide the optimum rotational speed of the shafts 26. The gear 42 is connected to a surface driven shaft which is connected to it through the drill rod 10.

As is the case in all of the embodiments of this invention a suitable liquid would need to be pumped in use through the drill rod to the bit to flush earth and rock cuttings from the hole being drilled. In FIG. 1 to 4 embodiments the flushing liquid would pass from the drill rod or a separate liquid conduit in it through suitable bores (not shown) in the disc 14 to exit from ports at or near the base of the disc.

The FIG. 5 and 6 embodiment of the drill bit differs from that of FIG. 1 principally in that the axis of the rock cutter drive shafts are downwardly inclined relatively to the axis of the drill rod. The disc 14 is suitably wedged shaped so that the rock cutters 16 and 18 are held in convergence towards each other at the forward end of the bit.

The drive arrangement of the FIG. 5 embodiment of the drill is illustrated in FIG. 6 where it is shown to include an electric motor 48 having a primary drive shaft 50, a secondary drive shaft 52, a universal coupling 54 between the two shafts, a cage 56 which is fixed to the motor for rotatably holding the shaft 52 at its inclined angle on suitable bearings 58, and a pinion gear 60 which is fixed to the cage 56. An eccentric sleeve 62 is keyed to the shaft 52 and carries a housing 64 which is fixed to the rock cutter 16 and is rotatable through bearings on the sleeve 62. The housing 64 carries a ring gear 66 which, as with the previous embodiment, is in partial mesh with the fixed pinion gear 60.

In the FIG. 6 system, however, the eccentric gear is the ring gear 66 and the fixed gear is the pinion 60 which is concentric with the drive shaft 52 which means that the rock cutter will rotate in the same direction as the drive shaft 52. The drive arrangement of the cutter 18 of this embodiment has, unlike that of the FIG. 1 and 2 embodiment where both rock cutter drive arrangements cause the cutters to rotate in the same direction against the drive shaft direction, a drive arrangement which causes the rock cutter 18 to rotate in a direction opposite to that of the cutter 16. To achieve this counter rotation, the drive arrangement of the cutter 18 is the same, with the exception of the primary and secondary drive shafts and the cage 56, as that of FIGS. 2 and 3 where the ring gear is fixed to the cage 56 and the pinion is rotatable with the rock cutter 18 so that the cutter 18 will rotate in the opposite direction to its drive shaft 52 as opposed to the same direction of rotation of the cutter 16 on its shaft.

The opposite direction of rotation of the rock cutters 16 and 18 will cause the drill bit to rotate about the axis of the drill rod without any external force being applied to the drill rod 20 and cause, together with the fact that no gap exists between the convergent cutters on the drill cut line the bit to be self boring without the necessity of a pilot hole. In this embodiment optimum drilling action is obtained by braking the drill rod 10 against rotation while drilling progresses.

With both of the described embodiments of the drill of the invention suitable seals, not shown, would be located between the discs 14 and the cutters of the bits to prevent the ingress of the earth and stone cuttings into the cutters to damage the drive arrangements of the bits.

The invention is not limited to the precise details as herein described. For example to optimise the drill hammer and cutting speeds to suit materials of differing hardness the throw of the eccentrics and the ratios of the drive gears may be varied to obtain the required hammer impact force and cutting speed. In addition the rapidly rotating eccentrics and/or the relatively slowly rotating rock cutters may be provided with additional centrifugal or balance weights in order to increase the counter movement or hammer impact force of the bit.

We claim:

1. An activated earth drill assembly comprising, an elongated drill rod having an upper portion and a lower portion and defining a longitudinal axis, a drill bit attached to the lower portion of the drill rod, the drill bit including a drive arrangement having two opposed drive shafts which extend outwardly away from the drill rod, each shaft defining an axis of rotation, means for rotationally driving the drive shafts, about its axis of rotation and a rock comminuting cutter eccentrically mounted on each drive shaft for rotation therewith, the eccentric mounting providing for both rotational movement of each cutter about the respective axis of rotation and movement of the cutter upwardly and downwardly in a direction generally perpendicular to the axis of rotation as each cutter is rotated by the respective drive shaft.

2. The drill assembly of claim 1, wherein the two rock cutters have masses which are substantially equal and wherein the rock cutters are mounted on the respective drive shafts such that the eccentric upward and downward movement is 180° out of phase.

3. The drill assembly of claim 1, wherein the axis of rotation of the drive shafts are axially aligned and are perpendicular to the longitudinal axis of the drill rod.

4. The drill assembly of claim 1, wherein the rotation axis of each drive shaft is angled downwardly somewhat away from the upper portion of the drill rod.

5. The drill assembly of claim 1, wherein the means for rotationally driving the drive shafts includes, an elongated shaft which extends between the drive shafts and the upper portion of the drill rod, means for rotating the shaft from a position remote from the drive shafts, and a gear box attached to the drive shafts and to the elongated shaft for transmitting the rotation of the elongated shaft directly to the drive shafts.

6. The drill assembly of claim 1, wherein the means for rotationally driving the drive shafts includes, a drive motor disposed within the drill bit attached to each drive shaft, each drive motor configured to impart rotational movement to each associated drive shaft, and

means connecting to the drive motors to supply power to the drive motors.

7. The drill assembly of claim 1, wherein the means for rotationally driving the drive shafts includes means for reducing the rotational speed of each rock cutter relating to the rotational speed of the associated drive shaft.

8. The drill assembly of claim 1, wherein the drill bit is spherical in shape with each of the rock cutters being substantially hemispherical in shape and each having an outer surface which is formed to include outwardly extending protrusions.

9. The drill assembly of claim 6, wherein one drive motor is rotated is a first direction thereby rotating the one associated rock cutter in the first direction and the other drive motor is rotated in a second direction opposite the first direction thereby rotating the other associated rock cutter in the second direction.

10. The drill assembly of claim 1, wherein the drill rod is formed to include an inner conduit through which a drill flushing liquid may be forced.

* * * * *

United States Patent [19]

Williams et al.

[11] **Patent Number: 4,592,432**

[45] **Date of Patent: Jun. 3, 1986**

[54] **AUTOMATICALLY OPERATED BORING HEAD**

[76] Inventors: **Russell R. Williams, R.R. #1; Clyde W. Lestage, R.R. #1, Box 65A, both of Danville, Iowa 52623**

[21] Appl. No.: **740,434**

[22] Filed: **Jun. 3, 1985**

[51] **Int. Cl.**[4] **E21B 7/04; E21B 7/26**

[52] **U.S. Cl.** **175/26**; 175/19; 175/61; 175/62; 175/73; 175/104

[58] **Field of Search** 175/19, 26, 45, 62, 175/73, 74, 94, 104, 61

[56] **References Cited**

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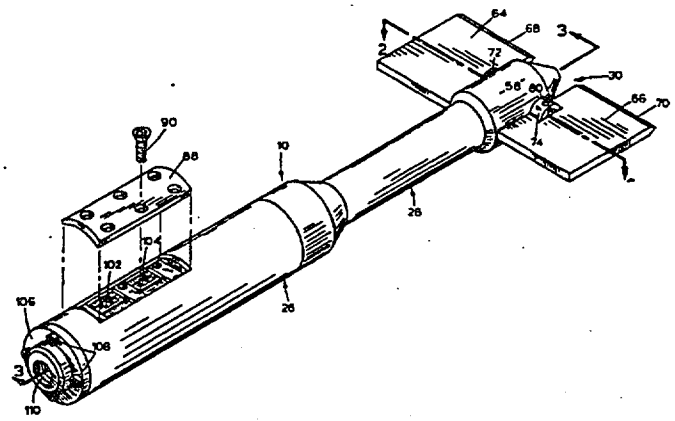
Primary Examiner—James A. Leppink
Assistant Examiner—Hoang C. Dang
Attorney, Agent, or Firm—Morton S. Adler

[57] **ABSTRACT**

A boring head for forming a horizontal hole for a pipe installation in the subsoil beneath a roadway and the like is provided with an electrical operable guide extending forwardly from its leading end that can be selectively elevated or lowered to change the plane of forward movement of the head through the subsoil so that the location of the hole at the end of the bore can be accurately predicted. The respective movements of the guide, upwardly and downwardly, are automatically effected in response to a battery operated electronic control system designed to sense and maintain a horizontal position and to convert any sensed deviations therefrom into appropriate signals for activating and deactivating movement of the guide. The boring head is provided with a motion detecting component operably connected to the guide so that in the absence of motion in the head, the guide is rendered immobile.

10 Claims, 6 Drawing Figures



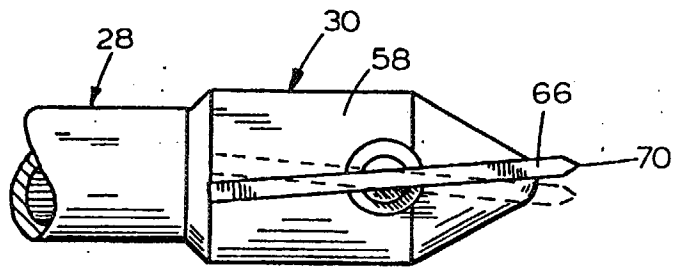


FIG. 5

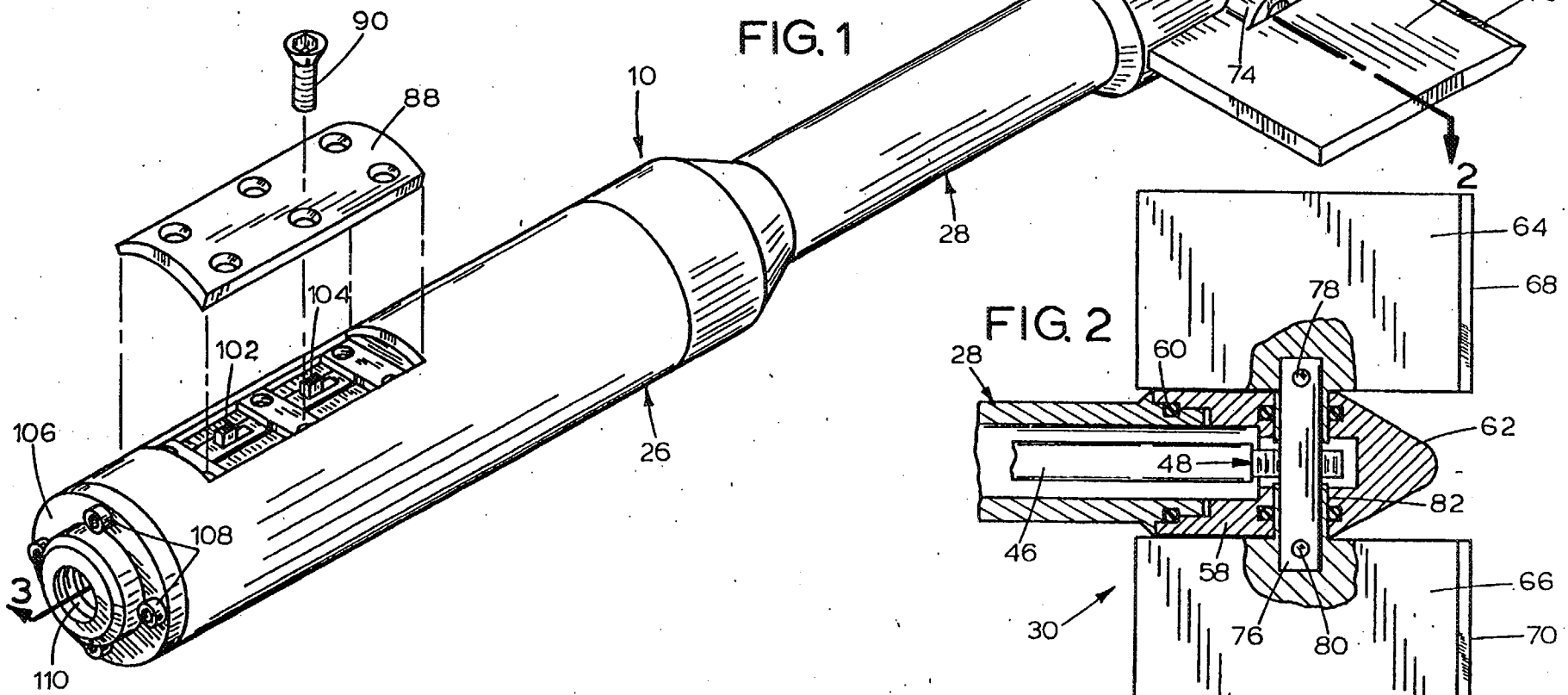


FIG. 1

FIG. 2

FIG. 3

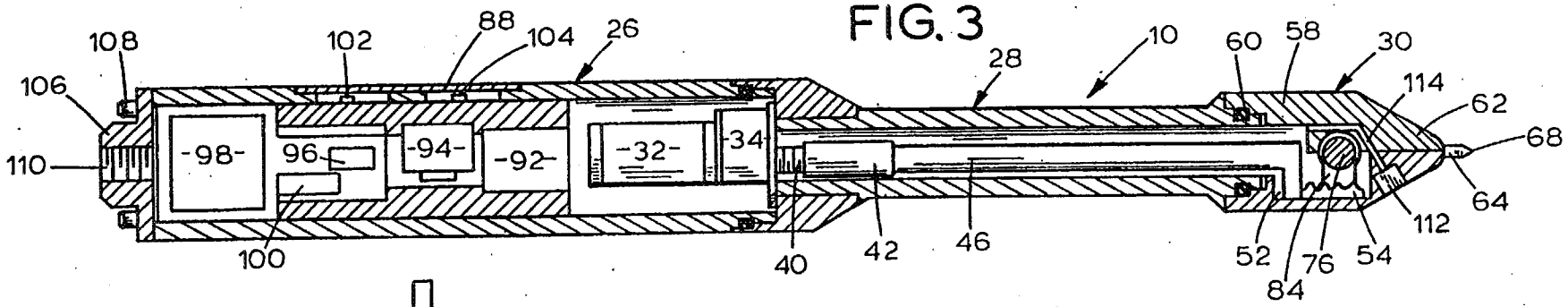


FIG. 4

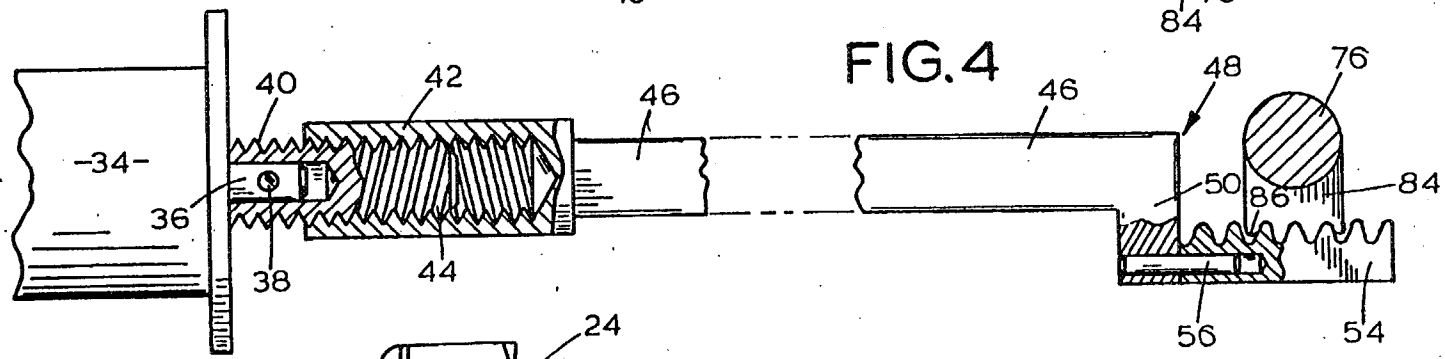
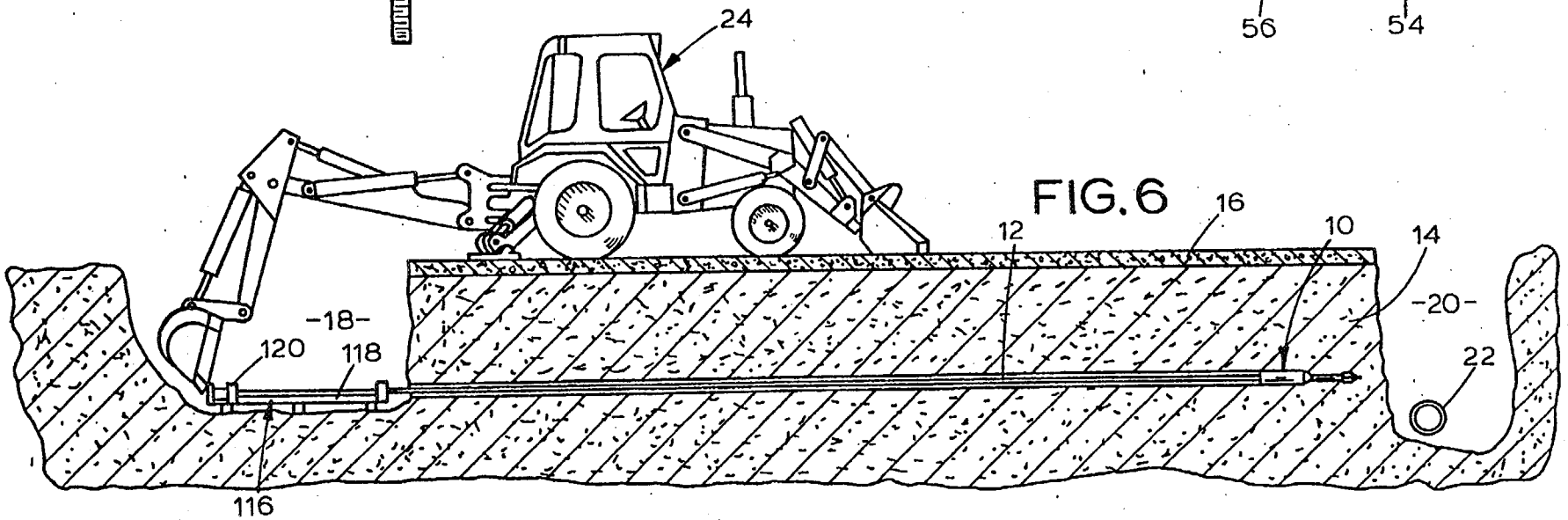


FIG. 6



AUTOMATICALLY OPERATED BORING HEAD

BACKGROUND OF THE INVENTION

This invention relates to improvements in boring apparatus for forming horizontal holes for pipe installation beneath roadways, sidewalks, driveways and the like and includes an improved automatically operated guiding system so that the location of the hole at the end of the bore can be accurately predicted.

In laying pipelines that traverse roadways and the like, it is a common practice to provide excavated ditches, openings or pits at opposite sides of the roadway and to tunnel between the same beneath the roadway to avoid the time and expense of digging up the roadway and replacing it as exemplified in U.S. Pat. Nos. 2,349,033, 3,132,701, 3,451,491 and 4,249,620.

In such procedure, a boring head is started in one ditch to exit in the other and there is an ever present problem of maintaining a proper plane of movement of the head through the subsoil so that it will exit at the desired location in the far ditch. Addressing this problem, U.S. Pat. No. 2,349,033 provides fixed radial fins on the trailing or force receiving end of the head calculated to maintain the boring head on a line in which it is originally started but does not provide for correction for deviation from such line. In U.S. Pat. No. 3,132,701, an hydraulic cylinder is used to raise or lower the trailing end of the head to change the pitch of the bore but this is a fixed correction which must be monitored and deliberately readjusted from time to time depending upon the actual plane of movement. U.S. Pat. No. 3,451,491 provides a guide frame which can be raised or lowered at the trailing end by a screw jack and thus has the same drawbacks as the device in U.S. Pat. No. 3,132,701. In U.S. Pat. No. 4,249,620, a small pilot hole is first formed which is later enlarged and for purpose of alignment, if it is determined that the pilot hole is not properly aligned, a new one is formed. It is apparent that these prior devices for establishing a desired path of movement of a horizontal boring head have the disadvantage of being fixed adjustments that are not responsive to any deviation from the line set and must be constantly monitored on a more or less trial and error basis for continual manual adjustment and resetting from time to time as the situation may require.

SUMMARY

One of the important objects of the present invention is to provide an improved boring head for tunnelling beneath a roadway or the like for a pipe installation that includes an electronically controlled automatically operated guide mechanism for maintaining the head on a predetermined plane of movement from its entry into the subsoil beneath one side of the roadway to its exit point at the other side thereof.

In accordance with the present invention, a vertically movable guide, preferably in the form of a pair of canard stabilizers or fins on the leading end of the head are elevated or lowered to change the plane of forward movement of the head through the use of a suitable gearing assembly connected to a small direct current electric motor with reversible high torque. A battery operated electronic control system for regulating movement of the guide or stablizers includes a gyroscope that senses and maintains true horizontal positioning and adjusts for deviations therefrom and which generates signals relative to such positioning that are transferred through an amplifier to a receiver-transmitter that in turn converts the sensed information in degrees up or down into digital signals for transmission to a relay that operates the electric motor for elevating or lowering of the guide or stabilizers according to preestablished data supplied to the processing apparatus. A pressure responsive accelerometer in the head for detecting motion is operatively connected to the electric motor so that said motor will function only when the head is in motion to avoid stalling. When pressure is removed by the motive power and/or the head is static, the accelerometer is deactivated.

The foregoing objects and such further objects as may appear herein, or be hereinafter pointed out, together with the advantages of this invention will be more fully discussed and developed in the more detailed description of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the new guided boring head in this invention with a cover plate over switch components shown in exploded position,

FIG. 2 is a view from the line 2—2 of FIG. 1 and partially in section showing the guide or stabilizers at the leading end of the boring head,

FIG. 3 is a longitudinal sectional view taken on the line 3—3 of FIG. 1,

FIG. 4 is an enlarged fragmentary fore-shortened view to show details of the threaded coupling and the gearing associated with the guide or stabilizers represented in FIG. 3,

FIG. 5 is a side elevational view of the leading end of the boring head showing the guide or stabilizers in an upwardly pitch in solid lines and in a downwardly pitch in broken lines, and

FIG. 6 is a side schematic view of a roadway with ditches at opposite sides and this boring head disposed for boring a hole beneath the roadway and propelled by a source of power represented by a backhoe.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, the new guided boring head assembly of this invention is designated generally by the numeral **10** as best seen in FIG. 1. The environment for which head assembly **10** is particularly designed is illustrated in FIG. 6 where assembly **10** is shown attached to pusher rods **12** for forming a horizontal hole through the subsoil **14** beneath a roadway **16** between ditches or pits, **18**, **20** at opposite sides of the roadway **16**. In laying pipelines that traverse roadways and the like, it is a common practice to form a hole between ditches **18**, **20** to avoid the time and expense of tearing up and replacing the roadway in order to provide a connection to a pipe **22** laid in one ditch such as **20**. Various sources of power have been used for pushing or driving a boring head through the subsoil such as bulldozers, requiring a larger ditch, hydraulic rams and as shown in FIG. 6, a backhoe **24** which we preferably use since such equipment is usually present at the work site and thus no special or additional equipment is necessary or has to be brought in.

Assembly **10** is designed to overcome the disadvantages of prior hole boring devices discussed above relative to maintaining an accurate plane of horizontal movement of the boring head and, as will be described in detail, is provided with an automatically operable

guiding mechanism for maintaining a predetermined plane of movement through the subsoil so that the location of the hole at the end of the bore can be accurately predicted and be positioned at a desired location.

Assembly 10 comprises generally a respective rear and forward housing section 26, 28 with section 28 being concentrically reduced relative to section 26 and a guidable boring head section 30 operably secured to section 28 as shown.

Within the forward portion of housing 26, there is suitably mounted a small twelve volt direct current 1/200 horsepower electric motor 32 with reversible high torque calibrated to rotate three degrees per second and operably connected through the gear reduction unit 34 to shaft 36 that extends into section 28 and is secured by pin 38 to the externally threaded collar 40. An internally threaded coupling 42 operably engages collar 40 and the externally threaded end 44 of rod 46 that is axially aligned with shaft 36 as best seen in FIG. 4. Rod 46 extends forwardly to a point 48 within head section 30 as best seen in FIG. 2 where leg portion 50 extends downwardly into chamber 52 of section 30 (FIG. 3) and is suitably secured to the horizontally disposed toothed rack or plate 54 as by a pin 56 (FIG. 4). Thus far described, it will be understood that as motor 32 rotates shaft 36, collar 40 and coupling 42 will move horizontally either rearwardly or forwardly depending upon the direction of rotation of shaft 36 and collar 40 and correspondingly move rod 46 and plate 54 either rearwardly or forwardly for purposes that will later be described in more detail.

The boring head section 30 is one of the important novel features of this invention and comprises a cylindrical body 58 suitably secured to the forward end of section 28 and includes O-ring seals 60 as seen in FIGS. 2,3 and is provided with a cone shaped leading end 62. At opposite sides of body 58 are like canard stabilizers or fins 64, 66 each having respective bevelled leading edges 68, 70. The canards 64, 66, on facing sides, are provided with integral annular sockets or wells 72, 74 that embrace opposite ends of a shaft 76 (FIG. 2) which extends through body 58 and are secured to said ends by the respective pins 78, 80. Shaft 76 is supported in suitable bearings 82 for limited movement about its longitudinal axis and is provided with a depending rocker member 84 having a lower arcuate toothed edge 86 for meshing engagement with plate 51 as best seen in FIG. 4. By this arrangement, it will be appreciated that as plate 54 is moved back and forth, shaft 76 will be rocked so that canards 64, 66 are tilted upwardly or downwardly as illustrated in FIG. 5 whereby an accurate horizontal plane of movement through the subsoil can be maintained for determining the location of the hole at the end of the bore.

An automatic control system for operating the canards 64, 66 is another important feature of this invention and this is accomplished by what we refer to as an electronic package located in housing 26 which comprises respective components that are all commercially available for inter-connection for the purposes intended and for which no invention, per se, is being claimed except as relates to the combination and arrangement as will appear.

With reference more particularly to FIG. 3, the interior of housing section 26 can be accessed by the removable cover 88 secured by screws 90 and there is mounted within housing section 26, a pitch gyroscope 92, an amplifier 91, a receiver-transmitter 96, a battery power pack having five and twelve volt connections 98, a relay 100 and two switches 102, 104. The rear end of section 26 is provided with a removable cap 106 secured by stud screws 108 for easy installation and replacement of the battery pack 98. Cap 106 also has coupling means 110 for the pusher rod 12 as will be later referred to.

The gyroscope 92 is the sensing element of this control system for sensing and regulating the horizontal position of assembly 10 and is available in a form programmed to provide information as to any change in horizontal position, up or down, through the amplifier 94 to the receiver-transmitter 96 which in turn is programmed to process such information in degrees up or down into digital signals to the relay 100. The motor 32 is connected through switch 102 to the battery pack 98 and the relay 100 with information from the receiver-transmitter 96 controls the up/down and on/off phases of motor 32 whereby rod 46 is moved forwardly with an up signal and rearwardly with a down signal as described and the movement of the canards 64, 66 are controlled accordingly. Such movement of the canards 64, 66 need not exceed five degrees. Switch 104 connects the components other than motor 32 to the battery pack 98 for five volt operation.

Because of the small capacity motor 32, movement of the canards 61, 66 in a static position could result in stalling and this is avoided by use of an accelerometer 112 in the boring head 30 (FIG. 3) from which a wire (not shown) extends through tubing 114 to the circuit of the motor 32. Accelerometer 112 is also a standard piece of equipment used because it is pressure responsive and when no pressure is present such as when assembly 10 is static, the circuit to motor 32 is open so motor 32 cannot operate and will not operate until assembly 10 is in motion to provide pressure on accelerometer 112 for closing the motor circuit. This is, of course, merely a safety factor and does not otherwise affect the operation of the canards. As indicated above, all of the electric and electronic components of this control system within housing 26 and including the accelerometer 112 are commercially available for the purposes described together with all necessary interconnecting wires and plugs.

With reference to FIG. 6, assembly 10 is shown for forming a horizontal hole beneath roadway 16 from ditch 18 to ditch 20. For this purpose, a suitable grade plate 116 is placed in ditch 18 at the desired grade level and is provided with a pair of spaced guide rails 118 for which only one is shown, having a longitudinal axis parallel to the intended axis of the hole. Assembly 10 is positioned on the grade plate 116 with the cone end 62 disposed for entering the subsoil 14. One end of a pusher rod section 12 is suitably secured to coupling 110 at the rear end of assembly 10 and the other end of such rod is suitably secured to a pusher head 120 designed for movement in engagement with rails 118. The pushing force against head 120 is provided, preferably, by the backhoe 24 in a well known manner and as head 120 and assembly 10 move through the subsoil for the length of each rod section 12, additional sections 12 can be added as required.

Once the hole has been completed and assembly 10 has entered ditch 20, assembly 10 can be removed from the pusher rod 12 whereby as rods 12 are being withdrawn, any pipe (not shown) to be placed in the hole just formed, can be coupled to rod 12 in any well known manner to be pulled through the hole. Accordingly, in view of the foregoing, it is thought a full understanding

of the construction and operation of this invention will be had and the advantages of the same will be appreciated.

We claim:

1. A boring head assembly for automatically maintaining a horizontal plane while forming a hole for a pipe installation through the subsoil beneath a roadway and the like, comprising:

an elongated cylindrical housing having a leading and trailing end adapted to be pushed or driven through the subsoil,

a boring head removably secured to said leading end,

a shaft disposed through said boring head transversely of the longitudinal axis of said housing,

a pair of canard stabilizers disposed respectively at opposite sides of said boring head and each secured to a respective end of said shaft,

rocker means in said boring head for effecting limited movement of said shaft in respective opposite directions about its longitudinal axis,

electrically operably means in said housing operatively connected to said rocker means whereby movement of said rocker means correspondingly moves said canard stabilizers to and away from a horizontal plane,

a battery operated switch controlled electronic circuit in said housing, comprising:

a relay operably connected to said electrically operable means,

means for sensing the horizontal position and any deviations therefrom of said housing and for transmitting signals relative thereto,

means for receiving and amplifying said signals, and

means for receiving said amplified signals and converting the same in degrees up and down into digital signals and transmitting the same to said relay for effecting selective upwardly and downwardly movement of said canard stabilizers.

2. An assembly as defined in claim 1 wherein said electrically operable means is a 1/200 horsepower direct current electric motor with reversible high torque.

3. An assembly as defined in claim 1 wherein said means for sensing the horizontal position of said housing is a gyroscope.

4. An assembly as defined in claim 1 including means on said boring head responsive to motion thereof and operably connected to said electrically operable means whereby in the absence of motion of said boring head, said canard stabilizers are rendered immobile.

5. An assembly as defined in claim 4 wherein said means responsive to motion is a pressure responsive accelerometer.

6. A boring head assembly for automatically maintaining a horizontal plane while forming a hole for a pipe installation through the subsoil beneath a roadway and the like, comprising:

an elongated cylindrical housing having a leading and trailing end and adapted to be pushed or driven through the subsoil,

a boring head removably secured to said leading end,

a shaft disposed through said boring head transversely of the longitudinal axis of said housing,

a pair of canard stabilizers disposed respectively at opposite sides of said boring head and each secured to a respective end of said shaft,

a direct current electric motor with reversible high torque-mounted in said housing,

a motor shaft on said electric motor extending towards said leading end,

an elongated rod disposed in said housing in axial alignment with said motor shaft,

one end of said rod being in spaced relationship to said motor shaft and the other end extending into said boring head,

a threaded coupling operably engaged with said motor shaft and said one end of said rod whereby rotation of said motor shaft in one direction effects the rearward movement of said rod and rotation of said motor shaft in the opposite direction effects the forward movement of said rod,

a rocker member assembly disposed in said boring head and operably connected to said rod for forward and rearward movement therewith and to said shaft in said boring head for effecting limited movement thereof in respective opposite directions about its longitudinal axis whereby movement of said rocker member in respective opposite directions acts to correspondingly move said canard stabilizers to and away from a horizontal plane,

a battery operated switch controlled electronic circuit in said housing comprising:

a relay operably connected to said electric motor,

means for sensing the horizontal position and any deviations therefrom of said housing and for transmitting signals relative thereto,

means for receiving and amplifying said signals, and

means for receiving said amplified signals and converting the same in degrees up and down into digital signals and transmitting the same to said relay for effecting operation of said electric motor to move said rod and rocker member in a direction dictated by said signals and correspondingly move said canard stabilizers.

7. An assembly as defined in claim 6 wherein said rocker member assembly includes:

a toothed rack disposed in said boring head and operably connected to said rod for forward and rearward movement therewith, and

said shaft in said boring head provided with a depending rocker member having a lower arcuate toothed end in meshing engagement with said toothed rack whereby movement of said toothed rack acts to rock said shaft in said boring head and correspondingly effect the movement of said canard stabilizers.

8. An assembly as defined in claim 6 wherein said electric motor is 1/200 horsepower.

9. An assembly as defined in claim 6 including means on said boring head responsive to motion thereof and operably connected to said electric motor whereby in the absence of motion of said boring head, said electric motor is rendered inoperative.

10. An assembly as defined in claim 9 wnerein said means responsive to motion is a pressure responsive accelerometer.

* * * * *

United States Patent [19]

Dismukes

[11] **4,436,168**

[45] **Mar. 13, 1984**

[54] **THRUST GENERATOR FOR BORING TOOLS**

[76] Inventor: **Newton B. Dismukes, 2952 Buttonwood Dr., Carrollton, Tex. 75006**

[21] Appl. No.: **339,001**

[22] Filed: **Jan. 12, 1982**

[51] **Int. Cl.**[3] **E21B 4/04**

[52] **U.S. Cl.** **175/94**; 175/107; 175/104; 175/61; 173/163

[58] **Field of Search** ..... 175/62, 65, 67, 94, 175/101, 102, 104, 105, 106, 107; 173/163, DIG. 1

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,251,916	8/1941	Cross	175/284
3,181,631	5/1965	Nielsen	175/104
3,389,758	6/1968	Bühler	175/104
3,873,156	3/1975	Jacoby	299/17
4,031,971	6/1977	Miller	175/67

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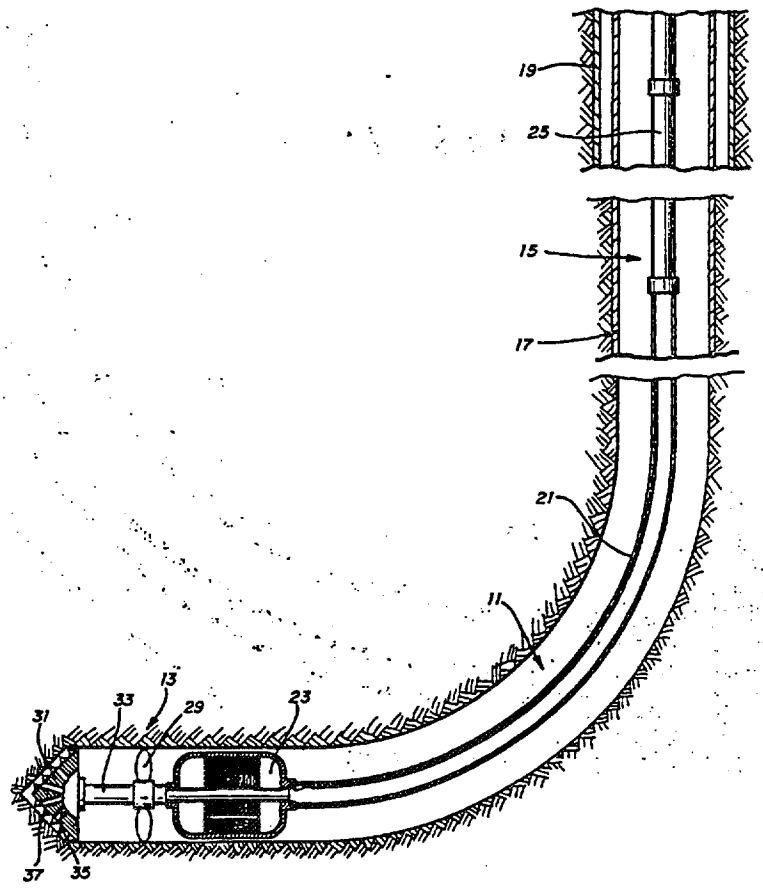
Assistant Examiner—William P. Neuder
Attorney, Agent, or Firm—Sidney A. Johnson

[57] **ABSTRACT**

The present invention provides an electrically powered system for advancing a rotary boring tool in situations where the inclination of the bore hole is such that the force of gravity does not provide sufficient forward thrust. One or more marine screw propellers are rotated by the motor which itself is restrained from rotation by being fixedly connected to a flexible, twist resistant conduit for conducting the drilling fluid and electric power from the surface. The system may also provide for different rotative speeds for propeller and bit and for counter-rotating propellers to minimize torque forces on the conduit.

15 Claims, 5 Drawing Figures



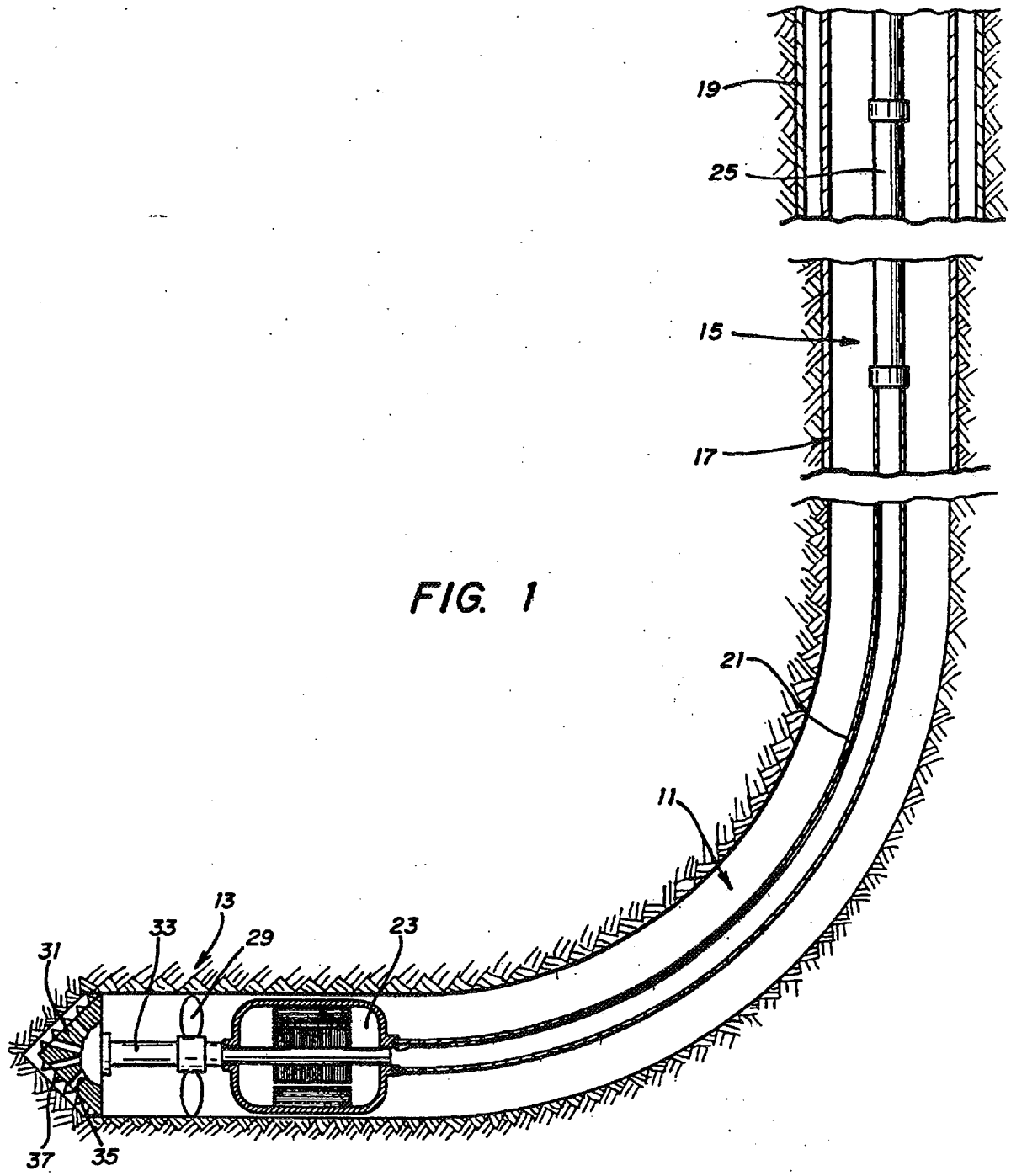


FIG. 1

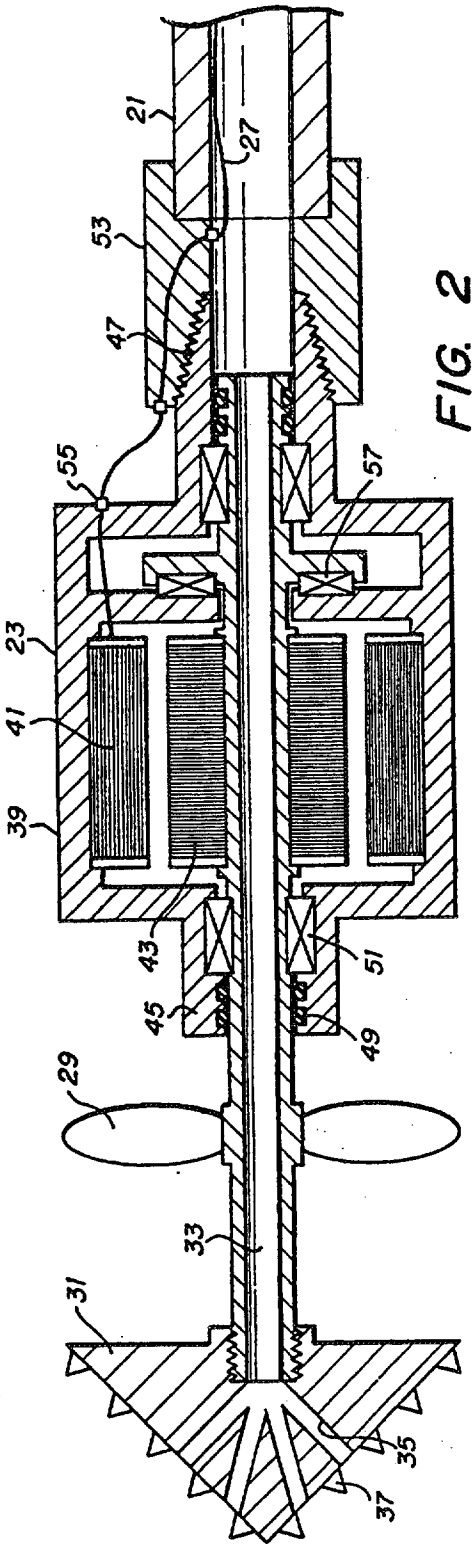

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FIG. 2

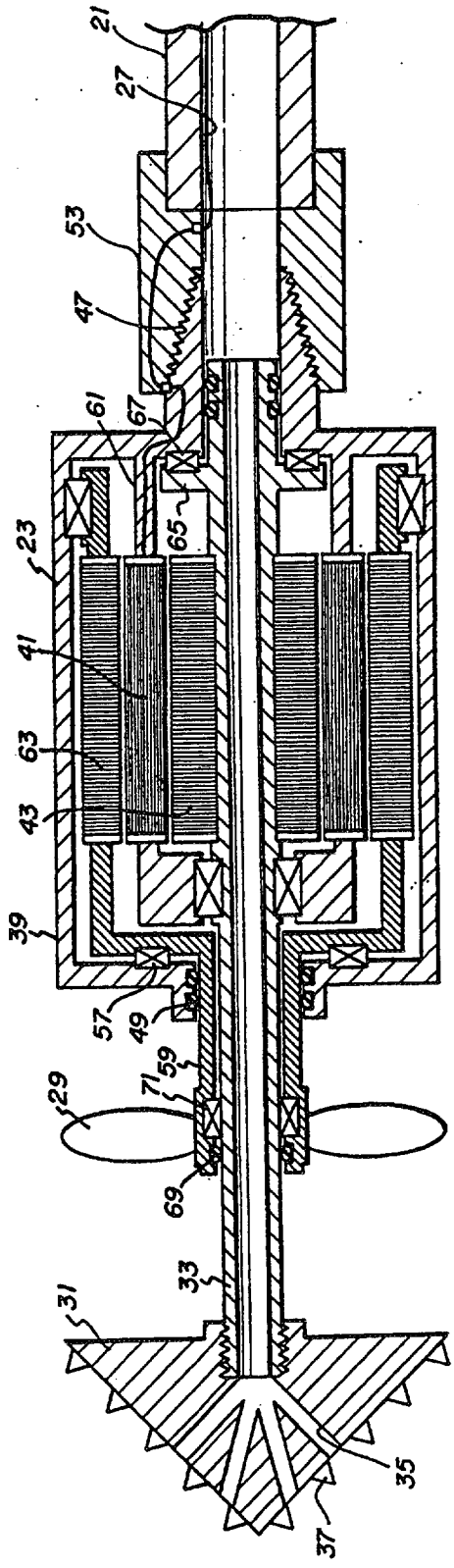
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FIG. 3

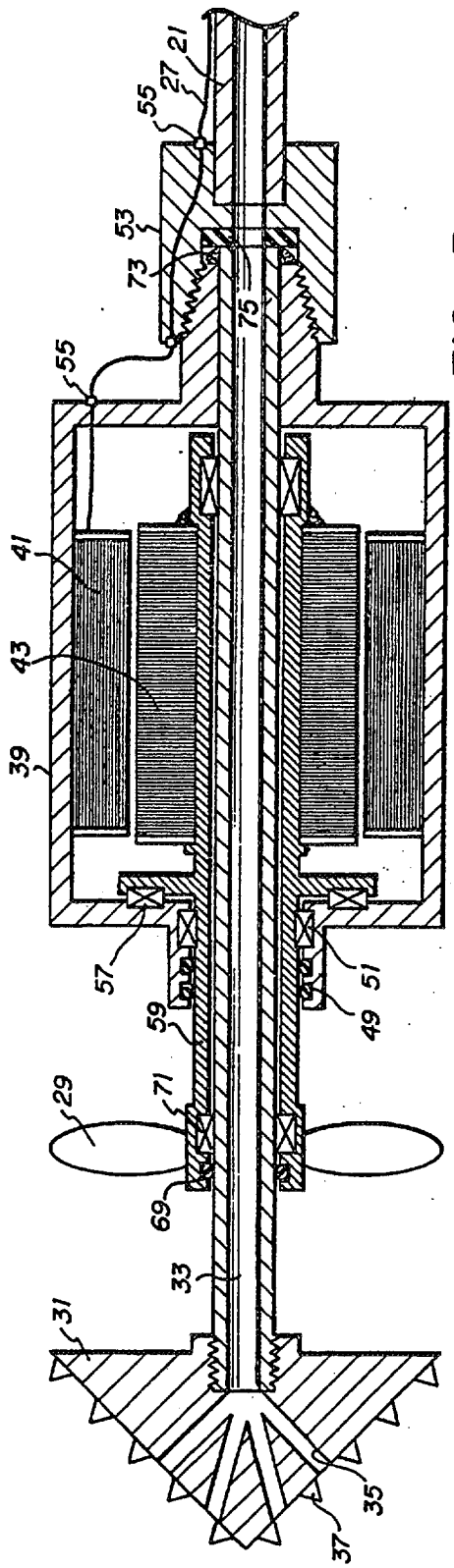
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FIG. 5

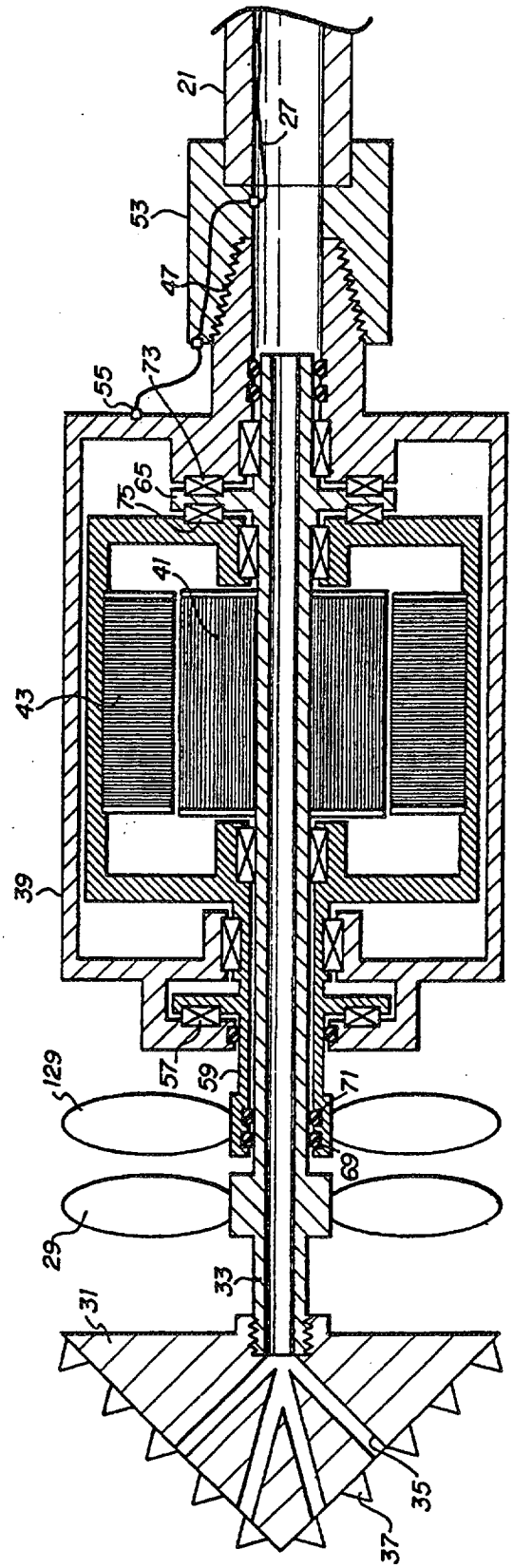
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FIG. 4

THRUST GENERATOR FOR BORING TOOLS

RELATED APPLICATIONS

This application is related to my application Ser. No. 207,798 filed Nov. 17, 1980 entitled "ROTARY EARTH BORING TOOL" which application is directed to the provision of a system utilizing power derived from the circulating drilling fluid for providing forward thrust for a boring tool.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention also relates to the provision of a system, preferably electrically powered, for providing forward thrust for a fluid immersed boring tool. More particularly, the invention provides the necessary thrust, a dynamic force, for the operation of a rotary boring tool in situations, such as the drilling of generally horizontal bore holes, where the force of gravity does not act to provide effective forward thrust. The invention is especially efficaceous with flexible drill pipe or conduit such as may be used in drilling bore holes having a small radius of curvature.

2. Description of the Prior Art

Hydraulic power has been used to rotate boring tools in drilling vertical and deviating bore holes for many years. Typical of such tools is the Dyna-Drill, offered by the Dyna-Drill Company, a division of Smith International, Inc. of Irvine, California. The power generated by the Dyna-Drill is used, and only used, to rotate the drilling bit. The system is used with conventional drill pipe and drill collars to provide the desired weight on bit or thrust.

A. McDougall, U.S. Pat. No. 469,841 discloses a system for dredging in which a boring tool is mounted on the same shaft as a propeller. Flow of liquid circulated for the dredging operation causes both to rotate. Thrust for the boring tool, however, is obtained by the weight of the system. The reverse circulation system disclosed actually tends to lift McDougall's boring tool rather than to advance it.

A water jet propelled nozzle head for cleaning pipes and conduits is disclosed by U.S. Pat. No. 2,710,980 to Pletcher in which jets direct water against vanes to rotate an outer section relative to an inner section which is fixedly secured to a hose. Neither the rotative nor the advancing force developed is adequate for subsurface earth boring.

More generally, the prior art is rich in the field of drilling directionally deviated wells using rotary bits turned either from the surface or by subsurface mud turbines.

Roy Cross in U.S. Pat. No. 2,251,916 discloses a system for solution mining of salts occurring in thin layers where forced circulation of the solvent is necessary to effectively contact and dissolve the material to be mined. Generally, he discloses the use of horizontally directed nozzles to direct a stream of fresh solvent, specifically water, against the face of the material to be mined, specifically potash salts. In one form of his invention, shown in his FIG. 5, Cross schematically shows an electrically driven device which purportedly will produce horizontal circulation and at the same time cut away residue salts not dissolved by the solvent. Rotation of an electric motor shaft is supposed to rotate a drill bit on one end thereof and a propeller generating forward thrust on the other end. Since the motor housing is freely suspended and has no resistance to twisting, as soon as any torque is imposed on the shaft by the propeller or the drill bit, the housing rather than the shaft would rotate. Thus, the device shown is inoperative.

SUMMARY OF THE INVENTION

The instant invention utilizes the principles of a marine screw propeller to derive thrust forces for the operation of an earth boring tool. The marine screw propeller is normally used to develop the thrust needed to move a vessel through water. According to "Principles of Naval Architecture", Vol. II, edited by Rossell and Chapman, and published by the Society of Naval Architects and Marine Engineering, "propellers derive the propulsive thrust by accelerating the fluid in which they work". The term "marine screw propeller" as used herein includes any rotating device which develops thrust relative to the axis of rotation by accelerating the fluid in which it works.

Thrust derived from a marine screw propeller in accordance with my invention provides the 'weight on bit' necessary for earth boring. This thrust may also provide the force required to advance a conduit, preferably neutrally buoyant in the drilling fluid, through which drilling fluids and energy needed for the boring operation are supplied.

In accordance with the present invention the shaft or shafts upon which the propeller or propellers are mounted are caused to rotate by an electric motor. The electric motor may be either an alternating or a direct current motor. Either the field or the armature or both of the motor may rotate and be fixed to a hollow rotating shaft. In the simplest form of my invention where a single shaft is employed and rotated by the motor, the drilling bit will be fixed to the forward end of the shaft. Where a plurality of shafts are employed, the bit will be fixed to the forward end of the innermost and longest shaft which usually, though not necessarily, will carry a marine screw propeller to generate additional thrust.

The shaft to which the bit is attached is hollow to allow the passage of drilling fluid therethrough to the bit for discharge therefrom. The drilling fluid serves to cool the bit and remove cuttings from the newly formed bore hole. The amount of drilling fluid circulated should be sufficient to discharge the functions of bit cooling and cutting removal but not so great as to significantly inhibit bit advance. However, the reaction force of the ejected fluid will be great enough to push the bit backward if rotation, and hence thrust, ceases. Where bit and propeller or propellers are mounted on a single shaft, the bit is self non-stalling, since as the bit tends to stall forward thrust rapidly approaches zero and the reactive forces of the discharged drilling fluid retract the bit. In cases where the thrust generating propeller is on a different shaft than the bit, the rotation of the bit may be monitored from the surface and, should the bit stall, the flow of power to the motor may be adjusted to reduce or terminate propeller rotation and to allow the reactive forces generated by the discharging drilling fluid to retract the bit.

Since the drilling system of my invention is primarily intended for use in drilling substantially horizontal holes, the conduit for conducting drilling fluid and electric power to the motor and bit combination is so constructed as to be flexible and capable of conforming to the curvatures of the well bore. On the other hand it

must have sufficient resistance to twisting so that it will resist and substantially prevent free rotation of the motor housing. The use of a neutrally buoyant drilling system is taught and claimed in my copending application Ser. No. 304,098, filed Sept. 21, 1981. The term "neutrally buoyant" as used herein means that the density of a mass immersed in the drilling fluid is from 70 to 130 percent of the density of the fluid.

In the simplest form of my invention the thrust generating propeller and the drilling bit are mounted on a single hollow shaft extending from the forward end of the motor housing and driven by the rotor, usually the armature, of the electric motor. The stator, usually the field, is fixed to the motor housing to which the flexible conduit is fixedly connected. The conduit conducts the drilling fluid to the motor housing from whence it flows through the hollow rotating shaft to the drilling bit and is discharged through suitable ports therein. Any specific type of motor may be employed, either alternating or direct current. A series field, direct current motor may be used, since there is no danger that the load would be removed from the motor under working conditions. A shunt field or a compound field direct current motor may also be used. Generally, a polyphase alternating current induction motor is preferred.

To increase the vailable thrust, particularly where drilling in hard formations, it will generally be desirable to have the propeller rotate at a greater speed than the bit or to have a plurality of thrust generating propellers. More than one propeller may, of course, be placed on a single shaft. Where increased thrust is to be obtained by having the propeller rotate at a higher speed than the rotation speed of the drill bit, coaxial shafts projecting from the forward end of the motor housing would be employed. The drill bit would be connected to the forward end of the longer shaft.

In situations where both shafts are driven by the electric motor separate rotors might be employed to drive each of the shafts. By appropriate design of the number of poles or commutator segments the ratio of the speeds of the two shafts may be selected. A propeller may be placed on the inner bit-carrying shaft so that much or all of the thrust required for the drilling action may be generated on the inner shaft, with the thrust generated by the outer-shaft propeller available for advancing the motor housing and conduit. Where a plurality of propellers are used on coaxial shafts, counter rotation of the propellers and hence of the shafts will generate thrust more effectively. The type of motor disclosed in U.S. Pat. No. 2,462,182 where both field and armature rotate in opposite directions with each driving counter rotating coaxial shafts may also be employed. Counter rotation of propellers and shafts in addition to effectively generating thrust will also impose a minimum net amount of rotative torque forces on the housing. This, in turn, minimizes the twist resistance that must be withstood by the conduit.

In lateral boring operations the power required may be divided into two parts: first, the power needed to rotate the drilling tool, and second, the power needed to generate the advancing force, or thrust, required to cause the system to move forward which, of course, includes the "weight on bit" necessary to achieve penetration. Studies of rotary drilling practice show that relatively little power is required at the bit to rotate it, usually in the range of from a few horsepower up to one hundred or more depending upon the diameter of the hole, the kind of bit, the type of formation being drilled, the weight on the bit or forward thrust and the speed of rotation. In normal drilling practice the weight on bit, which results from the mass of drill collars used, may vary from a thousand pounds up to fifty thousand pounds or more. To translate weight on bit, a static gravity force, into horsepower, marine practice shows that bollard pull of a tugboat amounts to 15 to 40 or more pounds per shaft horsepower. Using a figure of 30 pounds of thrust per horsepower, 300 horsepower would deliver a penetrating force of 9,000 pounds (weight on bit) on the bit. Rotative power required could be of the order of 10 horsepower. The ratio of dynamic, advancing thrust to rotative power in this example is 30. This ratio may vary as noted above. In consideration of the above factors it has been found that the ratio of dynamic thrust horsepower to rotative horsepower may vary from as low as one to 220. Additionally, since the dynamic thrust must not only provide the equivalent of weight on bit but also the force for advancing the drilling system through the horizontal portion of the well bore, the ratio is usually greater than one. Speeds of propeller rotation in excess of the speed of bit rotation are especially useful for attaining the higher ratios of dynamic thrust horsepower to rotative horsepower. The more easily penetrated, softer formations would utilize the lower ratios while the harder formations would require the higher ratios.

It is desirable and generally feasible to utilize gravity forces to furnish at least some portion of the thrust required to advance the conduit, the motor and to provide weight on bit. Each thousand pounds of gravity force from the weight of drill pipe and any drill collars which can be transmitted to the system in the horizontal portion of the well bore would save from about 25 to 70 shaft horsepower. The amount of gravity thrust at the bit is limited, of course, by the resistance of the conduit to deformation in compression. The stiffness of the conduit and hence its ability to transmit forward thrust is governed by the flexibility required to enable it to pass through the minimum radius of curvature in the bore hole. The tubular conduit comprising short metallic pipe joints interconnected by unions capable of unidirectional misalignment described and claimed in my copending application Ser. No. 265,997, filed May 21, 1981, will traverse well bores having a radius of curvature as small as thirty feet and will have sufficient stiffness to transmit substantial advancing force to the system. Other flexible conduits with appropriate reinforcement will transmit useful advancing force, particularly where the minimum radius of curvature to be encountered is one hundred feet or more.

In drilling ordinary earth formations using conventional drilling bit, the bit rotation speed is preferably of the order of from 40 to 400 r.p.m. To obtain optimum thrust is such situations, the propeller or propellers preferably should rotate at considerably higher speeds. In such situations a plurality of shafts are required with the outer shaft or shafts rotating at the higher speeds. Any marine screw propeller on the innermost shaft of course would rotate at the same speed as the bit. In the discussion of specific embodiments of my invention hereinafter, various systems for obtaining different speeds of shaft rotation are described in an illustrative, not a limiting, sense.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a form of electric motor driven propeller bit, partly in cross section and partly schematic, in

position for drilling a horizontal extension of a deviated well bore.

FIG. 2 is an enlarged view of the motor, propeller and drill bit of FIG. 1 showing details of the hollow motor shaft and the mounting of the bit and propeller thereon.

FIG. 3 shows an alternative form of motor, propeller and bit combination wherein two coaxial motor driven shafts are employed with the propeller mounted on the outer shaft.

FIG. 4 shows still another form of motor, propeller and bit combination employing two co-axial motor driven shafts wherein the motor field is affixed to one shaft, the armature to the other shaft and the two shafts rotate in opposite directions.

FIG. 5 shows a form of my invention wherein both the inner shaft and the housing are fixedly connected to a rotating flexible conduit carrying the drilling fluid and electric power and the rotor or the motor drives the outer shaft carrying the propeller in a direction counter to the direction of rotation of the conduit and inner shaft.

In the various figures of the drawings, like parts are designated by like reference characters.

DESCRIPTION OF PREFERRED EMBODIMENTS

One form of electrically powered thrust generator and boring tool is shown in FIG. 1. The tool is shown in position to drill a horizontal extension of well bore 11 in earth formation 13. As shown well bore 11 is deviated from vertical portion 15, which may be drilled in the conventional manner and, as shown, is provided with the usual casing 17, generally throughout its vertical depth, and an upper surface casing 19.

Flexible conduit 21 provides communication between the surface and the electric motor, generally indicated by the numeral 23, for the transmission of drilling fluid and electric power. Conduit 21 must have flexibility to conform to the curved well bore, must withstand the pressure differential between the drilling fluid within its and the returns on the outside, and must be resistant to twisting. It is also desirable that it be neutrally buoyant in the drilling fluid circulating in the well bore so that it is essentially weightless and its advance offers minimum impedance to the thrust generated by the motor-driven propeller as described hereinafter. A polyolefin such as polyethylene or other plastic material, such as epoxy resins or polyamides, reinforced with glass, steel or carbon fibers may be used. Flexible conduit 21 need not extend all the way to the surface but rather it may be connected to the lower end of conventional drill pipe 25 and lowered into the well bore using a conventional drilling rig, not shown. The drill pipe and the conduit are provided internally with electrical conductors 27, as shown in Fig. 2, for the transmission of electric power from the surface to motor 23. In operation motor 23 rotates propeller 29 and drill bit 31 which are mounted on the forward end of hollow shaft 33. Hollow motor shaft 33 transmits the drilling fluid from conduit 21 through motor 23 to bit 31 from whence it exists via ports 35. Bit 31 is shown as being provided with hardened abrasive inserts 37, such as tungsten carbide or polycrystaline diamonds to facilitate the drilling action, especially in hard earth formations.

FIG. 2 shows in more detail the arrangement of the components that comprise the drilling system of FIG. 1 of my invention. The electric motor comprises a housing 39 which encloses the field or stator 41 of the motor and within which the armature or rotor 43 is affixed to and rotates shaft 33 in operation. Annular extensions at the forward end 45 and rear end 47 of the housing serve as journal boxes for the hollow shaft 33. Rotary seals 49 and bearings 51 permit the shaft to rotate freely while preventing drilling fluid introduced through conduit 21 and surrounding the motor housing from entering the motor housing. Rear housing extension 47 is externally threaded to receive internally threaded female coupling 53 fixed to the end of conduit 21. Thus, conduit 21 will resist the tendency of the stator and motor housing to rotate in a direction counter to the rotation of shaft 33 as a torque load is imposed through the action of the drill bit and the propeller. Electrical conductor 27 which is carried by conduit 21 passes through coupling 53 and is connected to the motor by means of fluid-proof connectors 55. Thrust bearings 57 transmit the forward thrust of propeller 29 to housing 39 which, in turn, transmits a pulling force on conduit 21 via coupling 53.

In the form of my invention shown in FIGS. 1 and 2 the drilling bit and propeller rotate at the same speed. The forward thrust generated by rotation of the marine screw propeller provides weight on bit and via thrust bearing 57 provides the necessary forward thrust to advance the motor and conduit as drilling progresses.

In the form of my invention shown in FIG. 3 two concentric hollow shafts driven by electric motor 23 are employed. The drill bit 31 is fixed to the forward end of longer, inner shaft 33 and the marine screw propeller 29 fixed to outer shaft 59. The field or stator 41 of the motor instead of being fixed to the outer shell of the motor housing as in FIG. 2 is carried by an internal, annular ring 61, integral with the housing and so spaced as to receive an inner annular armature or rotor 43 and an outer annular armature or rotor 63. Rotor 43 is carried by shaft 33 and rotor 63 by outer shaft 59.

Forward thrust generated by rotation of propeller 29 is transmitted by outer shaft 59 via thrust bearing 57 to housing 39. In this case, however, the forward thrust must not only advance the housing and conduit as drilling progresses but also must be transmitted to the rotating inner shaft to provide the necessary weight on bit. To transmit this thrust, shaft 33 is provided with collar 65 and the requisite force applied via thrust bearings 67.

To prevent leakage of drilling fluid into the annulus between the two hollow shafts and into the motor, rotary seal 69 is provided. Bearings 71 near the forward end of the outer shafts serve to maintain proper clearance between the rotating shafts.

In the form of my invention shown in FIG. 3, the propeller may be rotated at a much higher rate of speed than the bit. Such relationship is frequently desirable to obtain increased thrust as discussed above.

Another form of my invention employing concentric hollow rotating shafts is shown in FIG. 4. In this embodiment the field 41 of the motor is fixed to one shaft and the armature 43 to the other. Both field and armature are free to rotate within the outer casing 39 of the motor housing. The field and the armature will rotate in opposite directions and hence inner shaft 33 and outer shaft 59 will likewise rotate in opposite directions. The absolute speed of rotation of field and armature will be dependent upon the load imposed upon shafts 33 and 59. Since it is usually desirable that more horsepower be utilized for generating thrust than for rotating the bit, it is desirable that each shaft carry a propeller. As shown propeller 29 is mounted on shaft 33 and propeller 129 on

shaft 59 with rotary seal 69 preventing leakage of drilling fluid into the annulus between the shafts and bearings 71 maintaining alignment. Since shaft 33 and shaft 59 will rotate in opposite directions and since it is desired that the rotation of each generate forward thrust, the pitch of the blades on the two propellers will necessarily be opposite in direction.

As mentioned previously one form of motor wherein both field and armature rotate in opposite directions is disclosed in U.S. Pat. No. 2,462,182 to D. A. Guerdan et al assigned to Westinghouse Electric Corporation.

Forward thrust generated by the rotation of propeller 129 is transmitted to housing 39 via thrust bearing 57 for advancing the housing and conduit and will be available to supplement the thrust generated by propeller 29 to provide additional weight on the bit 31. The relative amounts of forward thrust generated by propellers 29 and 129 will be dependent upon the absolute speed of rotation of each, which in turn will depend upon the load imposed restraining rotation of each shaft. Because of variations in the load imposed on the drill bit and turbulence of the fluids in which the propellers are operating, the relationship between the thrust generated by each will vary. In view of this, collar 65 on inner shaft 59 is suitably recessed to receive thrust bearings 73 for receiving thrust from housing 39 and thrust bearings 75 for transmitting thrust to outer shaft 59 and hence to housing 39.

Several advantages are obtained by using the embodiment of FIG. 4. Counter rotation of the propellers, particularly where closely spaced, results in more efficient generation of forward thrust. Also, importantly, counter rotation of the motor parts and shafts, which are linked to the motor housing only via rotating seals and bearings, results in the transmittal of minimal rotative torque to the housing and hence to the conduit. This, in turn, reduces the amount of twist resistance that must be built into the conduit.

A form of my invention wherein the electric motor is used only to provide the forward thrust for the system is disclosed in FIG. 5. In this embodiment the conduit 21 is rotated at the speed at which it is desired to rotate shaft 33 and bit 31. Referring back to FIG. 1, the drill pipe 25 may be rotated from the surface by the rotary table on a conventional drilling rig. This, in turn, will rotate conduit 21. In this form the conduit is fixedly connected not only to motor housing 39 but also to shaft 33 and bit 31 will rotate with the conduit. As shown, the end of shaft 33 extends slightly beyond the rear end of motor housing 39 and is welded 73 thereto. Rear housing extension is externally threaded to receive internally threaded female coupling 53 and fixed to the end of conduit 21. Sealing rubber ring 75 may be inserted between the mating faces of coupling 53 and the end of the shaft. Electrical conductor 27, shown as carried externally of conduit 21, is connected to connector 55 on the coupling and thence through the coupling to a connector 55 on the motor housing.

The field or stator 41 of the electric motor is fixed to the housing and rotates with it. Rotor armature 43 is fixed to the outer concentric shaft which carries propeller 29, rotation of which generates the necessary forward thrust to provide weight on bit and to advance the system. As in the embodiments shown in FIGS. 3 and 4, thrust bearings 57 transmit the forward thrust to the housing, inner shaft and bit and conduit. The embodiment of FIG. 5 is particularly suitable where the drilling characteristics are such that a high weight on bit is desired along with a relatively low speed of bit rotation.

Since many modifications and possible embodiments and uses may be made of the apparatus of this invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown is to be interpreted as illustrative not as limiting.

I claim:

1. A rotary drilling system for drilling a well bore in the earth comprising in combination:
   a. an electric motor comprising a housing and at least one rotor;
   b. a twist resistant flexible conduit for conducting drilling fluid and electric power to one end of said housing of said electric motor;
   c. at least one rotor driven hollow shaft projecting from the other end of said housing;
   d. hollow shaft driven bit means;
   e. marine screw propeller means mounted on said rotor driven shaft rotation of which generates forward thrust along the axis of said shaft;
   f. means for transmitting the forward thrust generated by said propeller to said bit means, said housing and said conduit; and
   g. coupling means connecting the end of said conduit and said motor housing, said coupling means transmitting torque from the motor housing to the conduit to resist the tendency of the motor housing to rotate in a direction counter to the rotation of said hollow shaft as torque is imposed to the housing through the action of the drill bit and the propeller.

2. The drilling system of claim 1 in which there is a single rotor driven hollow shaft projecting from said housing and in which the propeller means and the bit means are both mounted on said shaft.

3. The rotary drilling system of claim 1 in which there are two concentric rotor driven hollow shafts the inner of which extends beyond the outer hollow shaft and the bit means are mounted at the end of the inner hollow shaft and the propeller means are fixed to the outer hollow shaft.

4. The rotary drilling system of claim 1 in which there are two concentric hollow shafts projecting from the other end of the housing, the inner of which extends beyond the outer and the bit means are mounted on the end thereof, and the outer shaft is driven by the rotor and has propeller means fixed thereon.

5. A rotary drilling system for drilling a well bore in the earth comprising in combination:
   a. an electric motor comprising a housing, a stator affixed to said housing, and a rotor;
   b. rigid coupling means secured to one end of the housing;
   c. a twist resistant flexible conduit connected to the coupling means secured to one end of the housing to said electric motor for conducting drilling fluid and electric power thereto, said coupling means transmitting torque from the motor housing to the conduit to resist the tendency of the stator and motor housing to rotate relative to the conduit upon operation of said rotor;
   d. a hollow shaft projecting from the other end of said housing, said rotor being affixed to said hollow shaft;
   e. bit means affixed to the forward end of said hollow shaft;

f. marine screw propeller means mounted on said hollow shaft for generating forward thrust along the axis of said shaft; and

g. means for transmitting forward thrust from said shaft to said housing.

6. A rotary drilling system for drilling a well bore in the earth comprising in combination:

a. an electric motor comprising a housing, a stator affixed to said housing, and a rotor;

b. a twist resistant rotatable flexible conduit fixedly connected to one end of the housing of said electric motor for conducting drilling fluid and electric power thereto;

c. a pair of concentric hollow shafts projecting from the other end of said housing the inner of which projects beyond the outer shaft and drilling bit means affixed to the forward projecting end thereof;

d. means for connecting said rotor to said outer hollow shaft;

e. marine screw propeller means mounted on said outer hollow shaft for generating forward thrust along the axis of said shaft;

f. means for transmitting forward thrust from said outer shaft to said housing and said inner shaft; and

g. means for interconnecting the rear end of said inner shaft and said conduit for the passage of drilling fluid therethrough to said bit means.

7. A rotary drilling system for drilling a well bore in the earth comprising in combination:

a. a pair of concentric hollow shafts, the inner of which projects at one end beyond the outer and has drilling bit means affixed to the projecting end thereof;

b. a housing supporting said shafts in axial alignment and surrounding at least a portion thereof;

c. a twist resistant flexible conduit adapted to conduct drilling fluid and power fixedly connected to said housing and in fluid communication with the inner hollow shaft;

d. marine screw propeller means mounted on the outer hollow shaft in a manner such that rotation of said propeller means generates thrust in a direction toward the bit carrying end of the inner shaft;

e. means for transforming power carried by said conduit to a force causing said outer shaft to rotate; and

f. means for transmitting the thrust in said outer shaft generated by rotation of said propeller means to said housing, said inner shaft and said conduit.

8. The drilling system of claim 7 in which means are provided adjacent the extremities of the outer shaft for preventing the ingress of fluids into the annular space between the shafts.

9. A rotary drilling system for drilling a well bore in the earth comprising in combination:

a. a rotary boring tool affixed to the end of a hollow shaft;

b. an electric motor comprising a housing and a rotor;

c. a twist resistant flexible conduit fixedly connected to one end of the housing of said electric motor for conducting drilling fluid and electric power thereto;

d. marine screw propeller means for generating thrust connected to said rotor;

e. means for conducting drilling fluid from said conduit to said hollow shaft;

f. means for transmitting the forward thrust generated by said propeller means to said housing and said hollow shaft; and

g. coupling means connecting the end of said conduit and said motor housing, said coupling means transmitting reactive torque from the motor housing to the conduit to prevent relative rotation therebetween to resist the tendency of the motor housing to rotate in a direction counter to the rotation of said shaft when torque is imposed on the motor housing by the action of the rotary tool and the propeller.

10. A rotary drilling system for drilling a well bore in the earth comprising in combination:

a. inner and outer concentric hollow shafts the inner shaft projects at one end beyond the end of the outer shaft;

b. drilling bit means affixed to the projecting end of the inner shaft;

c. marine screw propeller means, rotation of which generates thrust along the axis of said shafts in a direction toward said drilling bit means, mounted on said outer shaft;

d. a housing supporting said shafts in axial alignment;

e. a twist resistant flexible conduit;

f. a rigid hollow coupling securing said housing relative to said conduit for transmitting torque between said housing and said conduit, said coupling being adapted to conduit drilling fluid and power to said housing and in fluid communication with the inner hollow shaft;

g. means for converting the power conducted by said conduit into a force causing rotation of said outer shaft and propeller means and rotation of said inner shaft and bit means; and

h. means for transmitting the thrust generated by said propeller means to said housing and said inner shaft.

11. The drilling system of claim 10 in which the means actuated by the power conducted by the conduit cause the outer shaft to rotate at a higher speed than the inner shaft.

12. A system for drilling a substantially horizontal well bore in the earth utilizing a rotating drilling bit and circulating drilling fluid for cooling said drilling bit and for returning earth cuttings comprising in combination:

a. an electric motor comprising a housing, a stator affixed to said housing, and a rotor;

b. a twist resistant flexible conduit substantially neutrally buoyant in said drilling fluid;

c. a hollow shaft extending through said housing and projecting from the other end thereof, said rotor being affixed to said hollow shaft;

d. said drilling bit affixed to the projecting end of said hollow shaft;

e. means for confining the flow of drilling fluid conducted by said conduit to the interior of said hollow shaft for discharge from said drilling bit;

f. marine screw propeller means mounted on said hollow shaft for generating forward thrust along the axis of said shaft;

g. means for transmitting said thrust from said shaft to said housing; and

h. hollow coupling means for conducting drilling fluid and power secured between the housing of said electric motor and said conduit, said coupling means limiting rotation of the housing of said elec-

tric motor relative to said conduit whereby torque is transferred between said motor and conduit.

13. A system for drilling a well bore in the earth comprising:

a. an electric motor comprising a rotor affixed to and adapted to rotate a shaft and a housing;

b. a single connection to said housing from the surface of the earth comprising a twist resistant flexible conduit connected to one end of the housing of said electric motor for conducting drilling fluid and electric power thereto;

c. a hollow shaft extending through said housing and projecting from the other end thereof, said hollow shaft having drilling bit means mounted on the projecting end thereof;

d. means for confining the flow of drilling fluid conducted by said conduit to the interior of said hollow shaft for discharge from said drilling bit;

e. marine screw propeller means mounted on said rotor driven shaft rotation of which generates thrust in the direction of said drilling bit; and

f. means for transmitting the forward thrust generated by rotation of said propeller to said bit means, said housing and said conduit, said conduit being adapted to limit rotation of said housing relative to the motor housing whereby torque is transmitted between said housing and said conduit.

14. A rotary drilling system for drilling a well bore in the earth comprising in combination:

a. an electric motor comprising a housing and at least one rotor;

b. a twist resistant flexible conduit fixedly connected to one end of the housing of said electric motor for conducting drilling fluid and electric power thereto;

c. inner and outer concentric rotor driven hollow shafts, the inner shaft extending beyond the outer shaft;

d. hollow shaft driven bit means mounted on the end of the inner hollow shaft;

e. marine screw propeller means mounted on said outer hollow rotor driven shaft, rotation of said propeller means generating forward thrust along the axis of said shaft; and

f. means for transmitting the forward thrust generated by said propeller means to said bit means, said housing and said conduit.

15. A rotary drilling system for drilling a well bore in the earth comprising in combination:

a. an electric motor comprising a housing and at least one rotor;

b. a twist resistant flexible conduit fixedly connected to one end of the housing of said electric motor for conducting drilling fluid and electric power thereto;

c. inner and outer concentric hollow shafts projecting from the other end of the housing, the inner shaft extending beyond the end of outer shaft, the outer shaft being driven by the rotor;

d. hollow shaft driven bit means mounted on the end of the outer shaft;

e. marine screw propeller means mounted on said outer rotor driven shaft, rotation of said propeller generating forward thrust along the axis of said shaft; and

f. means for transmitting the forward thrust generated by said propeller means to said bit means, said housing and said conduit.

* * * * *

United States Patent [19]

Guerber

[11] **4,185,703**

[45] **Jan. 29, 1980**

[54] **APPARATUS FOR PRODUCING DEEP BOREHOLES**

[75] Inventor: **Paul L. Guerber, Drancy, France**

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[21] Appl. No.: **908,969**

[22] Filed: **May 24, 1978**

Related U.S. Application Data

[62] Division of Ser. No. 749,833, Dec. 10, 1976, Pat. No. 4,116,285.

[30] **Foreign Application Priority Data**

Jun. 18, 1976 [FR] France 76 18585

[51] **Int. Cl.²** **C09K 7/00; E21C 7/06**

[52] **U.S. Cl.** **175/17;** 175/70; 175/72; 175/107; 175/104

[58] **Field of Search** 175/17, 91, 95, 104, 175/105, 106, 107, 334, 319, 11; 299/59, 57

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Assistant Examiner—Richard E. Favreau
Attorney, Agent, or Firm—Christel, Bean & Linihan

[57] **ABSTRACT**

This invention concerns the production of very deep boreholes. A rotary drilling tool is suspended at one end of a very long line of supporting elements such as a cable. During at least the entire duration of the drilling operation, the borehole is filled at least partly with at least one substance which remains in a liquid state and has a density greater than the mean density of the drilled ground strata. Thus any infiltrations in the borehole and the drilling debris move naturally upwards to the free surface of the liquid substance filling the borehole.

9 Claims, 11 Drawing Figures

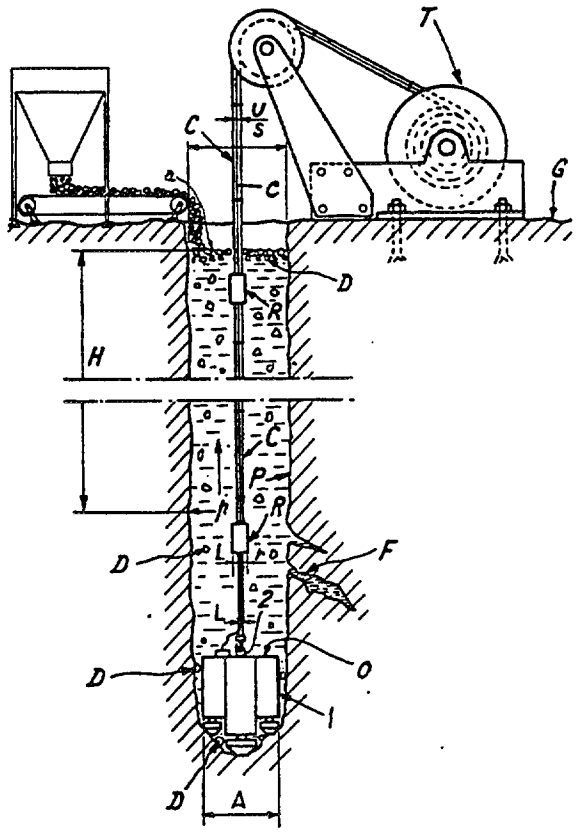


Fig. 1

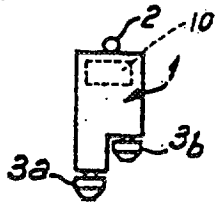


Fig. 3

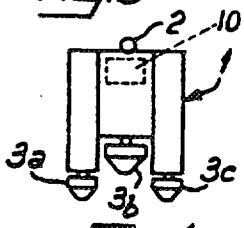


Fig. 6

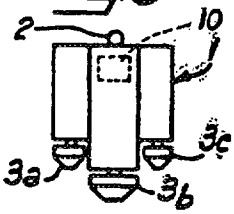


Fig. 2

Fig. 4

Fig. 7

Fig. 9

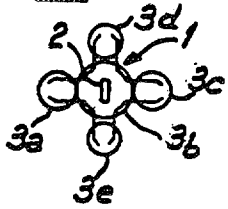


Fig. 5

Fig. 8

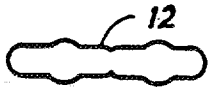


Fig. 10

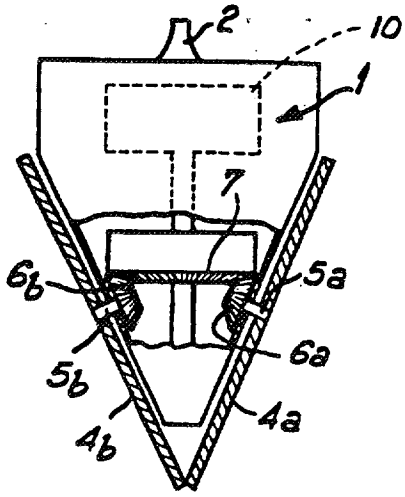
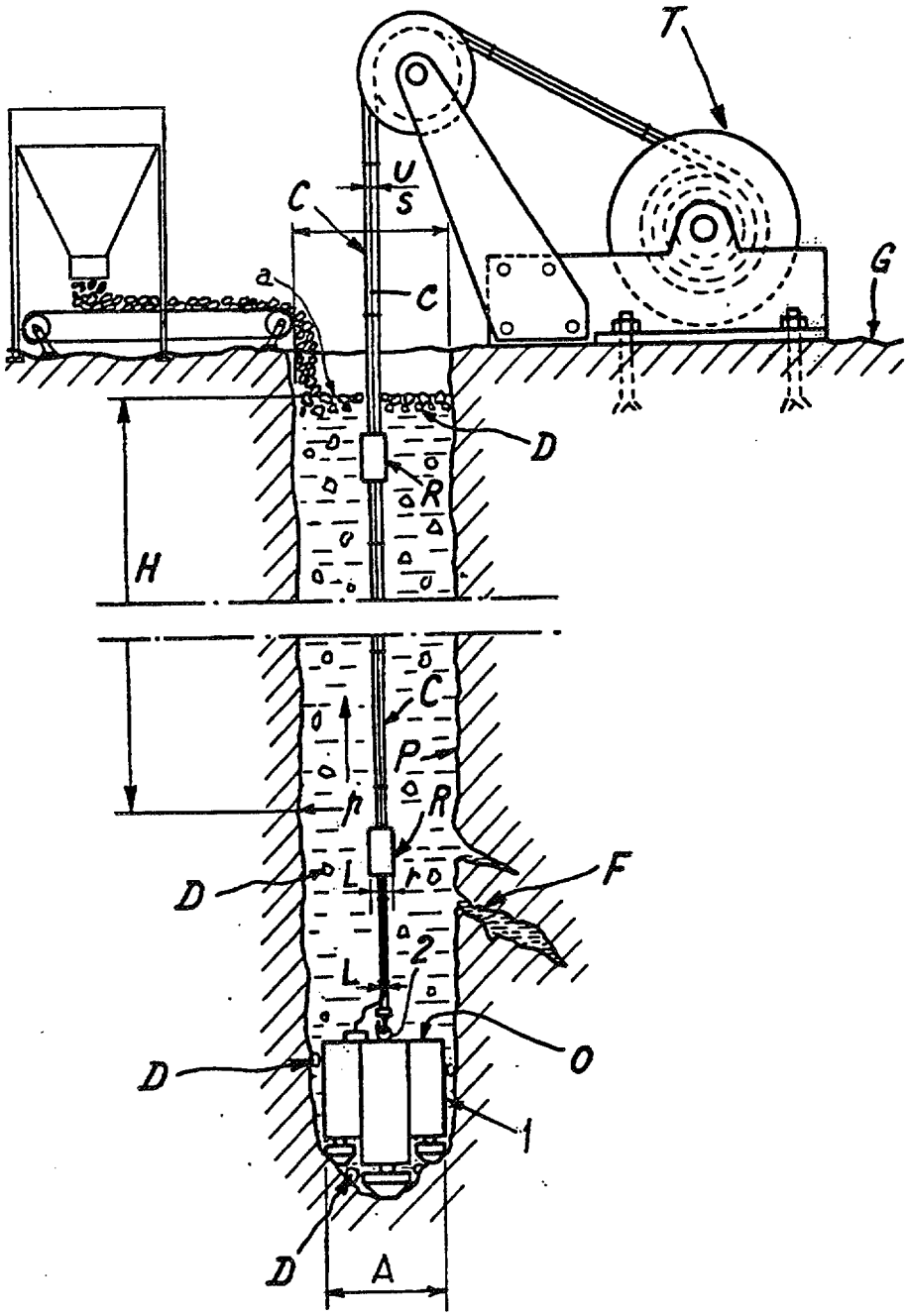


Fig. 11



APPARATUS FOR PRODUCING DEEP BOREHOLES

This is a division of application Ser. No. 749,833 filed Dec. 10, 1976, now U.S. Pat. No. 4,116,285 issued Sept. 26, 1978.

The present invention concerns a process of producing boreholes down to very great depths of several kilometers or tens of kilometers.

The ability to produce very deep boreholes can be usefully employed in very many advantageous fields: investigating and exploiting very deep strata, more particularly oil-bearing strata; geological and seismic studies, tapping geothermal energy etc.

Various processes are already known for carrying out deep drilling. There is the rotary drilling process, which makes it possible at the present time to achieve the greatest depths, of about 3500 m; this process uses a rotary tool, which is moved downwards in the borehole at the lower end of a line of tubes through which a strong current of water under pressure is injected into the said borehole; the debris is then discharged by water through the space between the walls of the borehole and the line of tubes. This known process, likewise the other known processes, in most cases require the borehole to be lined with casing tubes as it progresses, that is to say tube sections of an external diameter near to that of the borehole have to be put down in succession in order to prevent the walls from crumbling inwards and/or to prevent the borehole being invaded by infiltrations.

The well known rotary drilling process which has just been described and which is used in particular for oil well drilling operations, makes it possible to reach only limited depths, for the following reasons: first of all the line of tubes at the end of which the rotary drilling tool is moved downwards has to be given an internal cross-section sufficiently large to allow the passage of a relatively considerable flow of water to permit the entrainment of debris towards the surface; now, the weight of a line of tubes of this kind rapidly becomes prohibitive in the case of very deep boreholes. Furthermore the setting out of casing tubes in very deep boreholes is an extremely delicate operation and in any case is extremely expensive, more particularly since the tubes are usually not recoverable even when the borehole has ceased to be of any interest.

A first object of the invention is to make it possible to produce boreholes to depths which may be as much as several kilometers or even tens of kilometers, by a process which has neither the limitations nor the disadvantages of hitherto known drilling processes.

A second object of the invention is a process for drilling the ground to a very great depth, consisting in, as the drilling operations progresses downwards, filling the borehole at least partly, with at least one substance which at all points situated within said borehole, remains in the liquid state and has a density greater than the mean density of the drilled ground strata, so that debris and possible infiltrations in said borehole move naturally up to the free surface of the liquid filling said borehole.

Since debris moves up to the surface of the said liquid by natural flotation owing to the high density of the liquid material filling the borehole, the process according to the present invention obviates the necessity to have to inject considerable quantities of washing water into the bottom of the borehole, which makes it possible to replace the line of tubes carrying the rotary tool in the case of the known rotary drilling process mentioned hitherto, by a supporting element of much less linear weight, such as one or more cables or chains. Furthermore, from a certain depth at least, the column of liquid which fills the borehole produced by the process according to the present invention exerts on the walls of the said borehole a hydrostatic pressure which opposes the thrust of the surrounding strata and which in most cases obviates any need to use difficult and expensive tube casing operations.

In a preferred embodiment of the process according to the present invention, a borehole filling substance is used which is solid under normal pressure and temperature conditions, in other words surface conditions, and the said filling substance is kept in the liquid state at all points situated within the borehole by locally supplying suitable amounts of heat, which may advantageously be brought about by electrical resistances fixed at suitable points on the supporting elements of the rotary tool. This arrangement on the one hand offers the advantage of allowing a large range of filling substances to be used, under conditions which will be stated hereinafter. On the other hand, the use of a filling substance which is kept in the liquid state in the borehole only by artificial means offers the important advantage of providing for filling in and stopping the cracks in the walls of the boreholes, particularly so as to consolidate the wall regions which are fissured or cracked or even partly collapsed, without any need to resort to the use of casing tubes in these defective zones of the borehole. In fact the liquid substance filling the borehole enters any cracks which there may be in the borehole walls and, if these cracks are relatively deep, the filling material which enters them ceases to be subjected to the locally supplied heat, specially to the heating effect of the nearest electrical resistance, so that the said infiltrated filling substance returns again to solid state in the cracks which it therefore fills up, consolidating the walls of the borehole.

For drilling deep boreholes in the earth this preferred embodiment of the process according to the present invention has to take into account the laws of increasing earth temperature and increasing pressure as the depth of the borehole increases; in fact it is known that the underground strata of the earth exhibit a fairly rapid heat gradient, and as a result the filling material in a borehole produced by the process according to the present invention receives fron the drilled underground strata quantities of heat which become all the greater in proportion as the drilled strata are deeper. Furthermore, the melting temperature of the filling substance at any specific point in the borehole depends on the pressure prevailing at that point, and usually increases with the said pressure; now, this pressure and consequently the melting temperature also, increase with the depth of the point in question in the substance filling the borehole (if one disregarded the pressure of the ground, the purely hydrostatic pressure of the liquid substance filling the borehole would increase linearly with the depth and proportionally to the high density of the said filling substance; this density also itself depends on the said pressure and therefore tends to decrease when the depth and the temperature increase).

For all these reasons, process according to the present invention for drilling underground strata is preferably carried out in the following way: a plurality of

superjacent drilling sections are filled respectively with a same plurality of different filling substances each chosen so as to remain liquid at all points of the respective section of the borehole, taking into account the laws governing the increase in earth temperature and the increase in pressure with increasing depth in the borehole.

To accelerate the natural upward movement by flotation of the debris from the bottom of a very deep borehole different means may be used according to the present invention.

First of all it is possible to maintain the borehole filling substance, at least in the vicinity of drilling tools, at a temperature slightly below its boiling point so that when its boiling commences this will result in the production of bubbles of gas some of which may be absorbed by solid particles of debris so as to accelerate the upward movement of such particles, and which all tend to create in the liquid filling substance an upwardly flowing stream carrying along solid debris towards the free surface of the said filling substance.

According to a first variant, the liquid filling substance of the borehole is circulated during the drilling operation by pumping means which are set up at the ground surface and which comprise a suction duct immersed in the liquid filling the said borehole and a delivery duct, and by a conduit arranged approximately vertically in the said borehole and having an upper end connected to the said delivery duct and a lower end opening near the bottom of the said borehole. Since the upward movement of debris towards the surface of the liquid is brought about substantially by flotation, the pump may have a relatively low rate of through flow and the conduit arranged in the borehole may be given a relatively small internal diameter. Since it is also possible to use a flexible conduit, its weight and expense are very much less than those of a line of tubes such as is used in the known rotary drilling process mentioned hereinbefore.

In a second variant, a fluid of a density below that of the borehole filling liquid is injected, under pressure if necessary, into the bottom of the borehole during the drilling operation. This fluid could be a liquid of lower density than that of the filling liquid; but it is preferable to use a gas and more particularly compressed air, which, with a minimum rate of flow, promotes the upward movement of solid debris towards the surface in the same way as the bubbles of filling liquid did in the case of the embodiment of the present invention mentioned hereinbefore. Again in this second variant the compressed air can be brought to the bottom of the borehole by a flexible conduit of small cross-section and therefore of light weight and of an inexpensive type.

A further object of the invention is to provide an apparatus for drilling the earth to a very great depth, which comprises at least one a rotary drilling tool with an incorporated motor, means for moving the said tool downwards in the borehole, the said means comprising a line of supporting elements of great length having one end fixed to the said tool and a cross-section which increases from its end fixed to the said tool, electrical resistances fixed at specific points on the said line of supporting elements, at least one electrical able for supplying electrical power to the said resistances from the ground surface, and means for supplying the said motor from the ground surface.

By way of example, a description will now be given, and illustrated diagramatically in the accompanying drawings, of several embodiments of the present invention.

FIG. 1 and FIG. 2 show respectively a view in elevation and from below of a first embodiment of a rotary tool for carrying out the drilling process according to the present invention.

FIG. 3 and FIG. 4 show corresponding views of a second embodiment of a rotary tool.

FIG. 5 shows the transverse contour of a borehole drilled with the rotary tool illustrated in FIG. 3 and FIG. 4.

FIG. 6 and FIG. 7 show respectively a view in elevation and from below of a third embodiment of a rotary tool for carrying out the drilling process according to the present invention.

FIG. 8 shows the transverse contour of a borehole which may be drilled by using two juxtaposed tools such as that illustrated in FIG. 6 and FIG. 7.

FIG. 9 is a diagrammatic view showing a fourth embodiment of a rotary tool for carrying out the drilling process according to the present invention.

FIG. 10 is a view in elevation and in partial section of a fifth embodiment of a rotary tool.

FIG. 11 is a view in elevation of a preferred embodiment of an apparatus according to the present invention.

For drilling a borehole which may have a depth of 15,000 meters for example, by the process according to the present invention, it would be possible to use a rotary tool of a known type operated for example by a built-in electrical motor and comprising a single drilling element such as an abrasive disc or ring rotating about a vertical axis so as to drill a hole with a circular cross-section. However, a known rotary tool of this kind has the disadvantage of developing a reaction torque and compensation has to be provided for this in some way or other. In cases where a rotary tool of this kind is suspended at the lower end of a line of tubes the last tube of the line is sufficiently rigid to stand the reaction torque mentioned without being twisted thereby. But this would not be the case where the rotary tool in question is suspended at the end of a line of supporting elements such as cables, chains etc, which generally do not have sufficient transverse rigidity to stand the reaction torque but are twisted thereby. However, it is possible to improve these known rotary tools so as to permit use in carrying out the process according to the present invention, by adding means for standing or cancelling the reaction torque. A means of this kind may be for example a flywheel which the tool motor drives in rotational movement in a direction opposite to the rotation of the abrasive disc or ring.

The accompanying drawings show various embodiments of rotary tools which have been specially designed so as to obviate the disadvantages of the reaction torque and which consequently can be moved downwards into the borehole at the end of a line of supporting elements which have transverse flexibility such as cables, chains etc. The common characteristic of these embodiments of rotary tools for carrying out the drilling process according to the present invention consists in that they are arranged so as to drill a hole which has a non-circular cross-section.

The embodiment illustrated in FIG. 1 and in FIG. 2 comprises a casing 1 provided at its upper portion with an attachment element 2. This casing 1 includes in a manner known per se, which does not therefore have to be shown in detail, an electric motor 10 of a suitable

type and a reduction gear provided with two parallel output shafts whose ends project below the casing 1 at different levels, as FIG. 1 shows; there are fixed on the ends of these two output shafts of the reduction gear toothed rings 3*a* and 3*b* respectively which are thus driven in rotational movement in the same direction or in opposite directions about parallel vertical axes when the casing 1 is suspended by its attachment element 2 to the end of a line of supporting elements (not shown) such as a cable or a chain. The transverse contour of the borehole formed with a tool of this kind is substantially oval.

The embodiment illustrated in FIG. 3 and FIG. 4 differs from that described previously only in that the reduction gear arranged in the casing 1 comprises a third output shaft on which a third toothed ring 3*c* is secured at the same level as the ring 3*a;* the central ring 3*b* has preferably a diameter greater than that of the two side rings 3*a* and 3*c*. With this tool it is possible to produce a borehole whose transverse contour 11 is shown diagrammatically in FIG. 5.

The embodiment illustrated in FIG. 6 and FIG. 7 differs from that illustrated in FIG. 3 and FIG. 4 in that the central ring 3*b* is arranged at a level lower than that of the two side rings 3*a* and 3*c*. By arranging two drilling tools such as that illustrated in FIG. 6 and FIG. 7 closely side by side it is possible to produce for example a borehole with an elongated cross-section having the contour 12 shown in FIG. 8.

The plan view shown in FIG. 9 shows a tool whose reduction gear comprises five vertical output shafts arranged respectively at the center and at the corners of a square so as to be able to drive a central ring 3*b* and four side rings 3*a*,3*c*, 3*d* and 3*e* respectively.

In the embodiment illustrated in diagrammatic manner in FIG. 10, the toothed rings are replaced by two abrasive discs 4*a* and 4*b* whose shafts 5*a* and 5*b* extend by means of bearings not shown here through the lateral walls of the casing 1 in directions such that the two abrasive discs 4*a* and 4*b* form an acute angle and are almost in contact with one another at their respective lower edges; their shafts are driven in rotational movement by means of bevel gearwheels 6*a* and 6*b* and a toothed ring 7 fixed on the single output shaft of the reduction gear which is arranged along with the electric motor in the said casing 1. A variant of the tool illustrated in FIG. 10 comprises three abrasive discs.

By way of a variant, a toothed ring or a third abrasive disc can be arranged on the lower end of the casing 1 of the tool shown in FIG. 10.

In preceding embodiments the toothed rings or abrasive discs may be replaced also by bucket chains of known type.

To constitute a drilling apparatus according to the present invention, such as that which is illustrated in FIG. 11, a rotary tool O of one of the types previously considered and having a cross-section A is suspended by its attachment element 2 at the end of a supporting element C of great length, the cross-section L thereof increasing from its lower end which is fixed to the said tool O; to an upper end value U this supporting element C may be constituted for example by a cable 15,000 meters in length, whose cross-section near the point of attachment 2 of the tool O amounts to for example 1 cm^2, and 8,000 meters further on amounts to for example 12 cm^2 etc. Electrical resistances R of suitable values each having a cross sectional area r are fixed at predetermined points of the said cable C; the apparatus is also provided with electrical cables c for the supply of the aforesaid resistances R and the electric motor built into the drilling tool O. The dimensioning and the arrangement of the electrical resistances mentioned hereinbefore R will become clear from the following.

To excavate for example a borehole 15,000 meters in depth by the process according to the present invention, using the apparatus which has just been described, the following procedure is adopted for example:

First of all by conventional techniques a borehole of at the most 2,000 meters in depth is drilled, with a sufficient cross-section S to allow the downward movement therein of the drilling tool O by means of a winch T (FIG. 11). If, as is usually the case, the underground layers situated at a depth of more than 2,000 meters have a mean density which itself is lower than 3, the bottom of the borehole, which has been contacted by the drilling tool O moved downwards at the end of the supporting element C, is then filled with solid pieces of antimony trichloride by suitable means, for example that designated X in FIG. 11. The temperature which prevails at the bottom of the borehole being near 70° C., the lower electrical resistance R of the drilling apparatus is supplied with a sufficient electrical power to bring the antimony trichloride to its melting point, which is only 72° C. at atmospheric pressure. The electric motor of the drilling tool O is supplied, and its rings or abrasive discs then attack the bottom of the borehole, filled with melted antimony trichloride l. To carry on with the drilling it is advantageous then for at least the entire lower portion of the initial borehole to have also been filled with antimony trichloride in solid state, which is brought to melting point by a local supply of a suitable amount of heat from the electrical resistances R which are distributed along the supporting element C of the drilling tool O.

Thus, as has already been indicated, the work of the drilling tool O is facilitated by the fact that the tool is immersed in a liquid l. On the other hand, earth or rock debris D and also any infiltrations which occur, generally water, move upwards naturally to the free surface a of the melted antimony trichloride l because of their lower density (lower than 3). These debris and infiltrations D are then particularly easy to remove if the free surface a of the liquid antimony trichloride l is near the surface G of the ground. However, it is also possible to "skim" the said free surface a even where this is situated at a certain depth, by using simple well-known means. If some of the walls P of the lower portion of the borehole below 2,000 meters, which is filled with liquid antimony trichloride, comprise cracks or collapsed portions F, the liquid antimony trichloride l enters these immediately and, as soon as its temperature decreases, it solidifies therein and this has the effect of stopping any such cracks or fissures F and consolidating the walls P of the borehole, preventing or reducing any infiltrations. Furthermore, as the drilling progresses, the liquid antimony trichloride l exerts on the walls P of the borehole a pressure p which is proportional to the vertical distance H of the free surface l and the density of the liquid antimony trichloride l; this hydrostatic pressure p opposes the pressure of the ground and therefore ensures the stability of the walls P of the borehole without any need to provide casing tubes for these walls. However, it should be noted that the increase in this hydrostatic pressure p with the depth H produces an increase in the melting temperature of the antimony trichloride l,

whose liquid state can be maintained only by providing an increasing amount of heat as the depth H increases.

The drilling in liquid antimony trichloride can be continued, if there are no leakages, up to a depth slightly less than that where there exists underground a temperature in the vicinity of its boiling point (230° C. at atmospheric pressure) which again depends on the hydrostatic pressure p and consequently the depth H. The use of liquid antimony trichloride makes it possible to drill to a depth H of at least 4,500 meters, where there is a temperature in the vicinity of 217° C.

In order to continue the borehole below this last depth, pieces of selenium which are solid under normal temperature and pressure conditions are dropped on to the free surface a of the liquid antimony trichloride. The density of selenium being in the vicinity of 4.6, that is to say greater than that of the antimony trichloride in liquid form, the selenium pieces fall slowly to the bottom of the borehole, which is then at a depth of about 4,500 meters; the temperature of 217° C. which the solid selenium encounters in this region makes the selenium melt, and makes it possible to continue the drilling work of the tool O in a liquid medium, possibly with local supply of small heat amounts by means of the electrical resistances R fixed to the supporting element or suspension cable C for the drilling tool O. The drilling in the liquid selenium can be continued up to a depth at which a temperature slightly below the boiling point of selenium (689° C. at normal pressure) is reached; thus it is possible to reach a depth of about 9,500 meters. A final depth of about 15,000 meters can then be reached by using no longer selenium but tellurium, which has a density of 6.2, that is higher again (melting point equal to 450° C. and boiling temperature equal to 1390° C. at atmospheric pressure).

In cases where the drilled strata have a particularly low average density and where the risk of pollution are negligible, it is possible in the first phase of the drilling process described hereinbefore to use not antimony trichloride which has a density of 3 but sulphur which has a density of 2; its melting temperature (120° C.) and boiling temperature (444° C.) at normal pressure are such that the liquid sulphur can be used for carrying out the drilling method according to the present invention at depths of between 3,000 and 7,200 meters.

It will be clear from the foregoing that under certain conditions of use the carrying out of the drilling process according to the present invention may require no local supply of heat to make the filling substance remain in the liquid state, particularly at certain depths. However, in most cases it is very advantageous to provide the necessary means for these local supply of heat even if these means are not all permanently used. In fact it is advantageous for the liquid filling substance to be maintained throughout the borehole at a temperature considerably above its solidification temperature, on the one hand in order to reduce the viscosity of the said liquid substance, since high viscosity would slow down the upward movement of debris and any infiltrations, and on the other hand to facilitate the establishment in the said liquid substance of upwardly travelling currents which carry with them the debris and any infiltrations up towards the liquid free surface. According to one particular embodiment of the process according to the present invention it is even advantageous to keep the liquid substance filling the borehole at least in the vicinity of the drilling tools, at a temperature just slightly below its boiling point; under these conditions in fact there is a formation of a large number of vapour bubbles of the filling substance, producing upward currents in the liquid mass, and these bubbles may even be adsorbed by the solid particles of debris whose upward movement they accelerate.

Other means have also been indicated hereinbefore whereby the upward travel of debris and any infiltrations which have taken place towards the free surface of the liquid filling substance can be accelerated. The injection of compressed air at the bottom of the borehole near to the drilling tool is one of these means and a particularly effective one.

Of course the drilling process according to the present invention can be carried into effect by using filling substances which differ from those previously mentioned provided that they have in the liquid state a density considerably above the mean density of the strata which are being drilled. It is possible to use more particularly as the filling substance antimony Sb (density: 6.8; melting temperature: 630° C. and boiling temperature: 1460° C. at normal pressure), black powder Sb_2S_3, stibine Sb_2O_3, red powder for vulcanisation Sb^2O_5, sodium seleniate SeO_4Na_2, tellurite TeO_2, cryolite, silica gel, metals with a low melting point, or even glasses or crystals. In these latter cases, it is known that the density of glasses is 2.5 to 2.6 and that the density of crystals is 2.9 to 3.3, and their melting temperatures under normal pressure are between 700° and 900° C. The use of ordinary glass makes it possible to avoid using antimony trichloride and therefore, provided that intensive heating is made available, to use a very easily obtained and non-polluting filling substance. Thus is is possible to begin the drilling with antimony trichloride, then continue it with solid pieces of glass or crystals which, at the temperatures which are encountered, are more dense than liquid antimony trichloride, in which they can therefore move downwards, whilst being capable of hardening in fissures in the walls between 200° and 700° C.

Instead of being operated by a built-in electric motor, the rotary tool used for carrying out the drilling process according to the present invention can be operated by a turbine which is also built into the casing of the rotary tool and is supplied with a fluid, for example a gas under pressure or a liquid, which is brought from the ground surface by a suitable conduit. The fluid which has operated the turbine can be collected and returned to the ground surface by a riser conduit or may be discharged at the bottom of the borehole. In the latter case, preferably a liquid of lower density than the density of the filling liquid substance will be used, so as to prevent the driving fluid from accumulating in the bottom of the borehole; the simplest solution consists in using compressed air as the driving fluid. According to one variant, the driving fluid of the turbine is constituted by the filling substance, itself which is brought from the surface in the liquid state by a conduit and then is discharged at the bottom of the borehole after having operated the said turbine. The rotary tools operated by a turbine have the important advantage over those which are operated by an electric motor that they do not present any problems of electrical insulation, the solution to such problems being likely to be relatively complicated under the high pressure and temperature conditions in which tools are used for carrying out the drilling process according to the present invention.

There are very many possible future uses of earth drilling processes producing boreholes reaching depths

of several thousand meters or several tens of thousands of meters. In addition to scientific uses, there may simply be mentioned research into and the exploitation of strata, more particularly oil-bearing strata, and the recovery of geothermal energy, by various means and processes.

In most cases, the exploitation of a deep borehole produced by the process according to the present invention requires first of all emptying it of the liquid filling substance which it contains. This emptying should not present any very complicated problem since the said filling substance is constantly kept in the liquid state. This previous removal of the filling liquid may be necessary more particularly where the borehole gives access to a deep bed of ore or petroleum, or a pocket of hot water, steam or gas, the tapping of which makes it possible to supply for example an installation for the recovery of geothermal energy.

Other uses are possible for deep boreholes produced by the process according to the present invention, which do not require the removal of the liquid filling the borehole but on the contrary use this liquid, specially as a heat exchanger to recover geothermal energy.

The drilling process according to the present invention may also be carried out for drilling sea beds. When only shallow depths are concerned, the process can be carried out from an artificial island of any known type. If the site or requirements justify the creation of an island, preferably there will be used for this purpose a known process which is based on the use of a non-woven material, bags of cement grout, and various materials collected near the site. In the case of sea beds of medium depth, preferably a rigid pipe will be planted in the zone of the sea bed which is to be drilled, the upper portion of this rigid pipe having to extend to a sufficient height above the surface of the sea to allow drilling operations to be carried out. In this latter case, drilling operations are carried out from a floating platform which is anchored and level with which the upper end of the pipe terminates. As soon as this rigid pipe is in position, the upper portion can be replaced over a length of 40 to 50 meters or more by a large flexible tube mounted on ballast tanks, which makes it possible either to make it float or remain below the water so as not to hinder navigation.

In all cases, the cost price of boreholes drilled by the process according to the present invention is substantially equal to half the price of boreholes drilled by previously known processes.

The present invention is not limited to the embodiments described hereinbefore; all modifications thereto, wherein at least some of the means described are replaced by functionally equivalent means, are also within the scope of the present invention.

I claim:

1. Apparatus for drilling very deep boreholes in the ground without tubing, comprising at least one rotary drilling tool with a built-in motor, said drilling tool having a cross-sectional area A substantially equal to the cross-section S of the hole to be drilled, means for moving said tool downwards in the borehole, said means comprising a line of supporting elements of great length having a lower end fixed to said tool said line of supporting elements having a cross-sectional area which increases from a lower end value L much smaller than A and S to an upper end value U larger than L but much smaller than A and S, electrical resistances fixed at predetermined points on said line of supporting elements, said electrical resistances also having a cross-sectional area r much smaller than A and S, at least one electrical cable for supplying electrical power to said resistances from the ground surface, means for supplying said motor from the ground surface, and means for filling the borehole with at least one melting substance.

2. Apparatus according to claim 1, wherein the built in motor of the rotary tool is an electric motor and its supply means comprises an electric cable extending in said borehole from the ground surface.

3. Apparatus according to claim 1, wherein the driving motor of the rotary tool is a turbine and its supply means comprises a conduit for driving fluid, said conduit extending in said borehole from the ground surface to said turbine.

4. Apparatus according to claim 3, wherein the driving fluid is discharged by the turbine into the bottom of said borehole.

5. Apparatus according to claim 4, wherein the driving fluid of the turbine is constituted by a same liquid substance as the melting substance filling the borehole.

6. Apparatus according to claim 1, wherein the rotary drilling tool has a non-circular cross-section.

7. Apparatus according to claim 6, wherein the drilling tool comprises a plurality of rotary drilling elements some at least of which have axes of rotation inclined relatively to the vertical direction.

8. Apparatus according to claim 6, wherein the drilling tool comprises a plurality of rotary drilling elements having vertical axes of rotation, spaced from one another.

9. Apparatus according to claim 7, wherein some at least of the various rotary elements of the drilling tool are offset vertically relatively to one another.

* * * * *

175-104 CROSS REFERENCE SEARCH ROOM

Sept. 2, 1952 A. ARUTUNOFF 2,609,182

APPARATUS FOR DRILLING DEEP WELLS

Filed Nov. 23, 1946 2 SHEETS—SHEET 1

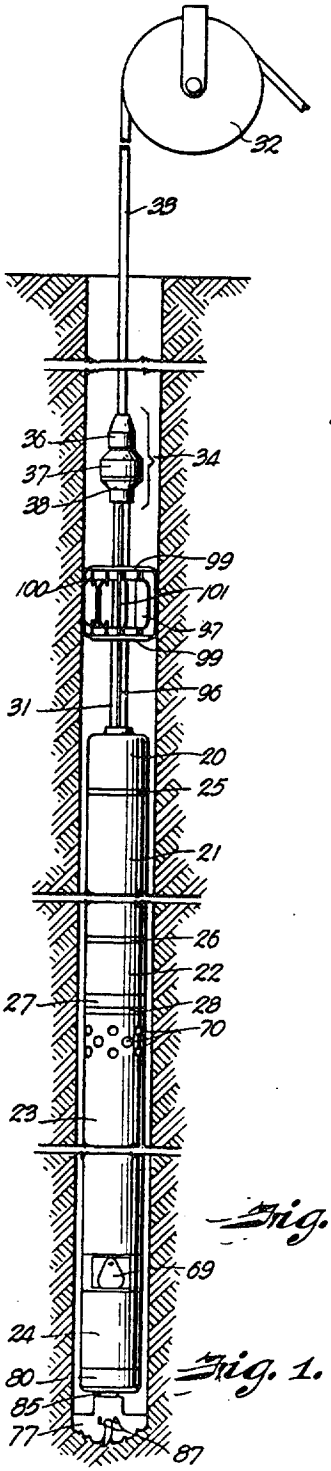


Fig. 1.

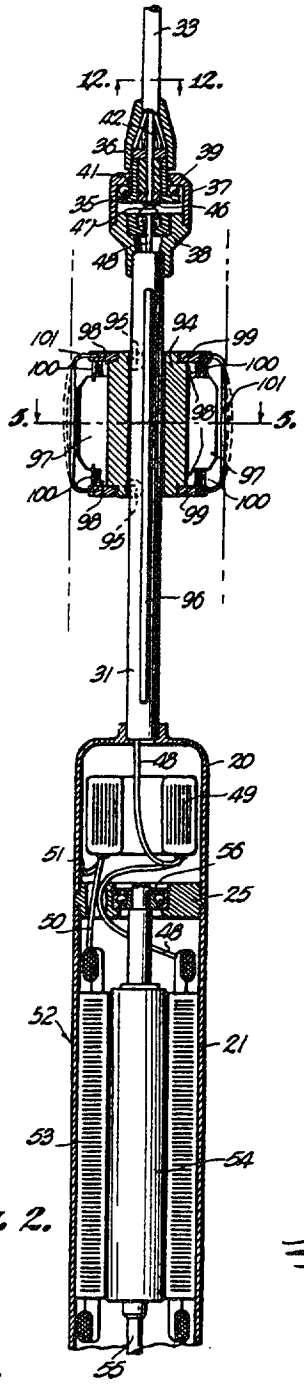


Fig. 2.

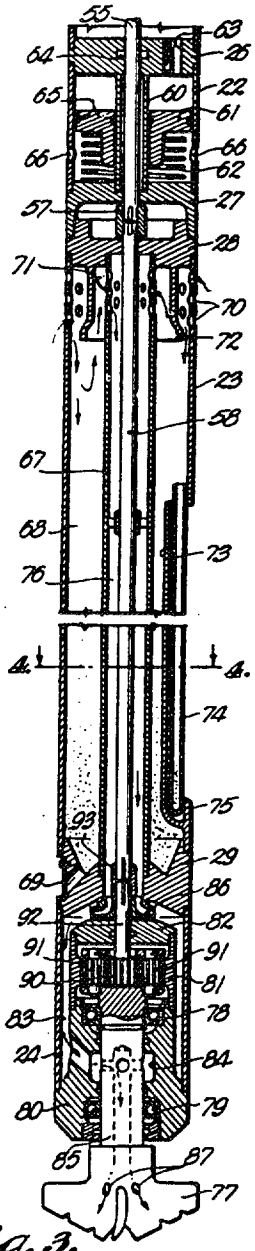


Fig. 3.

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APPARATUS FOR DRILLING DEEP WELLS

Filed Nov. 23, 1946

2 SHEETS—SHEET 2

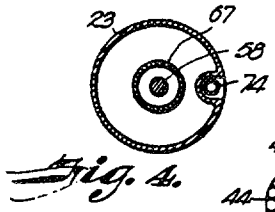


Fig. 4.

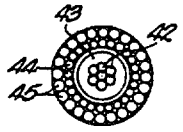


Fig. 12.

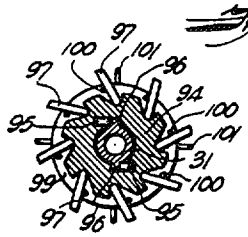


Fig. 5.

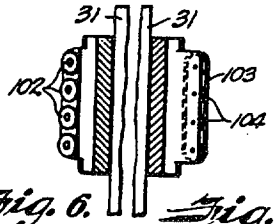


Fig. 6.

Fig. 7.

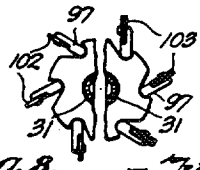


Fig. 8.

Fig. 9.

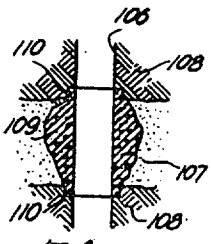


Fig. 10.

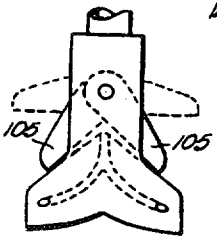


Fig. 11.

Fig. 13.

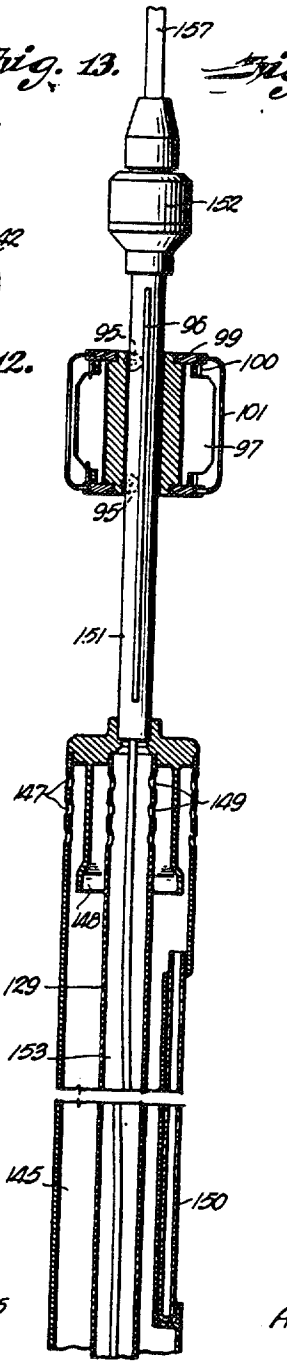
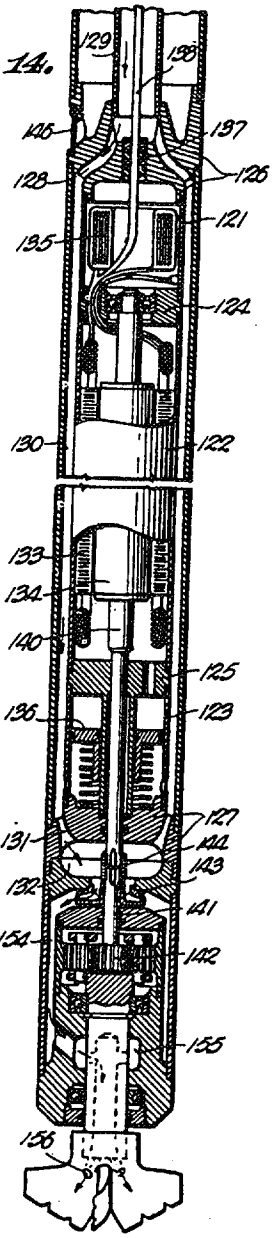


Fig. 14.



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Patented Sept. 2, 1952 2,609,182

UNITED STATES PATENT OFFICE

2,609,182

APPARATUS FOR DRILLING DEEP WELLS

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Application November 23, 1946, Serial No. 711,959

8 Claims. (Cl. 255—4.8)

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My invention relates to the drilling of deep oil wells and has for its main objective the provision of a method which is superior to the existing and well-known rotary and cable-tool methods.

For shallow depths, cable drilling with its free falling bit action has some advantages over the rotary method of drilling, but these advantages disappear with increasing well depth so at great depth rotary methods are used in spite of the fact that productive strata may be easily missed and passed unnoticed due to masking of bore walls by mud which must be employed to carry out the cuttings.

The cable-tool method requires withdrawal of bit and bailing of cuttings, whenever the bit has advanced but a few feet. The cable-tool method also requires the setting of strings of casing where loose side wall material tends to sluff into the bore hole. It should be noted that cementing off of sluffing formations as proposed hereinafter cannot be employed when drilling with ordinary cable tools because of the chattering action and pounding of the bit in subsequent drilling of the cement, while with the rotating bit employed in my device the cement may be readily drilled without impairing the strength or soundness of casing.

When using the rotary method, sluffing formations are usually overcome by the use of heavy circulating pumps at great cost which circulate large volumes of mud or other reagents to increase wall plastering properties of circulating fluid.

The objects of my invention therefore are:

(*a*) To provide a drilling unit suspended on a cable together with an improved suspension coupling whereby attachment of the drilling unit to the cable automatically completes electrical connections to the motor; said coupling also providing a swivel action so that any incidental rotation of the unit will not result in twisting of the cable on which the unit is suspended.

(*b*) To reduce the number of electrical conductors in the suspension cable to an absolute minimum (i. e., a single conductor) by using, as a driver in the suspended drilling unit, an induction motor together with a capacitor located inside the unit, the weight carrying wires of the cable being grounded and acting as a return conductor.

(*c*) To provide a locking device whereby the drilling unit is locked against rotation and at the same time is free to slide vertically within the well bore.

(*d*) To provide a cable operating through a stuffing box which will not leak under high pressure conditions encountered when drilling-in into some productive formations.

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(*e*) To provide a practical form of apparatus which will keep the surface being drilled clean by local circulation of water in the bottom of the well bore, and will segregate and accumulate by sedimentation the cuttings in a container of sufficient capacity to require a minimum number of withdrawals for their disposal.

(*f*) To provide an apparatus which will produce samples of all drilled strata in their proper geological sequence and show the thickness of the strata in easily inspectable, visual form.

(*g*) To provide a drilling method whereby a well drilled by tools suspended on a cable can be completed to full depth without use of strings of casing to prevent sluffing of the side walls and whereby when sluffing formation is encountered drilling is continued to a safe depth, after which the well bore is underreamed and cemented, then redrilled leaving a strong tube of cement where the rotating bit penetrates the cement without impairing the strength or soundness of tube which remains.

With the above objects in view as well as others which will appear as the description proceeds, my invention consists in the novel features herein set forth, illustrated on the accompanying drawings and more particularly pointed out in the appended claims.

In the accompanying drawings which form a part of the specification and are to be read in conjunction therewith and in which like reference numerals are employed to indicate like parts of the various views,

Fig. 1 is a side elevation of my drilling unit,

Figs. 2 and 3 are enlarged longitudinal cross sections of the drilling unit showing, respectively, the upper and lower portions thereof,

Fig. 4 is a sectional view taken along the line 4—4 of Fig. 3 in the direction of the arrows,

Fig. 5 is a sectional view taken along the line 5—5 of Fig. 2 in the direction of the arrows,

Figs. 6 and 7 are longitudinal cross sections illustrating two modifications of the antirotation collar for my drilling unit,

Fig. 8 is an end view of the modification shown in Fig. 6,

Fig. 9 is an end view of the modification shown in Fig. 7,

Fig. 10 is a cross section of the underreamed portion of a well after same has been cemented and drilled,

Fig. 11 is a view showing an underreamer,

Fig. 12 is an enlarged cross section taken along the line 12—12 of Fig. 2 in the direction of the arrows, and

Figs. 13 and 14 are longitudinal cross sections of a modified form of drilling unit showing, respectively, the upper and lower portions thereof.

Referring more particularly to Figs. 1, 2 and 3 of the drawings, the main casing of my drilling unit is made up of five generally cylindrical sections 20, 21, 22, 23 and 24 connected end to end by the coupling members 25, 26, 27, 28 and 29. A tube 31 which hereinafter will be referred to as the torque tube is rigidly secured to the upper section of the casing, the whole elongated assembly thus formed being suspended from the derrick pulley 32 by means of a cable 33.

Mechanical connection between the cable and the upper end of the torque tube is effected through a swivel coupling 34 in order to permit relative rotation between the two. This coupling has a flanged support 35 attached to the cable by a gripping member 36, and, cooperating therewith, a complementary collar or hanger 37 attached to the torque tube by the member 38; the hanger is rotatable with respect to the flanged support, bearings 39 being interposed between the two to carry the weight of the drilling unit. A packing gland 41 prevents intrusion of water into the upper end of the torque tube.

As shown in enlarged cross section in Fig. 12, the aforementioned cable is made up of a group of central conductors 42 surrounded by insulation 43 and by two rows of high tensile strength armor wires 44 and 45 laid on in opposite directions to give the cable a nonspinning or non-twisting characteristic. The interstices between the latter wires are filled with a rubber-like material of such physical properties that it welds itself to the steel wires and form a voidless cable of smooth exterior. It should be noted that while the material fills the exterior grooves between adjacent wires of the outer layer it does not wholly cover the wires, but instead leaves the crest or outermost portion of each exposed.

At the swivel coupling the armor wires of the cable make electrical connection with member 36 and serve to ground the drilling unit, while the central conductors 42 terminate in an insulated contact 46 against which the spring loaded contact 47 is urged. From contact 47 a conductor 49 extends downwardly through the tube 31 and connects to one side of drill motor 52, the other side of the motor being grounded (i. e., connected electrically with the armor wires of the cable) by means of a conductor 50 which is connected to a terminal 51 on the upper section of the drill casing.

The motor 52 is single phase, and preferably of the induction type, having in addition to its main winding a starting winding having capacitor 49 in series therewith for starting purposes. Its field structure 53 is fixedly positioned in the shell 21 and its armature 54 is mounted on the shaft 55, the upper end of the shaft in turn being supported in a bearing 56 while the lower end is journaled in member 26. The weight of the armature is supported by a collar 57 splined to the lower extremity of the motor shaft which collar rests on member 28 and also serves to couple the motor shaft to an extension shaft 58.

Around the lower end of the motor shaft is a stationary sleeve 60 depending from the member 26. Together, this sleeve and the outer shell 22 form an annular chamber in which a piston 61 is free to move. A heavy coiled spring 62 urges

the piston upwardly while standing on the piston is a column of oil which extends up through aperture 63 on through the motor chamber and capacitator chamber and finally up through tube 31 filling the interior of the swivel coupling clear to the packing gland 41. This body of oil surrounds and encloses all electrical parts effectively insulating same. Packing gland 64 prevents leakage of the oil in the motor chamber downwardly around shaft 55 and glands 65 prevent similar leakage around the piston.

The chamber immediately below the piston communicates with the space outside the unit through breather holes 66 whereby the piston may adjust its position automatically to accommodate the changes in the volume of the oil which occur as the result of heating and the like. It also should be noted that oil is under higher pressure than is the fluid outside of the drilling unit and accordingly that any clearance developed at the gland 41 due to swivel action of the coupling 34 will merely allow leakage of a little oil without permitting intrusion of outside fluid into the upper end of the unit.

Below the breathing arrangement just mentioned is a sleeve 67 which, with the shell 23, forms an elongated annular chamber 68 hereinafter to be referred to as the cutting accumulator. At the bottom of the accumulator is a dump valve 69. Intake apertures 70 are provided at the top of the accumulator and corresponding apertures 71 are provided in the upper end of sleeve 67, the two sets of apertures being separated from one another by a deflector skirt or baffle 72 extending down between them from member 28.

In the outer shell is a longitudinal trough-like depression 73 which accommodates an easily removable and replaceable transparent sampling tube 74. The open upper end of the tube extends into chamber 68 through an aperture in the top of the depressed section of the shell, while the lower end is held in place by a lip 75 which forms a socket at the bottom of the depressed section.

The bit 77 of the drilling unit is supported in suitable bearings 78 and 79 carried by the bottom piece 80, the latter part being secured to the casing section 24. Rigidly affixed to the upper end of the bottom piece is an internally toothed ring gear 81 and this in turn is surmounted by a stationary cap 82, the whole assembly being of such diameter as to leave an annular passageway 83 around it. The passageway communicates with a small annular chamber 84 encircling the drill stem 85 and, as will be described presently, a centrifugal impeller 86 drives drilling fluid through the passageway into the chamber wherefrom it escapes through the hollow drill stem and apertures 87.

The ring gear 81 forms part of an epicyclic gear train which includes a driving pinion 90 and also a plurality of planet gears 91 meshing both with the pinion and the ring gear. These planet gears are carried by a yoke provided at the upper end of the drill stem, and thus they turn the bit 77 as they move in their orbit around the driving pinion. The driving pinion and the impeller 86 are rotated by a shaft 92 journaled in the cap 82, this shaft being coupled to shaft 58 by a collar 93. The bearings and the gears are sealed off by packing glands as shown to prevent injury thereof by the drilling fluid.

Returning now to the torque tube 31, attention is directed to the collar-like member mounted thereon. This member which hereinafter will be referred to as the antirotation collar com-

prises a hub 94 splined to the torque tube so that it is movable axially thereof without being rotatable relative to the tube. Rollers 95 are arranged on the hub to cooperate with the longitudinal ribs of splines 96 as shown. Around the periphery of the hub is a series of circumferentially spaced vertical slots, and in each slot there is a flap or dog 97 having vertically aligned trunnions 98 about which the dog can pivot to a certain extent within its associated slot. A pair of rings 99 carrying actuating pins 100, one for each dog, are arranged on the top and bottom of the hub. These rings are rotatable with respect to the hub and are connected to each other by four springs 101, the normal shape of which is shown by dotted lines in Fig. 2.

Having thus described the structure of my deep well drilling unit, I now will explain the manner in which it is used. The surface equipment associated with the unit is not shown but it will be undertsood that it includes in addition to the cable hoist, a suitable source of electrical current for the drill motor. Conveniently this may be a generator driven by the same prime mover used to operate the hoist, one output terminal of the generator being connected through a suitable switch to the central conductors 42 of the cable and the other output terminal being connected to the cable's armor wires 44 and 45 as a ground.

Construction of the well begins with the drilling of a large hole to accommodate the so-called surface pipe. The drilling unit, suspended from cable 33, is lowered through the derrick floor and allowed to advance slowly with its motor running. Through shaft 55 and its extensions 58 and 92 the motor drives pinion 90 causing planet gears 91 to move in an orbit around the interior of the stationary ring gear 81. This movement of the planet gears turns the bit 77 at a fraction of the motor speed, and thus is drilling effected as the unit advances. Cuttings are carried away from the bit in a manner presently to be described.

The rotation of the motor and drill in one direction naturally produces a torque tending to rotate the casing in the opposite direction, and therefore suitable surface clamps (not shown) are provided to hold the unit against rotation as it descends through the derrick floor. When the full length of the unit is in the bore hole the clamps are removed. Now however springs 101 of the antirotation collar engage the interior wall of the hole and resist rotation of their associated rings 99; consequently, as the backward thrust of the motor urges the casing, the torque tube 31 and the hub 94 in a counterclockwise direction (see Fig. 5) the pins 100, by remaining stationary pivot the flaps or dogs 97 outwardly causing all of them to engage and bite into the side wall of the bore hole simultaneously. After the initial engagement of the dogs, the backward thrust of the motor increases the grip of the collar on the side wall, and this effectively prevents further rotation of the drilling unit. Although it is locked against rotation, the torque tube 31 still is free to move axially relative to the hub 94 and hence the drilling unit will advance due to its own weight as the cable is payed out. Rollers 95 facilitate such advance by minimizing the friction set up between the torque tube and the hub 94 as a result of the backward thrust of the motor.

When drilling has progressed to the point where the shoulder of coupling member 38 rests on hub 94 a material reduction in the force exerted on the bit due to the weight of the unit takes place. The bit 77 therefore does not get a proper "bite" and there is an immediate drop in the motor's consumption of electrical power. This is registered at the surface by suitable electrical instruments connected to the motor circuit and the operator witnessing the change may now open the circuit to halt the motor; doing this eliminates the torque which theretofore maintained the dogs 97 engaged with the side wall and, thus released, the antirotation collar at once slides down the length of the torque tube because of its weight.

If the motor now is restarted the backward thrust will cause the dogs 97 to lock the antirotation collar firmly to the side wall in its new location, after which by paying out the cable the operator may cause drilling to take place as before. When the unit has again advanced a distance equal to the length of the torque tube 31, the motor may be halted momentarily to release and drop the antirotation collar; it then will be restarted to reset the collar and carry the drilling further, this cycle being repeated as often as necessary.

It should be noted that there automatically is a sharp reduction in the backward thrust on the casing of the unit and the antirotation collar, when as a result of the member 38 reaching hub 94 the bit 77 fails to get a proper bite. This reduction in the backward thrust reduces the grip of the dogs 97 on the side wall so that even if the motor is not halted the device will creep forward due to its own weight and continue drilling at somewhat slower speed than otherwise. The creeping characteristic may be improved if desired by providing wheels 102 on the dogs as shown in Figs. 6 and 8 or by providing each dog with a caterpillar tread or chain 103 mounted on suitable sprockets or wheels 104 as shown in Figs. 7 and 9.

As the drilling unit advances it naturally is necessary to carry the cuttings away from the bit and this is accomplished at the start of the drilling operation simply by inserting a hose into the bore hole beside the unit to flush the cuttings out of the hole as the unit descends through the derrick floor. When the full length of the drilling unit is in the hole the hose is removed and thereafter it is necessary only to keep sufficient fluid in the hole to insure that the unit is entirely submerged.

With the unit submerged the rotating impeller 86 draws the fluid into the casing through intake apertures 70, thence through apertures 71 and duct 76, and expels same by driving it through the annular passage 83, chamber 84, the hollow drill stem and apertures 87. The fluid thus expelled carries the cuttings from the bit upwardly around the outside of the casing and they subsequently are drawn into the cutting accumulator 68 through the intake apertures 70. Instead of passing out of the accumulator through apertures 71, however, the cuttings are deflected downwardly at high velocity by the skirt or baffle 72 and due to their higher specific gravity they continue downwardly and settle to the bottom. Part of the cuttings will, of course, enter the mouth of the transparent tube 74 so that, as drilling progresses through different strata, specimens of the strata will be built up in the tube in proper geological sequence and in proper relative thickness.

When the accumulator is full of cuttings the unit is lifted out of the hole and emptied. In

doing this it is convenient to insert a water hose securely in one of the intake apertures 70 as same appears at the surface and then continue raising the unit with the hose thus secured thereto. When the entire unit is out of the ground it is displaced to one side of the hole; dump valve 69 is opened and water introduced into the upper end of the accumulator and through the hose previously inserted flushes out the cuttings. The dump valve then is reclosed, the water hose unhooked, the unit lowered back into the bore hole and the drilling cycle resumed.

With a drilling unit 150 feet in length operating from a 186 foot derrick it is necessary to lift the unit from the hole to remove the cuttings in this fashion on the average of about once for each 60 foot advance in drilling. This withdrawal of the unit from the hole also offers an opportunity for inspecting the bit at proper intervals and resharpening or replacing it if necessary. At the same time the operator may examine the samples which have been collected in the transparent tube 74 to determine the character of the formation drilled. The tube is removed and emptied by raising it slightly, swinging its lower end away from the casing and then lowering it to withdraw the upper end.

It will be convenient at this point to refer to Figs. 13 and 14 which illustrate a drilling unit of modified construction wherein the cutting accumulator is above, rather than below, the motor and its associated equipment. The lower section of the drilling unit is identical to that shown in Fig. 3 and need not again be described. Immediately above this section and centrally disposed within the exterior casing 120 is an auxiliary housing of reduced diameter, made up of cylindrical sections 121, 122 and 123 fastened end to end by coupling members 124 and 125. This housing is supported and covered at its ends by coupling members 126 and 127, the member 126 containing ducts 128 which extend from the interior of sleeve 129 to the annular passageway 130 surrounding the auxiliary housing and the member 127 containing ducts 131 which extend from the annular passageway to chamber 132.

Within the auxiliary housing is a motor having a field structure 133 and an armature 134, together with an associated capacitator 135 and a breather piston 136. The essential arrangement and function of these parts is like that in the drilling unit previously described, it being understood, however, that the column of insulating oil standing on the piston extends only up through the motor chamber and capacitator chamber, the upper end of the latter chamber being sealed by a stuffing box 137 around the electrical conductors 138. The motor shaft 140 is coupled directly to the shaft 141 of the driving pinion 142 and the impeller 143 by means of a collar 144 splined to both shafts.

Above the auxiliary housing is an annular chamber 145 which forms the cutting accumulator. This has a dump valve 146 at its bottom and intake apertures 147 at the top. An annular baffle 148 separates the latter apertures from apertures 149 in the top of sleeve 129 while a removable transparent sampling tube 150 is provided in one wall of the casing as shown. The torque tube 151 rigidly secured to the top of the cuttings accumulator, and the antirotation collar mounted thereon, are like those previously described, the same being true of the swivel coupling 152

In general, the mode of operation of the modified drilling unit is like that of the unit shown in Figs. 2 and 3. When the motor is operated to drive the bit, impeller 143 draws fluid from the bore hole into the casing through intake apertures 147 thence through apertures 149 and ducts 153, 128 and 130 into chamber 132 and expels same by driving it through the annular passageway 154, chamber 155, the hollow drill stem and apertures 156. The cuttings, carried upwardly from the bit by the fluid thus expelled, enter the accumulator through apertures 147 and there are collected. The antirotation collar functions to hold the casing against rotation, as previously described, while at the same time permitting the unit to advance axially of the hole as drilling progresses. If any rotation of the drilling unit does occur this will have no tendency to twist the cable 157 in view of the swivel action permitted by coupling 152.

It will be observed that the modified construction uses a motor of smaller diameter than that illustrated in Figs. 2 and 3, but it brings the motor close to the bit, thus avoiding a long drive shaft.

If in the course of using either type of drilling unit a loose and sluffing formation is encountered, the level of cuttings in the transparent sampling tube will be higher than usual for a given footage drilled, so that the driller will discover the situation when the unit is withdrawn from the hole and the tube is examined. The condition may be verified by inserting an empty sampling tube, lowering the unit until the drill is near the bottom but not in contact therewith, running the motor for an interval and then withdrawing the unit. When operated in this fashion no drilling takes place but the unit serves as a bailer, collecting loose matter in the accumulator as the fluid is circulated therethrough. The presence of undrilled formation in the accumulator and sampling tube when the unit returns to the surface thus will confirm the original indication and the bailing operation then may be repeated one or more times until the accumulator ceases to collect loose matter. This, of course, will occur when the sluffing has stopped and a cavity has been formed in which the rock matter has assumed its natural angle of repose.

A centrifugally expanding underreamer (Fig. 11) next is fitted to the unit in place of the bit and lowered into the bore hole to the level of the cavity. The underreamer has blades 105 which remain folded during the descent and which are extended by centrifugal force (see dotted lines) when subsequently rotated by the motor. After the regions immediately above and below the cavity have been enlarged by the underreamer the motor is stopped, the unit is withdrawn from the hole and a quick-setting cement compound is introduced into the cavity. The cement is permitted to set, then the drilling unit with the bit once more attached thereto is lowered into the hole and the drilling proceeds as before, thereby to extend the hole through the cement and on down deeper into the formation. The resultant hole (106) is illustrated in Fig. 10 where the numeral 107 indicates a strata at which sluffing has occurred, 108 represents the solid formation above and below that strata and 109 is the cement. It will be noted that the solid formation has been underreamed at 110 so that the cement which seals off the sluffing strata is firmly anchored thereto.

In the event that gas formation is encountered, the well is loaded with water to overcome gas

pressure and drilling is continued. Should the gas pressure be excessive, however, so that the gas breaks through the water, the bore hole is underreamed in the same fashion as described above except that the well meanwhile is shut in, a so-called lubricator or stuffing box being arranged around the cable by which the unit is suspended; after underreaming the high pressure zone is cemented and redrilled, leaving around the hole a tube of cement capable of withstanding the pressure. It will be noted that the smooth exterior of the cable facilitates the use of a stuffing box around same to seal the well.

My drilling unit may be run in or out of the bore hole in about one-tenth of the time required to assemble and lower, or disassemble and raise, the sections of the drill pipe used in the rotary method of drilling. This saving in time is an exceedingly important factor because in practicing the rotary method the bit must be changed on the average of about once for each 60 foot advance in drilling (in other words, about as often as my unit must be raised to empty the cuttings accumulator). The total time saved by use of my device in drilling a deep well thus will be very great.

Bringing cuttings out of the hole by my method also is more economical and efficient than doing this by the mud circulation method employed in rotary drilling, as will be apparent from the fact that such mud circulation requires continuous operation of pumps of several hundred horsepower.

A further advantage over the rotary method resides in the fact that with my unit there is no danger of productive strata being passed unnoticed due to masking of the side walls by the circulating mud, as frequently happens in rotary drilling. Neither is there any danger of passing a sluffing formation. (In the rotary method, on the other hand, sluffing formations usually are not recognized until the drill has advanced a considerable distance past the formation and the drill stem has twisted off; to remedy the situation when this happens ordinarily requires setting a string of casing, with a consequent reduction in the size of the bore hole.)

Obviously, bits, underreamers, and core barrels of any type commonly employed in rotary drilling can be used effectively on my unit.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinbefore set forth together with other advantages which are obvious and which are inherent to the apparatus.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

Inasmuch as many possible embodiments of the invention may be made without departing from the scope thereof it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

Having thus described my invention, I claim:

1. A bailer for wells comprising a pump having an intake line and an exhaust line, means for lowering the pump into the well so that its intake is submerged, a motor operated to drive the pump, said intake line including a vertically elongated reservoir through the upper portion of which fluid flows under the influence of the pump, the fluid in the lower portion of said reservoir being relatively undisturbed whereby collection of sediment therein is encouraged, a vertical trough-like groove in a wall of the reservoir, a transparent elongated tube open at the top and closed at the bottom removably positioned outside the reservoir in the groove, and an aperture at the top of the groove through which the upper end of the tube extends into the reservoir to receive part of the sediment deposited.

2. In well drilling equipment of the type wherein a bit is driven by a motor that is lowered into the bore behind the bit and follows the bit downwardly as drilling progresses, said equipment being at least partially submerged, during drilling, in liquid introduced into the bore hole; the improvement which comprises a vertically elongated vessel connected to the motor housing and lowered into the bore hole therewith, said vessel having at its top an inlet port submerged below the surface of said liquid, said vessel also having at its top an outlet port, a pump driven by said motor, a duct connecting the intake side of the pump to said outlet, a duct extending from the discharge side of the pump and opening into the bore hole adjacent the bit, whereby liquid drawn into said vessel through said inlet port is discharged at the bit and recirculated upwardly in the bore hole back to said inlet port, and baffle means in said vessel between said inlet port and said outlet port for deflecting the liquid stream to induce the deposit in said vessel by sedimentation of detritus carried by said stream.

3. In well drilling equipment of the type wherein a bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, said equipment being at least partially submerged, during drilling, in liquid introduced into the bore hole; the improvement which comprises a vertically elongated vessel connected to the motor housing and lowered into the bore hole therewith, said vessel having at its top an inlet port submerged below the surface of said liquid, said vessel also having at its top an outlet port, a pump driven by said motor, a duct connecting the intake side of the pump to said outlet, a duct extending from the discharge side of the pump and opening into the bore hole adjacent the bit, whereby liquid drawn into said vessel through said inlet port is discharged at the bit and recirculated upwardly in the bore hole back to said inlet port, and means for sharply altering the course of the liquid stream flowing from said inlet port to said outlet port thereby to discharge from the stream detritus carried thereby and cause same to collect by sedimentation in said vessel.

4. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, said equipment being at least partially submerged, during drilling, in liquid introduced into the bore hole; the improvement which comprises a vertically elongated vessel connected to the motor housing and lowered into the bore hole therewith, said vessel having at its top an inlet port submerged below the surface of said liquid, said vessel also having at its top an outlet port, a pump driven by said motor, a duct connecting the intake side of the pump to said outlet port, and a duct extending from the discharge side of the pump and opening into the bore hole adjacent the bit, whereby liquid drawn into said vessel through the inlet port and across the upper portion of the vessel is discharged at the bit and recirculated

upwardly in the bore hole back to said inlet port, the liquid in the lower portion of said vessel being relatively undisturbed whereby collection of sediment therein is encouraged.

5. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, said equipment being at least partially submerged, during drilling, liquid introduced into the bore hole; the improvement which comprises a vertically elongated vessel connected to the motor housing and lowered into the bore hole therewith, said vessel having in its top an inlet port submerged below the surface of said liquid, said vessel also having in its top an outlet port, a pump driven by said motor, a duct connecting the intake side of the pump to said outlet port, a duct extending from the discharge side of the pump and opening into the bore hole adjacent the bit, whereby liquid drawn into said vessel through the inlet port and across the top thereof is discharged at the bit and recirculated upwardly in the bore hole back to said inlet port, the liquid in the lower portion of said vessel being relatively undisturbed whereby collection of sediment therein is encouraged, a vertical trough-like groove in the wall of the vessel, an elongated tube open at the top and closed at the bottom positioned outside the vessel in the groove, and an aperture in the top of the groove through which the upper end of the tube extends into the vessel to receive part of said sediment.

6. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, said equipment being at least partially submerged, during drilling, in liquid introduced into the bore hole; the improvement which comprises a vertically elongated vessel connected to the motor housing and lowered into the bore hole therewith, said vessel having at its top an inlet port submerged below the surface of said liquid, said vessel also having at its top an outlet port, a pump driven by said motor, a duct connecting the intake side of the pump to said outlet port, a duct extending from the discharge side of the pump and opening into the bore hole adjacent the bit, whereby liquid drawn into the vessel through said inlet port is discharged at the bit and recirculated upwardly in the bore hole back to said inlet port, means for sharply altering the course of the liquid stream flowing from said inlet port to said outlet port thereby the discharge from the stream detritus carried thereby and cause same to collect by sedimentation in said vessel, and a vertically elongated tube open at the top and closed at the bottom detachably mounted on the vessel with the upper end of the tube inside the vessel to receive part of the detritus discharged from said stream.

7. In well drilling equipment of the type wherein a bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, said equipment being at least partially submerged, during drilling, in fluid introduced into the bore hole; the improvement which comprises a vertically elongated container connected to the motor housing and lowered into the bore hole with the motor, said container having near its top an intake port and an exhaust port, means including a pump driven by the motor for inducing a local circulation of the fluid at the bottom of the bore hole such that the fluid travels upwardly from the bit into the intake port of the container and thence out of the exhaust port, the fluid in the lower portion of the container remaining substantially undisturbed, a baffle device in the container in the path of the fluid flowing between said two ports for deflecting the fluid to induce sedimentation of the cuttings of the bit which are carried by the fluid, whereby said cuttings are collected in the container, a vertical trough-like groove in a wall of the container, an elongated tube open at the top and closed at the bottom removably positioned outside said container in the groove, and an aperture at the top of the groove through which the upper end of the tube extends into the container to receive part of the cuttings deposited.

8. Equipment as claimed in claim 7 wherein said tube is transparent.

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CROSS REFERENCE SEARCH ROOM

Dec. 15, 1953 A. ARUTUNOFF 2,662,735

APPARATUS FOR DRILLING DEEP WELLS

Filed Nov. 18, 1948 2 Sheets-Sheet 1

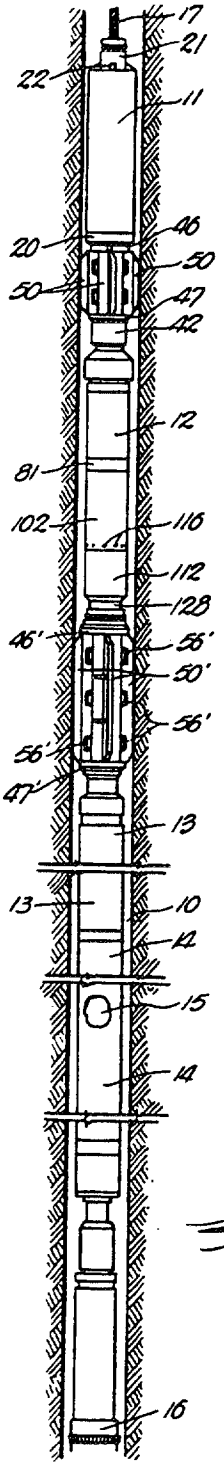

Fig. 1.

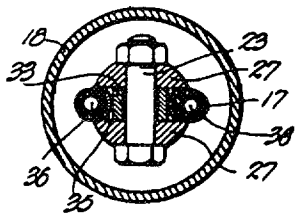

Fig. 3.

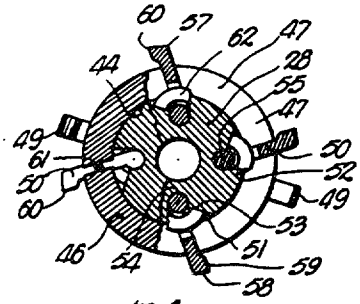

Fig. 4.

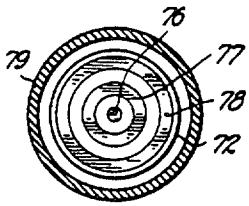

Fig. 5.

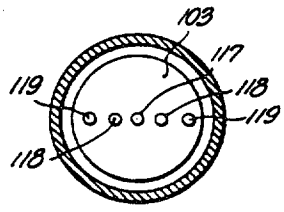

Fig. 6.

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2 Sheets-Sheet 2

Fig. 2.

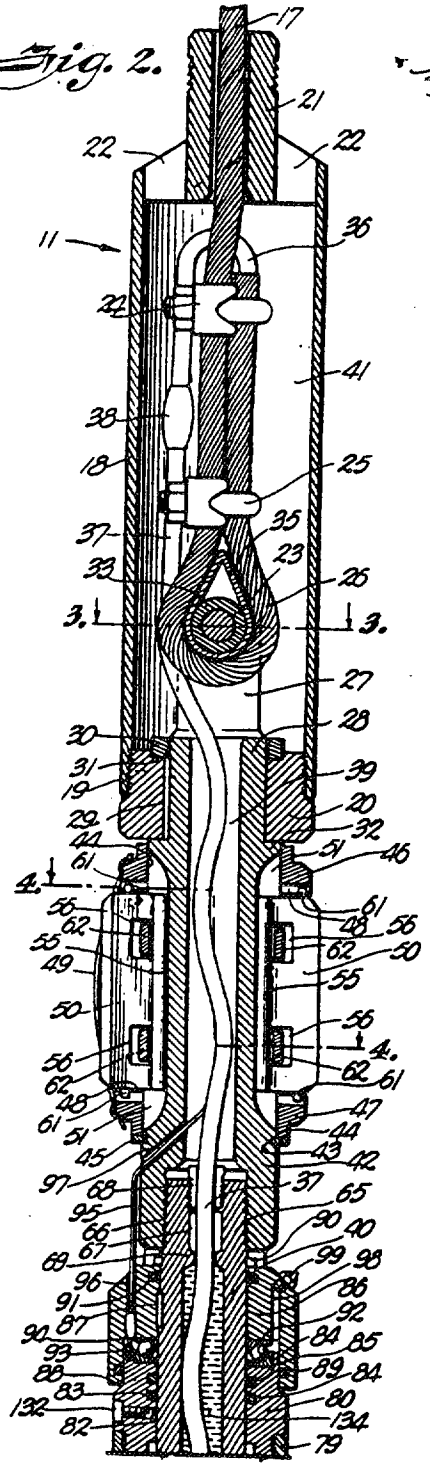
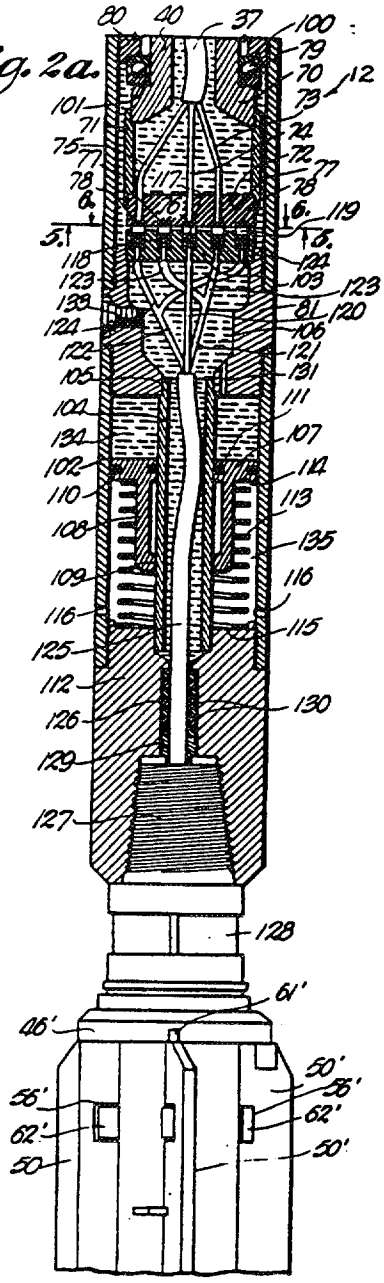


Fig. 2a.



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Patented Dec. 15, 1953

2,662,735

UNITED STATES PATENT OFFICE

2,662,735

APPARATUS FOR DRILLING DEEP WELLS

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Application November 18, 1948, Serial No. 60,709

11 Claims. (Cl. 255—4.8)

1

My invention relates to apparatus for drilling deep wells, such as disclosed in my application for patent on Method and Apparatus for Drilling Deep Wells, Serial No. 711,959, filed November 23, 1946, now Patent No. 2,609,182, of which this case is a continuation-in-part.

In general, my invention relates to apparatus for drilling deep oil and gas wells, and it deals more particularly with a drilling unit suspended on a cable, the upper end of the cable being connected to a suitable derrick or hoist at the surface so that it can be payed out as drilling progresses. The drilling unit comprises a rotary drill and means for rotating the same, all suspended from said cable (the means for rotating the drill comprising an electric motor), and the present invention is an improvement in the means for suspending or mounting the drill and rotating means therefor in such a manner as to avoid twisting of the weight carrying or suspending cable.

In the apparatus disclosed in my application referred to above, the cable from which the drilling apparatus is suspended is so constructed and arranged that it also includes means for conducting the electrical energy from above the surface to the motor suspended on the cable, and in the improvement disclosed herein the suspending cable likewise has incorporated therein conductors for the electrical energy to be supplied to the motor.

In providing a cable for suspending drilling apparatus of the aforementioned character, it is necessary that the cable be prevented from twisting due to the torque exerted on the apparatus by the rotating parts of the drilling apparatus, and it is an important purpose of my invention to provide a mounting for the rotatable drilling means and the driving means therefor so constructed that there will be no twisting action exerted on the cable. In order to accomplish this purpose there is provided, at the lower end of the cable, gripping means adapted to engage the wall of the well in such a manner as to hold the parts associated therewith against rotation.

In order to further assure against twisting of the cable due to operation of the rotating parts of the drilling apparatus suspended from the cable, a swivel is provided between the above mentioned gripping means and the mounting for the rotatable parts, so that should the mounting for the rotating parts have any rotative movement whatsoever in the well this will not be transmitted to the mounting for the gripping means associated with the cable.

Furthermore, in order to reduce the relative

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rotation of the two swivelly connected parts of the swivel connection, additional wall gripping means is provided, this being associated with the mounting for the rotating parts of the drilling apparatus in such a manner as to hold the lower member of the swivel connection against rotation.

It has been found in practice that a single wall gripping device, such as provided in the apparatus shown in my aforementioned application, is subject to some slippage, and hence will not at all times and under all conditions hold the lower member of the swivel connection provided between the cable and the mounting for the rotating parts against rotation; if the lower member of the swivel connection turns due to the failure of said gripping means to hold the parts positively against rotation, there is, of course, a possibility that the suspending cable will be twisted to some extent. In order to completely avoid this it has been found necessary to use the pair of wall gripping members with the swivel connection interposed between them, the upper gripping members being associated with the suspending cable and the lower gripping member being associated with the mounting for the rotating parts of the drilling apparatus.

It is a further important purpose of my invention to provide a mounting for the rotating parts of the drilling apparatus on a suspending cable that includes a swivel connection, which is of the utmost dependability mechanically as well as electrically, and which is embodied into one easily replaceable assembly.

The gripping means that I utilize for engagement with the well wall preferably comprises a torque shoe device having a plurality of shoes or gripping members that are so mounted as to be moved into engagement with the well wall to grip the wall, upon any rotation of the part upon which these gripping shoes are mounted, due to the torque exerted thereon by the rotating parts of the drilling apparatus. The shoes of the torque resisting apparatus must be so mounted that the mounting will resist the great stresses exerted thereon by the torque that these resist and the specific mounting of said shoes or gripping members disclosed herein is an important feature of my invention, in that it avoids any damage to the gripping appartus by the forces exerted thereon.

It is another important feature of my invention to provide a swivel connection that is provided with electrical contacts that are so mounted that a circuit will be maintained between the conductors in the cable suspending the apparatus

and the conductors leading to the motor that drives the rotating parts of the drilling apparatus at all times as the two parts of the swivel turn relative to each other about their axis, said electrical connections comprising contact rings and spring pressed contact members engaging with said contact rings to maintain the electrical connections.

Means is provided for insulating the electrical conductors comprising a body of oil surrounding the same and the above referred to contacts and to maintain a pressure on said body of oil higher than that of the drilling fluid, that contains water, in which the drilling apparatus is submerged.

It has been found, where high voltage current is conducted through conductors that are contained in a body of oil to provide the necessary insulating means for said conductors, that oil under pressure is not sufficient protection for preventing deterioration of said insulating oil and thus loss of dielectric strength. It has also been found that where there is the possibility of seepage or leakage of either the oil or a liquid containing water through a seal, that if such leakage occurs and water enters the body of oil, the moisture entering from the body of water will readily travel downwardly through the intermolecular space in the oil, thus contaminating the entire body of oil and lowering the dielectric strength thereof, whereas this deteriorating process does not occur where the point of contact of the water with the oil underlies the body of oil so that the travel of the moisture would have to be upwardly through the body of oil. It is one of the purposes of my invention to provide sealing means for the chamber containing the body of oil that is of such a character that all of the seals at which the outer body of water and the inner body of oil might come in contact are so located that the body of water lies below the body of oil at the seal, and thus any point of contact with the water would underlie the body of oil.

During operation of my drill it is inevitable that the lower part of swivel connection slowly rotates relative to the upper part due to the creeping of main torque shoes which although substantially holding the drilling unit from rotating, are subject to some slip as the unit advances. On an average, such creeping results in one revolution for every five or ten minutes of operation.

It is highly desirable to be informed of proper performance of swivel and unit as the drilling proceeds and therefore it is one purpose of my invention to provide signal means at the surface to indicate relative rotation of the two parts of the swivel so that signal is sounded once for every revolution. The frequency with which the signal means operates gives an indication of conditions being encountered in the well bore during the drilling operation. If, for any reason, the signal means ceases to operate, it will immediately be apparent to those at the surface that the two swivelly connected parts of the swivel member are rotating together (and that the swivel member is thus not functioning properly) or that both parts are stationary.

It is also a purpose of my invention to provide in conjunction with the means for securing the apparatus to the lower end of the cable a receptacle for refuse or debris that may be loosened or fall into the well bore from above the point at which the drilling operation is taking place, this material being commonly referred to in oil well drilling practice as "junk."

With the above objects in view as well as others which will appear as the description proceeds, my invention consists in the novel features herein set forth, illustrated in the accompanying drawings and more particularly pointed out in the appended claims.

In the drawings:

Fig. 1 is a side elevational view of my drilling apparatus, partly broken away, showing the same located in a well bore,

Fig. 2 is an enlarged longitudinal sectional view of the upper portion of the means for suspending the drilling unit from the cable,

Fig. 2a is a similar view of the lower portion thereof, the lower gripping means being shown in elevation and being partly broken away,

Fig. 3 is a section taken on the line 3—3 of Fig. 2 in the direction of the arrows,

Fig. 4 is a similar view taken on the line 4—4 of Fig. 2,

Fig. 5 is a similar view taken on the line 5—5 of Fig. 2a, and

Fig. 6 is a similar view, taken on the line 6—6 of Fig. 2a.

Referring more particularly to Fig. 1 of the drawings, the reference numeral 10 indicates a well bore in which my drilling unit is located. The drilling unit comprises an upper section 11, a section 12 swiveled thereto, a bailer section or detritus collector 13 connected to the lower end of the section 12, and a section 14 which contains the motor 15 for driving the drill 16 through suitable reduction gearing, not shown. In the drawings, the drill is shown as being a core drill, although any other suitable drill may be utilized.

The upper section 11 of the drilling tool is suspended from a weight supporting cable 17. The cable 17 is connected with the section 11 in the manner illustrated in Figs. 2 and 3 of the drawings, said section 11 comprising an open ended tubular portion 18, which is internally screw-threaded at 19 and is engaged at said threaded end portion by a nut 20. The upper end of said tubular member 18 has a tubular guide member 21 mounted centrally thereof, which is connected with the tubular member 18 by means of ears 22. The member 21 is what is commonly referred to as a "fishing neck." The cable 17 extends through the member 21 and is secured to a bolt 23 by means of cable clamps 24 and 25, by means of which said cable 17 is formed into a loop 26 embracing the bolt 23. The bolt 23 is mounted in a pair of upstanding ears 27 on an inner tubular member 28 provided in the section 11, the tubular member 28 being fixed to the nut 20 by means of a key 29 and a nut 30 screw-threadedly engaging with the end thereof and seated against a shoulder 31 on the nut 20, said tubular member 28 also having an annular shoulder 32 thereon so that said tubular member 28 is fixed by key 29 in position relative to the tubular member 18 by means of the nut 30 clamping the shoulder 32 against the nut 20.

A sleeve 33 surrounds the bolt 23 and a sheet metal guard member 35 is mounted between the sleeve 33 and the loop 26 formed in the cable 17. The cable 17 is made in a similar manner to that shown in my above referred to copending application, in that it has an outer weight sustaining sheath, and mounted within said sheath is an insulated electrical cable 36. The cable 36 is connected with an insulated cable 37 by a suitable splice 38. The electrical cable 37 extends into

the central passage 39 in the tubular member 28 and into the tubular swivel member 40 carried by the tubular member 28. It will be noted that the tubular member 18 is removable from the member 20 and thus from the member 28 so as to provide ready access to the cable clamps and the electrical connections within the same by merely unscrewing the same from the nut-like member 20 and sliding the sleeve-like member 21 upwardly on the cable 17. Also it will be noted that when the tubular member 18 is in position as shown in Fig. 2 it is open at the top thereof so that any debris that may be loosened above the location of the drilling apparatus will drop into the container provided by said tubular member 18, said container having a large chamber 41 therein that constitutes a debris or "junk" basket.

The tubular member 28 is provided with a cylindrical outer surface that extends from the shoulder 32 to the portion 42 thereof. The surface 44 is provided with an annular groove 43 and a stop collar or ring 45 is seated in the groove 43. A pair of rings 46 and 47 are mounted for relative rotation thereto on the cylindrical outer face of the member 28. The rings 46 and 47 are the same in construction, except for the fact that these are reversed. Each of said rings has a plurality of radial slots 48 therein, as shown in Fig. 4, and each has the ends of a pair of bowed out springs 49 fixed thereto (see Figs. 2 and 4). The springs 49 are of such a curvature that these will be flexed upon engagement with the wall of the bore 10 so as to firmly engage by spring pressure with the wall of the bore to hold the rings 46 and 47 against rotation in said well bore.

The springs 49 and the rings 46 and 47 constitute part of a gripping means for holding the upper section 11, which constitutes the upper member of a swivel connection, against rotation in the well bore. Said gripping means further comprises a plurality of shoes 50 that may be referred to as torque shoes, in that these shoes engage the wall of the well bore to prevent rotation of the tubular member 28 and thus of the upper section 11 of the well drilling device, which might otherwise occur due to the torque developed by the motor 15 in rotating the drill bit 16. The member 28 is provided with a plurality of longitudinally extending grooves 51, which have a pair of side walls 52 and 53, the side walls 53 being inclined much more to the radial than the side walls 52. Each of the grooves furthermore has a partly cylindrical bottom wall 54, which serves as a socket for receiving the integral hinge pin portion 55 on each of the shoes 50. Each of said shoes 50 also has a pair of longitudinally elongated openings 56 therein adjacent the hinge pin portions 55 thereof and has a thickened outer end 57, which has faces 58 and 59 thereon that meet at a sharp corner 60 so as to provide a gripping surface on each outer end of said shoes adapted to engage the wall of the bore to prevent rotation of the member 28 in a counterbore-clockwise direction as viewed in Fig. 4.

The shoes 50 are moved into gripping position upon any slight counter-clockwise rotation of the member 28 relative to the rings 46 and 47 by means of the projecting lugs or fingers 61 provided on each end of each of the shoes 50, which operate in the radial slots 48 in the rings 46 and 47. It will be obvious that if the member 28 is rotated in a counter-clockwise direction relative to the rings 46 or 47, as viewed in Fig. 4, the

pivot pin portions 55 will be swung around relative to the position of the lugs 61 so as to throw the gripping members 50 outwardly into engagement with the wall of the bore.

As the forces that will be acting on the shoes 50 are very great, the construction of the mounting of the shoes must be quite rugged. For that reason the pivot members of the shoes are mounted in the grooves in the thick tubular member 28 and are provided with strong retaining members comprising the arcuate bars 62 that have flat end faces that are welded face to face to the faces 52 and 53 of the grooves at 63 and 64, respectively, said arcuate bars 62 passing through the openings 56 in the members 50.

The tubular swivel member 40 is provided with an upper screw-threaded end portion 65 that is threaded into the internally threaded end portion 66 of the member 28, and a stuffing box is provided in the upper end of said swivel member 40 comprising the compressible packing 67 and the gland member 68 that compresses the packing 67 between itself and the annular shoulder 69 providing a reduced neck portion in the swivel member 40 within which the cable 17 fits. The packing 67 is thus compressed around the cable so as to provide a liquid tight joint around the cable within the member 40. The cable 17 extends to the lower end of the member 40, which has an annular enlargement 70 thereon, on which the cylindrical extension 71 is secured.

An insulating block 72 is mounted in the lower end of the cylindrical member 71, being seated in a recess in the end thereof, as shown in Fig. 2a, and the three conductors 73, 74 and 75 that are provided in the cable 17 extend from the lower end of said cable through suitable passages in the insulating block 72 to contacts provided on said insulating block. Said contacts, as shown more clearly in Fig. 5, comprise a central substantially circular contact 76 and a pair of flat ring-like contacts 77 and 78. The contact 76 is mounted on the axis of the cylindrical member 71 and thus on the axis of the swivel member 40 and the ring contacts 77 and 78 are concentric therewith. The conductor 74 is connected with the central contact 76, the conductor 73 with the ring contact 77 and the conductor 75 with the ring contact 78.

The member 12, which is swiveled on the member 11, comprises an outer tubular housing 79, with which an upper head 80 is screw-threadedly connected at one end thereof, and a lower head 81 is screw-threadedly connected at the other end thereof. The head 80 has a bearing portion 82 fitting the outer periphery of the tubular member 40, and said bearing portion is provided with a plurality of grooves 83, in which compressible sealing rings 84 are mounted. The head member 80 has an upwardly extending end portion 85 that is slightly reduced in diameter and is provided with a cylindrical outer surface, while the swivel member 40 has a flanged collar 86 keyed thereto by means of a key 87 so as to rotate therewith, said collar having a depending annular flange 88 overlapping the reduced upper end portion 85 of the head 80 of the member 12 and having a groove therein, in which the compressible sealing ring 89 is mounted. The retaining ring 90, mounted in a groove in the swivel member 40 holds the collar 86 from endwise movement and the joint between the collar 86 and the swivel member 40 is sealed by means of the sealing ring 91. An upper ball thrust bearing 92 is mounted between the mem-

bers 80 and 86, a space being provided between the members 80 and 86 for mounting this thrust bearing.

Mounted within said space is also a spring pressed contact 93, which is carried by the upper end member 80 provided on the tubular housing 79 and thus rotating with the member 12 and grounded to said member 80 and thus to the metallic parts of the drilling apparatus and the outer sheath of the cable 17. A contact 94 is mouhted in a recess in the collar 86 and a conductor 95 extends to said contact through the passage 96 in the collar 86, said conductor 95 being contained within the cable 37 and passing therefrom in the passage 39, as will be obvious from Fig. 2, a side passage 96 being provided from the passage 39 for the conductor 95 so as to bring the same out of the member 28. It will be seen that as the member 80 rotates relative to the member 86 and thus as the member 12 rotates or swivels on the member 11, the contacts 93 and 94 will engage once during each rotation of said parts. This is utilized as an indicating means or signal means to indicate by means of any suitable signal above the ground surface connected with the proper conductor within the cable 17 and grounded to the outer sheath of said cable 17 to indicate as to whether the upper and lower members of the swivel are rotating relative to each other and thus whether the apparatus is functioning properly. In fact the frequency of the signals will indicate the conditions in the well bore as, if any slippage of the gripping means 50 occurs, the relative rotation of the members 80 and 86 will either be retarded or will cease entirely. If in any case the gripping means 50 is not functioning perfectly, then the rotation induced in the upper section 11 due to the slight frictional resistance in bearing 100 and seals 84 and 91 will result in an undesirable twist in the cable 17.

The collar 86 is provided with a longitudinal passage 98 therein, which leads to the space between the lower end of the member 86 and the upper end of the member 80, and a valve 99 is provided thereon through which oil under pressure, which is an electrical insulator, is inserted in the passage 98 and all spaces in communication therewith. As the apparatus will be in a body of water in the well bore when the drilling operation is taking place, there will be water surrounding the members 80 and 86 and accordingly there will be water on the lower side of the seal 89 and oil on the upper side of said seal when the appaatus is in operation. However, it has been found that there will be no contamination of the oil and thus of its insulating and lubricating properties by upward passage of the moisture through the seal 89 into the body of oil, because, when the body of oil is above the body of water in the seal, no such intermingling of the moisture with the oil as would cause the same to deteriorate, will take place.

A ball thrust bearing 100 is mounted between a shoulder on the lower end of the member 80 and a shoulder 101 provided at the enlargement 70 on the swivel member 40. The section 12 further comprises a tubular member 102, which is screw-threadedly connected with the head 81, which thus serves as a coupling means between the tubular members 79 and 102. The member 81 has a seat at its upper end for an insulating block 103 and has an inner tubular member 104 secured in an opening 105 in the lower end thereof, which communicates with the chamber 106 within the member 81. The tubular member 102 serves as a piston chamber in which a piston 107 is mounted, which slides on the tubular member 104, serving as a guide for said piston, and within the bore of the tubular member 102. The piston has a rearward extension 108 having an additional guide opening 109 therein cooperating with the tubular member 102. Sealing rings 110 and 111 are provided in suitable grooves in the piston cooperating with the walls of the tubular members 102 and 104, respectively. A coupling 112 is screw-threadedly connected with the tubular member 102 and a compression coil spring 113 is mounted between the rear wall 114 of the piston 107 and the end wall 115 of the coupling 112. A series of openings 116 is provided in the tubular member 102.

Spring biased contact members 117, 118 and 119 are mounted in the insulating block 103, there being two of the contacts 118 and two of the contacts 119 arranged substantially diametrically opposite each other. Thus there are two contacts 119 engaging with the contact ring 76 and two contacts 118 engaging with the contact ring 77, and the single contact 117, which is on the axis of the swivel member 40, engaging with the contact 76. With this arrangement of contacts there will be assurance that there will always be a connection between the conductors 120, 121 and 122, and the conductors 74, 73 and 75, respectively, through said contacts, the conductor 121 having branch conductors 123 leading to the contacts 118 and the conductor 122 having branch conductors 124 leading to the contacts 119. The conductors 120, 121 and 122 extend from the cable 125, which extends through the passage in the tubular member 104 and leads to the motor 15. The motor 15 is a three phase motor and the electrical energy is thus supplied to said motor from the cable 36 in the supporting cable 17 through the cable 37 and the cooperating contacts to the cable 125 having the conductors that are connected with said motor.

The coupling 112 has a passage 126 therein, which leads to a suitable passage in the threaded end portion 127 of a member 128, which is connected with the coupling 112 and which is in turn connected with the section 13. The passage 126 is provided with a stuffing box comprising the packing gland 129 and the layers of compressible packing 130, which provide a liquid tight joint around the cable 125 in said passage 126.

A chamber is thus provided that is sealed so as to retain a body of liquid therein, which chamber includes the passage within the tubular member 104 and the chamber between the piston 107 and the bottom end wall of the member 81. In order to provide communication between this chamber and the chamber 106 in the member 81, a liquid passage 131 is provided in said member 81. The liquid chamber 106 communicates with the space between the tubular members 71 and 79 and also with the space within the tubular member 71 and thus with the passage in the swivel member 40. There being no seal between the member 40 and the tubular member 79, the space between the tubular swivel member 40 and the members 79 and 80 up to the sealing rings 83 will also be in communication with the other above referred to spaces. An insulating oil is injected into the spaces under pressure through the valve 133 in the member 81 and the air released through the valve 132 in the member 80.

The insulating oil is indicated by the numeral 134 in Figs. 2 and 2a.

As the drilling apparatus will be in a body of liquid containing water when in operative position in the well bore the column of water above the openings 116 will cause the liquid in the well bore under pressure to fill the chamber 135 back of the piston 107. However, the spring 113 will further urge the piston upwardly and thus the pressure on the oil 134 will be greater than the pressure of the liquid in the chamber 135 and, accordingly, at all seals the outward pressure exerted by the body of oil will be greater than the pressure of the liquid containing water on the outside of the seals. Thus if there is any leakage or seepage through the seals, it will be an outward seepage or outward leakage of oil rather than an inward passage of the liquid containing water.

The member 128 has gripping means provided thereon that are of identical construction to the gripping means that comprise the shoes 50 above described, except that said gripping means are of greater length. However, the shoes 50' of said gripping means operate in the same manner as the shoes 50 above described, and are mounted in a similar manner on the member 128 so as to cause the same to be thrown outwardly into engagement with the well wall upon any tendency of reverse rotation of the member 128 due to the rotation of the drill 16. Instead of providing a pair of openings in the shoes for the retaining means, three openings 56' are provided in each of said shoes, and it is obvious that any desired number of such openings and retaining bars or bands 62', which are the same in construction as the members 62 above described, can be provided, dependent upon the length of the gripping means and of the shoes. The shoes are provided with lugs 61' corresponding to the lugs 61 of the shoes 50, which operate in radial slots in ring members 46' and 47' corresponding to the ring members 46 and 47 previously described. The operation of the lower gripping means comprising the shoes 50' is exactly the same as that of the upper gripping means having the shoes 50.

It will accordingly be seen that the torque exerted on the apparatus by the rotary drilling operation will thus be resisted first by the shoes 50' to thus reduce rotation of the section 12 to a minimum. Furthermore the tendency of this rotation to be transferred to the section 11 will be entirely eliminated due to the cooperation of the upper gripping means 50 holding the section 11 stationary and the swivel connection between the section 11 and the section 12. Thus any tendency of the cable 17 to twist will be entirely avoided by the combination of gripping devices and swivel connection between the same provided in this drilling apparatus.

It will be noted also that the seals that are provided between two moving parts, where the only possibilities of leakage of liquid might occur, are so arranged that the outer body of liquid containing water is on the lower side of the seal and the insulating oil comprising the inner body of liquid is on the upper side of the seal. This is true of the seals 110, 111 and 89.

By the particular mounting of the pivoted shoes 50 and 50' by means of the bar-like member 62, a very strong connection is provided between these pivoted shoes and the members on which the same are mounted. The electrical connections and contacts are all in the body of insulating oil and the contacts are so constructed and arranged that there will always be a good contact between the cooperating contact members for any position of the parts of the swivel connection relative to each other. In addition to that, means is provided by means of the cooperating contacts 93 and 94 to give an instant indication or signal at the surface as to the performance of the gripping means and of the swivel connection.

The tubular member 18 serves as a housing for the cable clamping means so as to prevent any damage thereto and at the same time provides a basket for catching anything that might otherwise drop down to a point where it would interfere with the operation of the gripping shoes or other moving parts of the apparatus.

Having thus described my invention, I claim:

1. An anti-rotation device for a deep well drill comprising a hollow central body with longitudinal grooves, torque shoes pivoted against the bottom portion of said longitudinal grooves, said torque shoes having holes therein, fingers on the ends of said torque shoes, upper and lower rings rotatably mounted on said body, radial grooves in said rings controlling through the fingers on said shoes the position of said shoes, wall contact spring pieces connecting said rings, and hinges welded to said body and passing through said holes in said torque shoes.

2. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, the motor being suspended on a cable that is payed out to lower same into the ground; the improvement which includes a swivel coupling between the lower end of the cable and the upper end of the motor housing; said coupling comprising a first part secured to the lower end of said cable and a second part secured to the motor housing and supported on said first part but rotatable relative thereto about an axis longitudinal of the bore hole, a power supply line comprising a plurality of electrical conductors terminating at said first part, a motor input line comprising a plurality of corresponding conductors terminating at said second part, brushes on one of said parts co-acting with slip rings on the other part to electrically connect corresponding conductors of the respective lines regardless of the relative angular position of the two parts, means including said two parts providing an enclosure about said brushes and slip rings, an insulating liquid in said enclosure, means maintaining said liquid at a pressure in excess of the pressure outside said enclosure, means holding said first part against rotation about said axis, other means connected to said motor housing for resisting rotation thereof about said axis, an electrical signalling circuit extending from said swivel coupling to the surface, and a signal generator in said coupling operative to transmit electrical impulses over said circuit to the surface at a rate dependent upon the rate of relative rotation of said two parts.

3. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, the motor being suspended on a cable that is payed out to lower same into the ground; the improvement which includes a swivel coupling between the lower end of the cable and the upper end of the motor housing, said coupling comprising a pair of interfitting members relatively rotatable

about a vertical axis, one of said members secured to the lower end of said cable and the other secured to the upper end of the motor housing, means holding said one member against rotation about said axis, other means connected to said motor housing for resisting rotation thereof about said axis, an oil chamber disposed partly within each member, a rotary seal between the members resisting leakage of fluid into and out of said chamber, means including a thrust bearing in said chamber rotatably supporting said other member on said one member, and means maintaining the oil in said chamber at a pressure in excess of the pressure outside said chamber.

4. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, the motor being suspended on a cable that is payed out to lower same into the ground; the improvement which includes a swivel coupling between the lower end of the cable and the upper end of the motor housing, said coupling comprising a pair of interfitting members relatively rotatable about a vertical axis, one of said members secured to the lower end of said cable and the other secured to the upper end of the motor housing, means holding said one member against rotation about said axis, other means connected to said motor housing for resisting rotation thereof about said axis, an oil chamber disposed partly within each member, a rotary seal between the members resisting leakage of fluid into and out of said chamber, means including a thrust bearing in said chamber rotatably supporting said other member on said one member, and means maintaining the oil in said chamber at a pressure in excess of the pressure outside said chamber, an electrical signalling circuit extending from said swivel coupling to the surface, and a signal generator in said coupling operative to transmit electrical impulses over said circuit to the surface at a rate dependent upon the rate of relative rotation of said two members.

5. In well drilling equipment of the type wherein the bit is driven by a motor that is lowered into the bore hole behind the bit and follows the bit downwardly as drilling progresses, the motor being suspended on a cable that is payed out to lower same into the ground; the improvement which includes a swivel coupling between the lower end of the cable and the upper end of the motor housing, said coupling comprising a pair of inter-fitting members relatively rotatable about a vertical axis, one of said members secured to the lower end of said cable and the other secured to the upper end of the motor housing, means holding said one member against rotation about said axis, other means connected to said motor housing for resisting rotation thereof about said axis, an oil chamber disposed partly within each member, a rotary seal between the members resisting leakage of fluid into and out of said chamber, means including a thrust bearing in said chamber rotatably supporting said other member on said one member, a power supply line entering said chamber through an aperture in said one member, a motor input line entering said chamber through an aperture in said other member, means sealing each of said apertures, brushes and slip rings within the chamber carried by the respective members for electrically connecting corresponding conductors of the two lines regardless of the relative angular positions of said members, and means maintaining the oil in said chamber at a pressure in excess of the pressure outside said chamber.

6. An anti-rotation device for a deep well drill comprising a central body with longitudinal grooves, torque shoes having portions pivotally received in said grooves and having openings therethrough, and means for maintaining said shoes in assembled relation with said body comprising curved bars traversing said grooves, extending through said openings and fixed at the ends thereof to the walls of said grooves.

7. An anti-rotation device for a deep well drill comprising a central body with longitudinal grooves, torque shoes having portions pivotally received in said grooves and having openings therethrough, and means for maintaining said shoes in assembled relation with said body comprising curved bars traversing said grooves, extending through said openings and welded at the ends thereof to the walls of said grooves.

8. An anti-rotation device for deep well drills comprising a central body with longitudinal grooves, torque shoes having inner end portions pivotally received in said grooves and having openings therethrough, means for maintaining said shoes in assembled relation with said body portion comprising curved bars traversing said grooves, extending through said openings and fixed at the ends thereof to the walls of said grooves, said shoes having outer end portions adapted to engage the wall of said well, and means for moving said shoes into engagement with said wall upon rotation of said body comprising a pair of slotted rings, projections on said shoes engaging the slots in said rings, and means on said rings engaging said wall to hold said rings against rotation.

9. An anti-rotation device for a deep well drill comprising a central body with longitudinal grooves, torque shoes pivotally connected in said grooves, rotatable disks coaxial with said body at the upper and lower ends thereof, fingers on said disks engaging said torque shoes and adapted to swing said shoes outwardly to make contact with the well wall upon relative rotation between said disks and central body in one direction, and outwardly bowed spring members connecting the upper and lower disks and bearing against the well wall.

10. An anti-rotation device for deep well drilling comprising a central body, a plurality of torque shoes arranged longitudinally of said body and spaced circumferentially around said body, means connecting one edge of each shoe to said body for pivotal movement relative thereto, and means for swinging the free edges of said shoes outwardly to engage the well wall upon rotation of said body in one direction.

11. An anti-rotation device for deep well drilling comprising a central body, a plurality of torque shoes arranged longitudinally of said body and spaced circumferentially around said body, means connecting one edge of each shoe to said body for pivotal movement relative thereto, rotatable disks coaxial with said body at the upper and lower ends thereof, fingers on said disks engaging said torque shoes and adapted to swing said shoes outwardly to make contact with the well wall upon relative rotation between said disks and central body in one direction, and outwardly bowed spring members connecting the upper and lower disks and bearing against the well wall.

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ЭЛЕКТРОБУР

I.4. Электробур (рис.2) представляет собой погружной забойный агрегат, предназначенный для вращения долота при бурении нефтяных и газовых скважин и состоит из электродвигателя и шпинделя.

Соединение электродвигателя и шпинделя осуществляется посредством корпусных конических резьб, а валы их соединяются с помощью зубчатой муфты 24 и карданной втулки 23 с резиновыми кольцами. В верхней части электробура имеется переводник 2 с горловиной для захвата элеватором, оканчивающийся ниппелем замка для присоединения бурильных труб.

I.5. Электродвигатель электробура - асинхронный, трехфазный, маслонаполненный, с короткозамкнутым ротором - состоит из следующих основных узлов: статора, ротора, компенсатора, верхнего и нижнего сальников.

I.6. Статор I3 представляет собой цилиндр, в который запрессованы пакеты из магнитных и немагнитных листов. Пакеты из магнитных листов служат магнитопроводом, а пакеты из листов немагнитного листового металла служат в качестве опор для промежуточных подшипников ротора.

Обмотка статора - стержневая, схема обмотки - катушечная. Каждый стержень обмотки состоит из нескольких отдельных медных изолированных проводников прямоугольного сечения. Обмотка соедине-

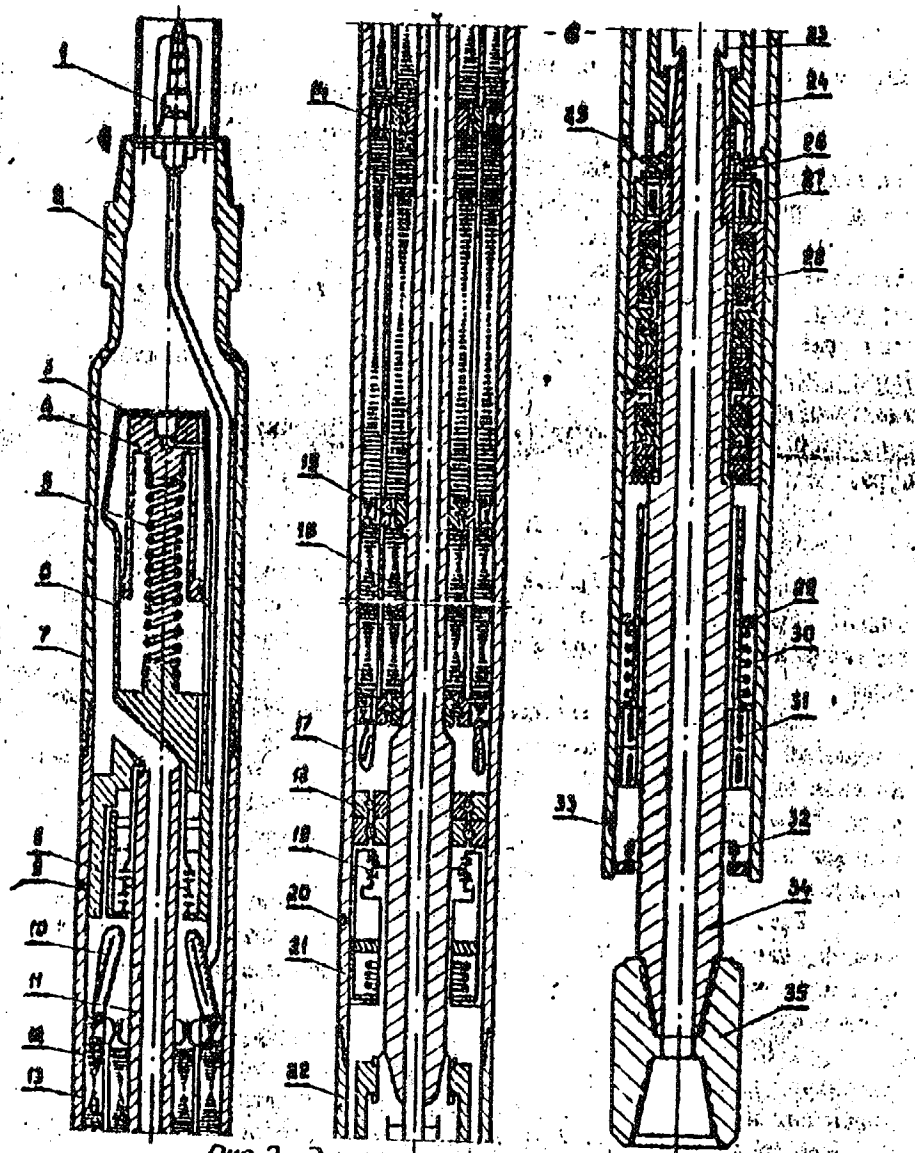


Рис.2. Электровур

1-Контактный стержень кабельного ввода; 2-переводник под элеватор; 3-резиновая диафрагма компенсатора двигателя; 4-поршень компенсатора; 5-пружина; 6-цилиндр компенсатора; 7-верхний соединительный корпус статора двигателя; 8-верхний сальник двигателя; 9-верхний клапан двигателя; 10-верхняя лобовая часть обмотки статора; 11-вал двигателя; 12-пакет магнитопроводной стали статора; 13-корпус статора; 14-промежуточный пакет статора из немагнитного материала; 15-промежуточный подшипник двигателя; 16-секция ротора двигателя; 17-нижняя лобовая часть обмотки статора; 18-нижний подшипник двигателя; 19-нижний сальник двигателя; 20-пробка; 21-нижний соединительный корпус статора; 22-корпус цилиндров; 23-вторичное уплотнение вала; 24-зубчатая муфта; 25-пробка; 26-упорный подшипник; 27-верхний радиальный подшипник; 28-секция шариковой пяты; 29-поршень компенсатора двигателя; 30-пружина компенсатора; 31-радиальный подшипник; 32-сальник; 33-клапан; 34-вал ротора.

на λ, путь запаян внутри машины, а три выводных конца с помощью изоляционного устройства присоединяются к кабельному вводу.

I.7. Ротор электродвигателя состоит из полого вала II, на который насажены отдельные роторные пакеты I 6., в промежутках между которыми расположены радиальные подшипники I5. Осевая опора ротора I8 выполнена в виде двух пятовых подшипников, устанавливаемых на нижнем конце вала. Роторные пакеты собираются из отдельных листов, клетка заливается алюминием или опрессовывается из медных отрезков с короткозамкнутыми кольцами.

I.8. С целью обеспечения нормальной работы обмотки электродвигателя и опор качения буровзрывные электробуры требуют защиты от проникновения в его полость промывочной жидкости. Для уплотнения верхнего и нижнего концов вала электродвигателя применены сальники 8 и I9, уплотняющими элементами в которых являются соприкасающиеся между собой торцовые кольца. Контакт между кольцами достигается за счет действия пружин и перепада давления. Одно из колец зафиксировано на валу и вращается вместе с ним, а второе, неподвижное, зафиксировано в корпусе.

I.9. Компенсатор 6 обеспечивает уравнивание внутреннего давления в полости двигателя над внешним за счет того, что на поршень кроме давления окружающей среды действует дополнительное усилие пружины. Компенсатор содержит запас масла и позволяет ему расширяться при нагреве во время работы электродвигателя, предотвращая возникновение чрезмерного внутреннего давления, а также компенсирует утечку масла через подвижные и неподвижные уплотнения. Внутренняя полость двигателя электробура заполнена трансформаторным маслом. Для уплотнения подвижных и неподвижных соединений в электродвигателе применяются резиновые уплотнительные кольца круглого сечения.

I.I0. Шпиндель электробура 22 служит для передачи осевой нагрузки, создаваемой частью веса бурильной колонны через корпус электробура на долото, минуя ротор электродвигателя, а также для передачи крутящего момента от электродвигателя к долоту. Он состоит из полого вала 34, смонтированного на подшипниках качения в корпусе 22. Верхняя радиальная опора состоит из двух роликовых под-

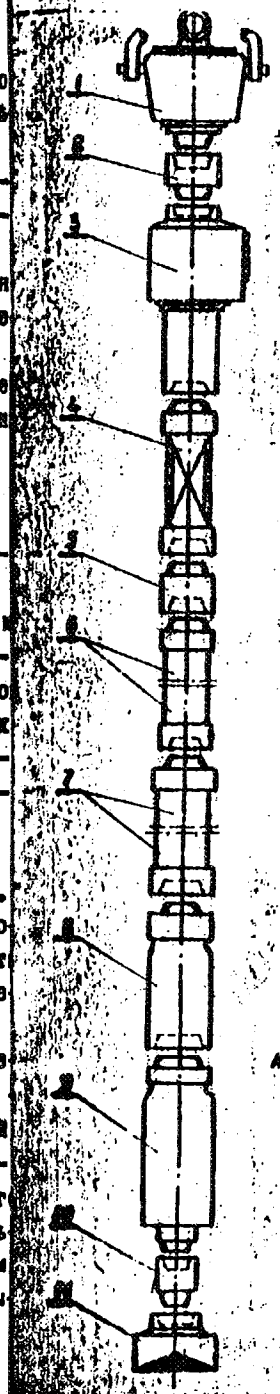
шипников 27, нижняя - из трех роликовых подшипников 31 или одного трехрядного роликового подшипника. В качестве осевой опоры использована многорядная пята из упорных подшипников 28 с резиновыми амортизаторами, позволяющими с достаточной равномерностью распределять осевую нагрузку на подшипники. Для восприятия осевых нагрузок, возникающих при подъеме инструмента или при проработке ствола скважины, в верхней части шпинделя установлена обратная пята в виде упорного шарикоподшипника 26. Внутренняя полость шпинделя заполняется авиамаслом МС-20. Для создания избыточного давления (по сравнению с окружающей средой), компенсации возможных утечек масла через места уплотнений и сброса масла при тепловом расширении в процессе работы, в средней части шпинделя имеется компенсатор принцип работы которого аналогичен принципу работы компенсатора электродвигателя. Для герметизации шпинделя верхний конец вала имеет манжетное уплотнение 23, а нижний - уплотнен торцовым сальником 32.

Технические данные электробуров приведены в приложениях 2 и

I.II. Токоподвод электробура служит для передачи электроэнергии с поверхности к электробуру, спущенному в скважину на колонне бурильных труб. Токоподвод состоит из отдельных двухконтактных (двухпроводных) кабельных секций, смонтированных в бурильных трубах (рис.4), используемых в качестве электрического провода (система питания "два провода - труба").

При спуске электробура в скважину кабельные секции, последовательно соединяясь, образуют непрерывную линию электропередач. Кабельная секция (рис.5) состоит из отрезка двужильного плоского кабеля, двухконтактного стержня и двухконтактной муфты и опор для крепления. Вместо двужильного кабеля возможно применение двух одножильных кабелей (по чертежу СКТБЭ 5ТМ.540.907).

Токоприемник предназначен для передачи электроэнергии от неподвижной системы - токоподводящего кабеля к вращающейся системе токоподводу в бурильных трубах, а также для перехода от трехфазной системы к системе "ДПТ" - два провода-труба путем заземления нижнего контактного кольца. Токоприемник ТЭ (рис.6) состоит из полого отвода I со смонтированными на нем токоприемными контактными кольцами I6 и вводной головкой, кожуха 8 с токоподводящим устройством осуществляющим при помощи щеток 5 непрерывный контакт с контактными кольцами. К ним посредством наконечников присоединяются концы



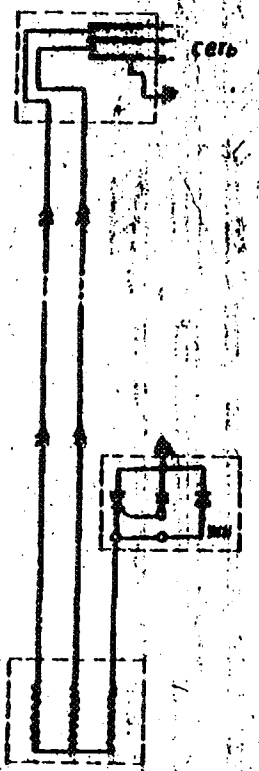
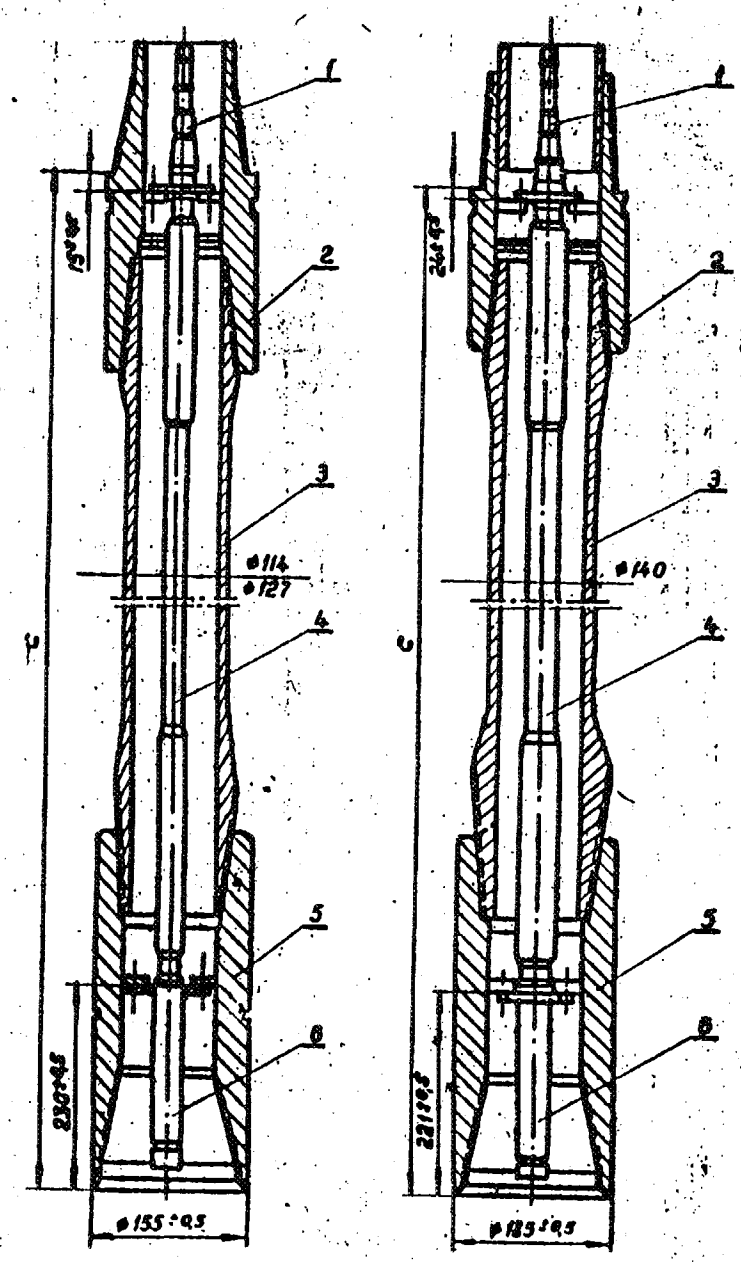


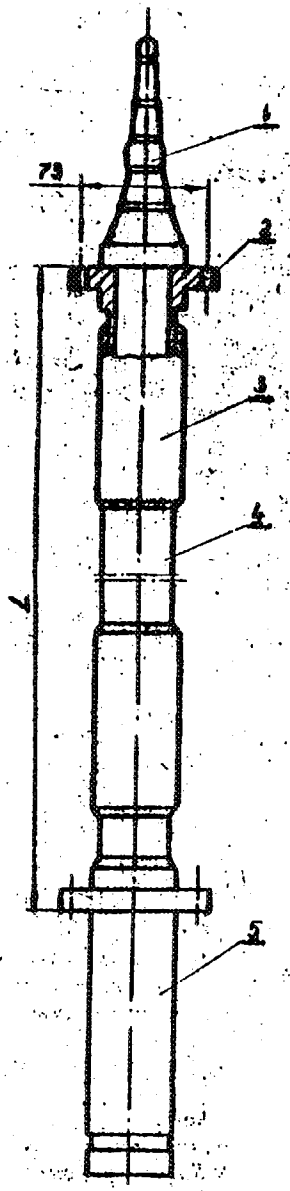
Рис.3. Компоновка бурильного инструмента при бурении скважин электробурами

1 - вертлюг
2 - переводник
3 - токоприемник
4 - квадратная штанга
5 - предохранительный переводник
6 - бурильные трубы
7 - УБТ
8 - устройство контроля изоляции, НЗП
9 - электробур
10 - наддолотный переводник
11 - долото

Рис.4. Бурильные трубы с кабельными секциями токопровода



1-двухконтактный стержень
2-ниппель замка
3-труба
4-кабельная секция
5-муфта замка
6-двухконтактная муфта



Черт. 5. Кабельная секция ТБТЭ-1сб.

1-двухконтактный стержень
2-опора
3-место сращивания
4-кабель
5-двухконтактная муфта

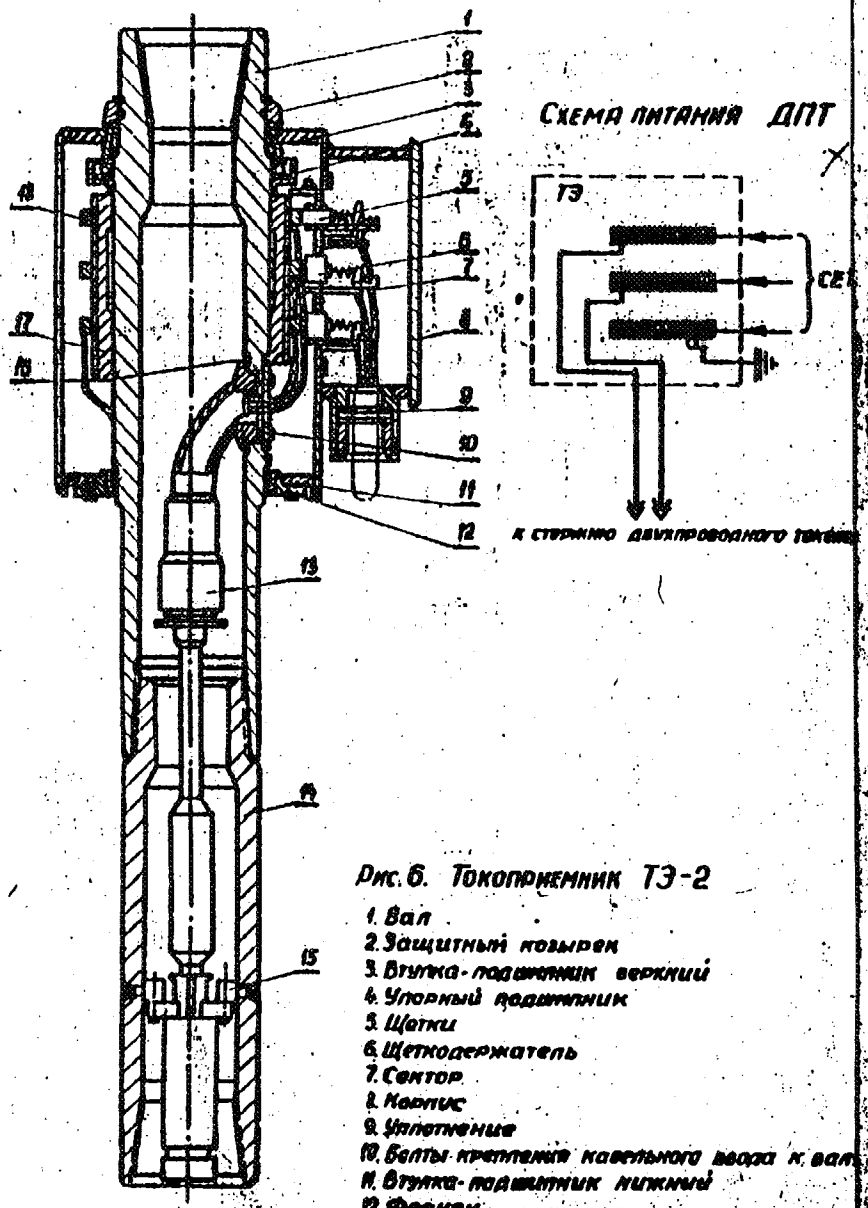


Схема питания ДПТ

Рис.6. Токоприемник ТЭ-2

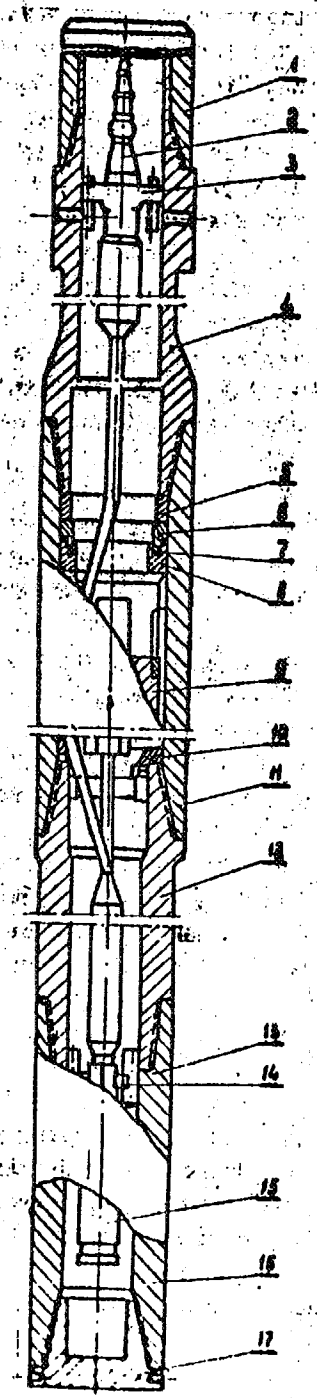
1. Вал
2. Защитный козырек
3. Втулка-подшипник верхний
4. Упорный подшипник
5. Щетки
6. Щеткодержатель
7. Сектор
8. Кожух
9. Уплотнение
10. Болты крепления кабельного ввода к валу
11. Втулка-подшипник нижний
12. Фланец
13. Кабельный ввод
14. Переводник
15. Опора крепления кабельного ввода
16. Медное уплотнительное кольцо
17. Механизированная ступица
18. Контактное кольцо

кабельной головки. Тело кабельной головки сделано из резины с армировкой и имеет утолщение, которое при зажатии фланцем образует уплотнение в боковом отверстии отвода. Вторые концы кабельной головки припаяны к шинам контактной кабельной муфты, устанавливаемой в центральном отверстии отвода. При наличии токоприемника на квадратную ведущую штангу, контактная муфта соединяется с контактным стержнем, смонтированном в нипеле ведущей штанги. Электрический контакт с контактными кольцами осуществляется постоянно нажимающими щетками, установленными в щеткодержателях 6, которые в свою очередь прижимены к металлическим пластинам. Щетки со щеткодержателями и металлические пластины смонтированы в кожухе, в бронзовых подшипниках которого вращается отвод. Для смазки подшипников предусмотрены масленки. Подключение токоприемника к питающей линии осуществляется трехжильным кабелем КТНЭ 3х50.

I.I2. Погружное устройство типа УКИ (рис. 7) или погружной контактор типа КЭП (рис. 8) предназначены для осуществления контроля сопротивления изоляции двухпроводного токоподвода и обмотки двигателя электробура относительно корпуса (земли) при отсоединенных от системы бурильных трубах.

I.I3. Основным элементом устройства контроля изоляции типа УКИ является бесконтактный полупроводниковый коммутирующий узел, представляющий собой встречно-параллельное включение управляемого и неуправляемого вентилей с целью управления. Схема включения УКИ в цепь электробура обеспечивает нормальное токопрохождение во всех трех фазах двигателя при наличии на нем рабочего напряжения и, в то же время, вводит весьма значительное сопротивление (приближающееся к разрыву цепи) в заземленную фазу при снятии рабочего напряжения с двигателя, что дает возможность производить замеры сопротивления электродвигателя и токоподвода относительно земли. Устройство УКИ не производит полного разрыва цепи заземленной фазы, а изменяет ее сопротивление от долей ома при наличии рабочего напряжения до десятков мегом при цикле контроля изоляции.

I.I4. Погружной электромагнитный контактор типа КЭП, также как и УКИ, предназначен для присоединения одной фазы обмотки двигателя электробура к бурильной трубе и отсоединении ее от бурильной трубы для проведения контроля сопротивления изоляции двухпроводного токоподвода и обмотки двигателя электробура относительно земли. Электрический контакт обмотки двигателя с бурильной трубой осуществляется двумя парами параллельно включенных открытых контактов. Замыкание



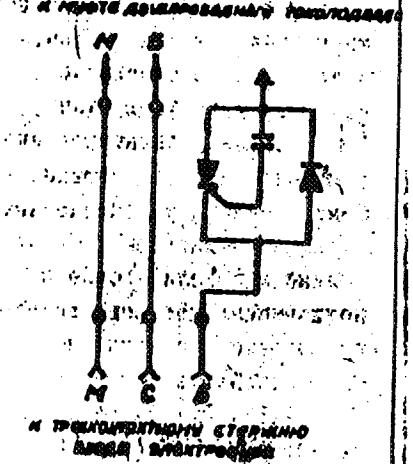
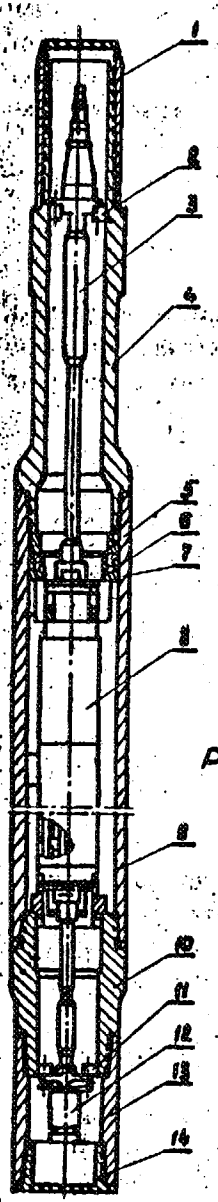


Рис.7. Устройство контроля изоляции

1-Колпак
2-двухконтактный стержень кабельного ввода
3-опора верхняя
4-переводник
5-проставочная втулка
6-кольцо
7-амортизационное кольцо
8-кольцо
9-контейнер
10-упорная втулка
11-корпус
12-промежуточный корпус
13-разъемная опора токопровода
14-опора нижняя
15-трехконтактная муфта кабельного ввода
16-переводник нижний
17-заглушка



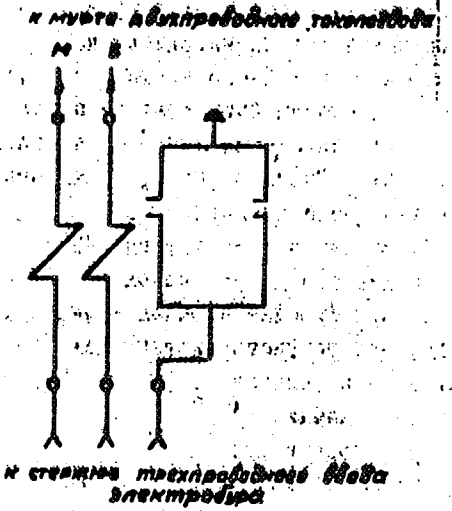


Рис.8. Погружной электромагнитный контактор

1-Заглушка
2-опора верхняя
3-двухконтактный стержень кабельного ввода
4-переводник
5-дистанционная втулка
6-амортизационное кольцо
7-опора
8-электромагнитный механизм
9-корпус
10-промежуточный корпус
11-опора нижняя
12-трехконтактная муфта кабельного ввода
13-нижний переводник
14-заглушка

этих контактов осуществляется силой притяжения двух электромагнитов, магнитные потоки которых действуют на общую подвижную систему, причем замыкание контактов производится после включения электробура на две фазы при помощи линейного контактора, установленного на поверхности. Отсоединение обмотки двигателя от бурильных труб осуществляется контактором после включения линейным контактором всей системы токоподвод-электробур. Таким образом, в отличие от УКИ, погружной контактор разрывает обесточенную цепь.

I.I5. В случаях отсутствия УКИ или КЭП, допускается работа с нижним заземляющим переводником.

I.I6. При бурении скважин электробурами необходимо использовать автоматический регулятор подачи долота. В качестве автомата подачи рекомендуется использовать АВТ-2, осуществляющего подачу инструмента в следующих режимах:

а) по скорости проходки;

б) по осевой нагрузке на долото;

в) по активной составляющей тока и осевой нагрузке на долото (режим АВТ).

В комплект АВТ-2 входят:

Силовой узел АВТ-I, состоящий из приводного двигателя П-82 и редуктора РВ-I000 с $i = II5$;

Мотор-генератор, состоящий из асинхронного двигателя и генератора.

Станция управления (РПДЗ-3 ЛГА 4905-53А2), датчик веса (ДВР-26);

пульт управления (БГА 905I-02AI);

приставка для электробурения (ПЭБ-I).

Силовые узлы АВТ-2 сочленяются с лебедками буровых установок "Уралмаш - 6Б" и "Уралмаш - 4Э", однако в комплект этих установок не входят и поставляются отдельно. Также отдельно, при условии требования заказчика, заводом УЗТМ поставляются заводочки ($\mathcal{Z} = 47$ для установки 4Э) для подключения силового узла АВТ-2.

I.I7. Редуктор-вставка планетарного типа, маслонаполненный (рис. 9) монтируется между двигателем и шпинделем электробура с целью снижения числа оборотов и, соответственно, увеличению крутящего момента электробура. Редукторы-вставки выполняются в диаметрах, соответствующих ряду электробуров и имеют передаточное отношение $i = 2$ и $i = 3$.

Для ограничения максимального крутящего момента электробура, при применении редукторов-вставок, исходя из механической прочности кон-

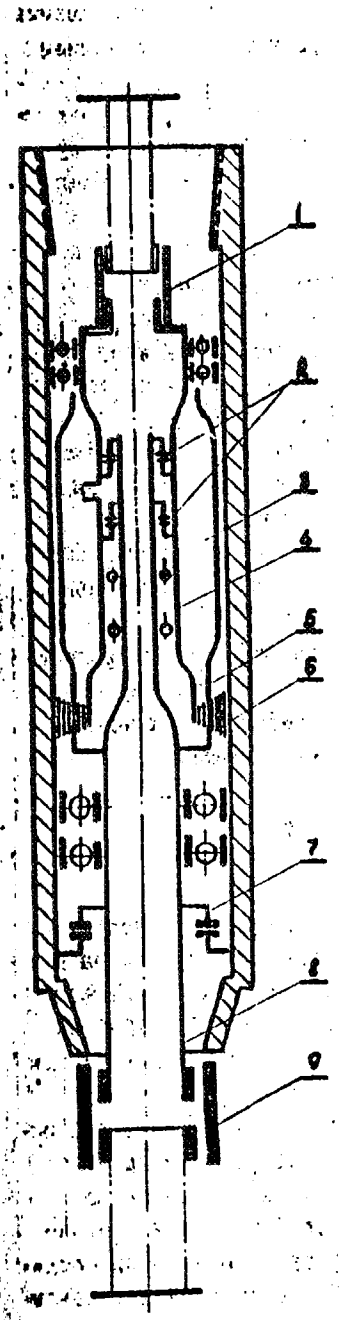


Рис. 9. Редуктор-вставка

I - муфта соединительная
2 - вальник верхний
3 - компенсатор
4 - ведущий вал-шестерня
5 - водило
6 - неподвижная шестерня
7 - вальник нижний
8 - ведомый вал
9 - муфта соединительная

струкции, номинальное напряжение электродвигателя должно быть понижено. Энергетические показатели электробуров с редукторами-ротаторами приведены в приложении 4.

I.I8. Телеметрическая система ТСЭ предназначена для контроля за геометрическими параметрами ствола скважины (угол наклона и азимута) и положением отклонителя в процессе бурения скважин электробурами и состоит из погружной и наземной аппаратуры.

Погружная часть, заключенная в отдельный немагнитный корпус, содержит комплект измерительных датчиков и электронной аппаратуры (рис. I0) и устанавливается непосредственно над электробуром, снабженным механизмом искривления, или без него. Наземный комплекс состоит из приемного пульта с указывающими и регистрирующими приборами, который может находиться как непосредственно на буровой у поста бурильщика, так и в подсобном помещении (в будке мастера) и фильтра для подключения наземного пульта к токоподводу электробура и разделения частоты силовой сети (50 гц) от частот системы.

Каналом связи служит токоподвод электробура, по которому информация от забойных датчиков поступает на поверхность к измерительным приборам.

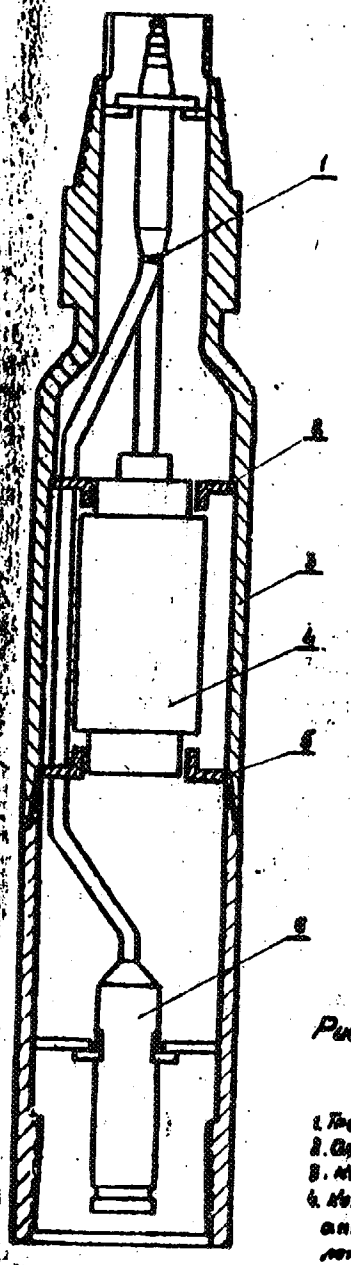
Кабельная секция системы в верхней части корпуса имеет трехконтактный стержень, а в нижней – трехконтактную муфту. На схему блока питания, расположенного в контейнере, подается питание от средней фазы кабельного ввода . Второй конец схемы-блока заземлен.

Пределы измерений глубинных параметров:

угол наклона скважины	$0 - 60^0$	$\pm\ 1{,}5^0$
азимут скважины	$0 - 360^0$	$\pm\ 7{,}5^0$
угол направления отклонителя	$0 - 360^0$	$\pm\ 7{,}5^0$.

I.I9. Механизм искривления скважины (МИ) (рис.II) предназначен для бурения наклонно-направленных скважин, зарезки нового ствола и борьбы с кривизной скважины. Выполняются они в диаметрах, соответствующих ряду электробуров (МИ-I64, МИ-I70, МИ-I85, МИ-2I5 и МИ-240) в I, I,5 и 2-градусном исполнении и устанавливаются между двигателем и шпинделем электробура.

I.20. Отбор керна при бурении электробурами осуществляется с помощью специального приспособления СК-I64/80 (рис.I2). Это приспособление представляет собой доработанную конструкцию керноотборника СК-I64/80 3д, разработанную ВНИИБТ и выпускаемую Павловским машиностроительным заводом, применительно к электробуру (изменены присоединительные переводники и смонтирован клапан). Керноотборник изготавли-



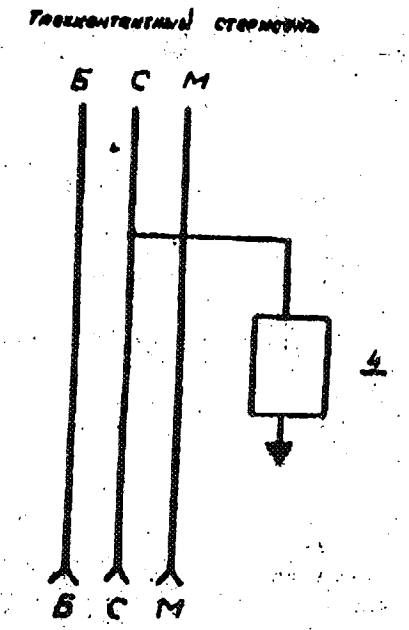


Рис.I0. Телеметрическая система (ТСЭ)

1. Трехконтактный стержень кабельной секции
2. Сорок бронзовый
3. Корпус
4. Контейнер герметичный с измерительной аппаратурой (угол наклона, азимут, положение отклонителя).
5. Опора шпинделя
6. Трехконтактная муфта кабельной секции

Схема соединения валов

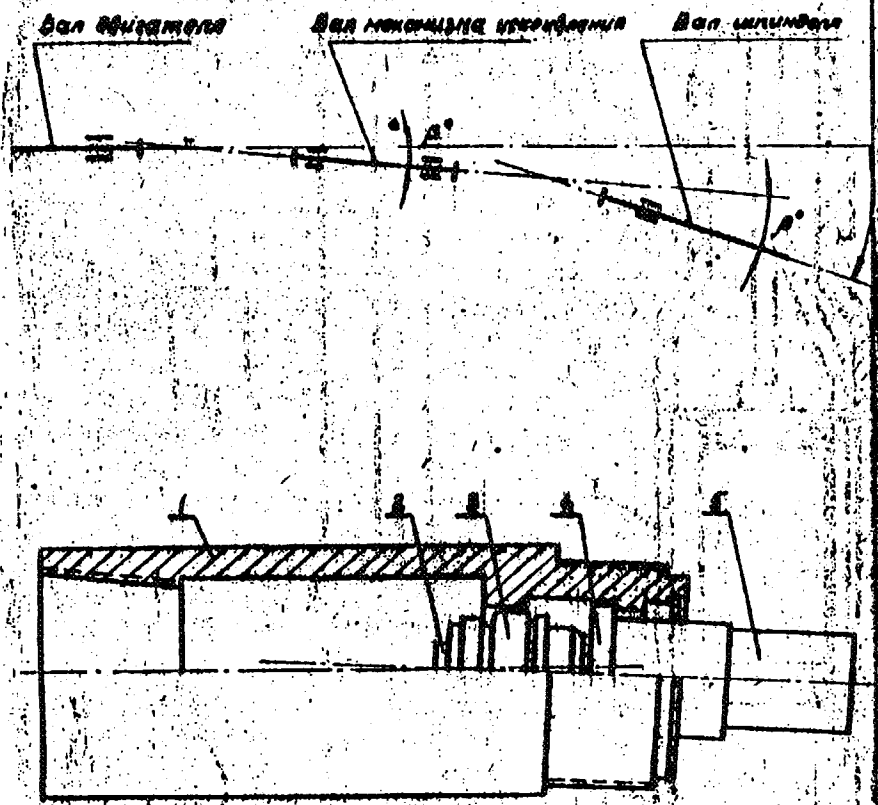
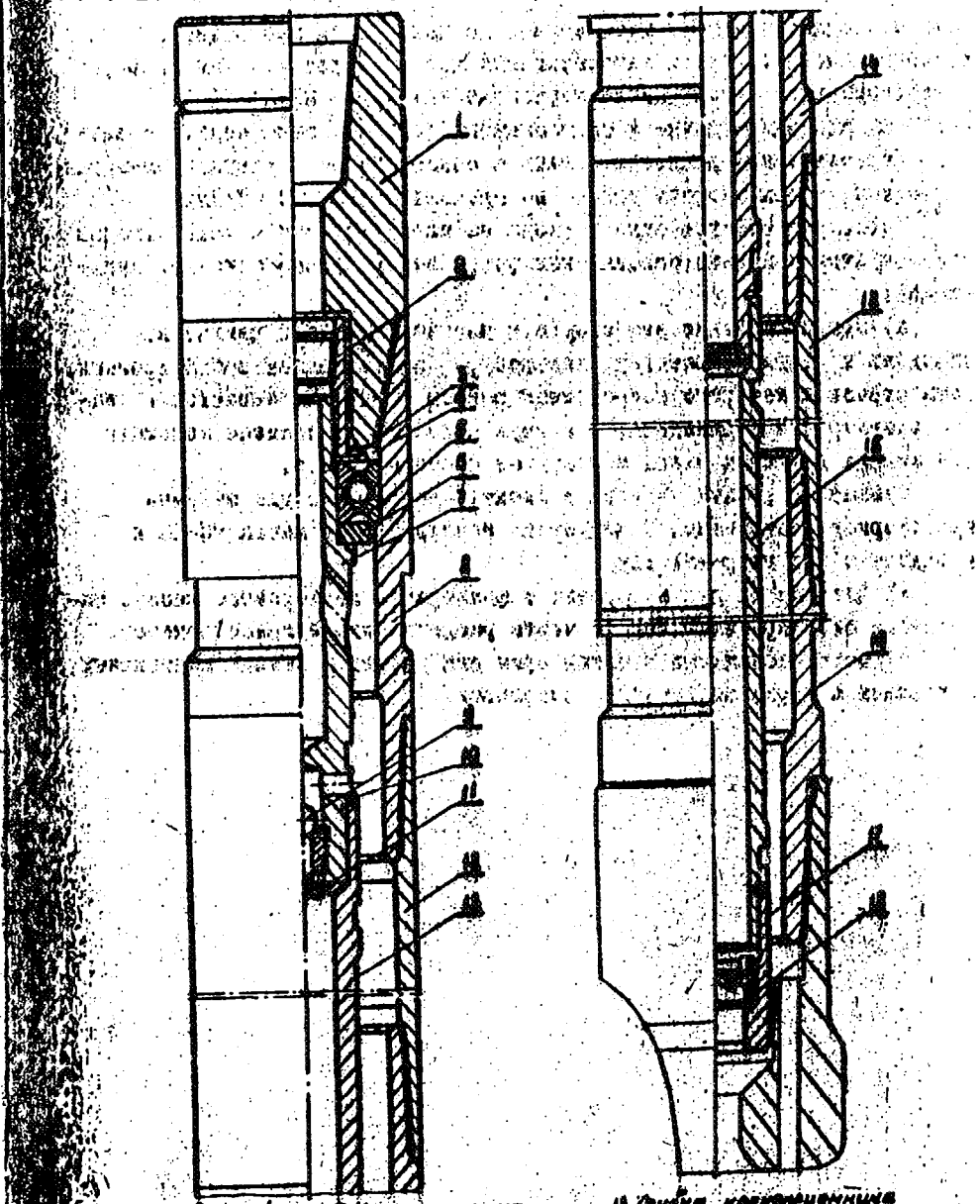


Рис. 11. Механизм искривления

1- корпус
2- гайка
3- полумуфта
4- подшипник
5- вал

Рис. 12. Устройство для отвода керна



1 Переводник верхний
2 Гайка
3 Шайба
4 Шайба
5 Шарикоподшипник
6 Шарнир разгружающий
7 Корпус клапана
8 Корпус подшипника
9 Шарнир
10 Шайба стопорная
11 Проволока
12 Корпус
13 Гайка контрольная
14 Переводник промежуточный
15 Труба центральная
16 Переводник нижний
17 Узел
18 Колокольчик собачковый

вается в односекционном исполнении, но может быть превращен в двух- и трехсекционный, путем навинчивания дополнительной секции корпуса и керноприемной трубы. Длина керноприемной трубы 8200; 16400 и 24600 мм для одно- двух- и трехсекционного исполнения соответственно.

Керноотборник должен работать с электробуром с редуктором-вставкой с тем, чтобы обороты долота не превышали 200-230 об/мин.

I.2I. Для обслуживания и ухода за электробурами и токоподводом используется комплекс специальных устройств и приспособлений, включающий:

а) Приспособление для замера и подкачки масла в двигатель, шпиндель и редуктор-вставку электробура, представляет собой тройник, один отросток которого посредством резьбы М10хI навинчивается в клапан двигателя или шпинделя, а к двум другим подсоединены манометр для замера давления масла и шланг от ручного насоса.

б)Бачки с ручным насосом и электро-подогревом для закачки трансформаторного масла в двигатель электробура и масла МС-20 в шпиндель и редуктор-вставку.

в) Устройство для подогрева и фильтрации касторового масла, питающееся от напряжения 220 в. через разделительный трансформатор.

г) Щетки контактные и щетки серы для чистки и смазки контактных (стержней и муфт) соединений токоподвода.

Начальник
отдела электробура
Ишеронского УБР

Ахадов Р.А.

ВВЕДЕНИЕ

Бурение на Апшеронском полуострове ведется более 150 лет. За этот период нынедействующие нефтяные месторождения Апшерона, ввиду длительной эксплуатации пластов, сильно истощились. В результате дренированности пластов значение давлений в них значительно снизилось, что привело к возникновению аномально-низких пластовых давлений. Указанный фактор приводит к осложнениям при бурении, обусловленных катастрофическим поглощением и уходом в пласты буровых растоворов. Геологический разрез нефтяных месторождений Апшеронского полуострова в основном представлен продуктивной толщей. По мере углубления скважин крепость горных пород возрастает, что существенно влияет на скорость бурения скважин. За длительный период буровых работ на Апшероне использовались в начале роторный и турбинный способы бурения. Роторным способом в основном бурились вертикальные скважины, бурение же наклонно-направленных скважин осуществлялось роторно-турбинным способом. Однако, использование турбобура по мере истощения пластов стало сокращаться, т.к. стали создаваться дополнительные гидродинамические давления, приводящие к поглощению и уходу буровых растворов. Поэтому по мере проведения бурения электоробуром, объемы работ из года в год возрастали и в 1982-1986 годах достигли 60-70 тыс.метров проходки в год.

Преимущества применения электоробурения на Апшероне следующие :

1. Высокие скорости бурения, связанные с наибольшей частотой вращения двигателя с долотом, достигающие 600-650 об/мин.

2. С целью увеличения рейсовых скоростей электробурения широкое применение получило использование алмазных долот и типа ИСМ. Средняя проходка на эти долота составляет 500-600м против 50-60м при роторном бурении с использованием трехшарошечных долот.

3. Бурение дренированных интервалов с АНПД осуществляется при минимальной производительности буровых насосов, что обеспечивает наименьшее гидродинамическое давление в кольцевом пространстве. Совокупно с добавками наполнителей (опилки, резиновая крошка и т.д.) предотвращается поглощение и уход раствора в пласты. Использование наполнителей при турбинном способе бурения не возможно ввиду засорения турбины, турбобура.

4. При бурении наклонно-направленных скважин непрерывно поступает информация о траектории ствола (кривизна, азимут) посредством телеметрической системы (ТС), установленной над электробуром. Регулирование траектории ствола скважины осуществляется механизмом искривления (МИ 1,5÷2,0), расположенным над шпинделем электробура, что обеспечивает гарантию попадания в цель.

5. Подача электороэнергии на электробур осуществляется кабельными секциями, закрепленными на бурильных трубах. Электрическое напряжение в кабельных секциях регулируется трансформатором 6 КВА, расположенным на электроподстанции, от 1200 до 1800 В, в зависимости от глубины скважины.

6. В процессе электробурения нагрузка на долото корректируется 3-мя датчиками силы тока, установленными над индикаторами, показывающими любой момент силы тока в каждой из трех фаз электродвигателя. На нефтяных промыслах, во многих случаях, учитывая плотность скважин на карте Апшерона, из-за наличия промысловых вышек невозможно бурить вертикальные скважины. Наиболее эффективным является использование электробура в кустовом бурении. Для уменьшения числа оборотов вала двигателя применяются редукторные вставки над шпинделем, что позволяет поддерживать число оборотов до 200÷250об/мин. Это позволяет использовать широкую гамму, в основном, высокооборотных, 3-х шарошочных долот.
Сравнение электробурения и турбобурения проводится по следующим основным критериям :

- Скорость бурения : коммерческая, механическая и рейсовая; м/ст. мес, м/час
- Цикл строительства скважин, сутки
- Скорость одного метра проходки
- Затраты на цикл строительства скважин
- Ремонт и техническое обслуживание турбобуров и электробуров, затраты времени и стоимость
- Износ буровых насосов (ремонт гидравлических элементов)
- Износ бурильных труб

К недостаткам электробурения следует отнести :

- Пробои в кабельных секциях, в основном по причине недостаточной отчистки стержней
- Нежелательность использования смазывающих добавок в раствор нефти, которые размегчают резиновые части кабеля
- Наличие в растворе пузырьков газа приводит к его проникновению в стыки секции, в следствии чего возникают пробои.
- Ограниченность применения электробурения в зависимости от глубины скважины
- Невозможность проведения геофизических работ через бурильные трубы при авариях.

В Апшеронском Управлении Буровых Работ (УБР) используются следующие типы электробуров :
Э - 240 , D=240мм
Э - 190 , выпуск 1970 года, 676 Оборотов/ мин.

При электробурении используются трехшарошочные долота типа :
III- 349,3 С ; III - 295,3 СГВ; III - 244,5 СГВ; III - 215,9 СГВ; СЗГВ; МГВ; III - 190,5 СГВ; СЗГВ и долота типа ИСМ; ИСМ - 295,2 МС; ИСМ - 242,1 МС; ИСМ - 214,3 МС-6; ИСМ - 188 МС.
При использовании редуктора ИСМ - 295,3РГ; ИСМ - 267,7РГ; ИСМ - 188РГ; ИСМ - 214,3РГ.

СКОТТИШ КАСПИАН ТРЕЙД Самед Абасгулиев

1. Бурение на Апшеронском полуострове ведется более 150 лет. За этот период на всех нынедействующих нефтяных месторождениях Апшерона ввиду длительной эксплуатации пласты сильно истощились. В результате дренированности пластов значение давлений в них значительно снизилось, что привело к возникновению АНПД. (аномально-низкие пластовые давления) Указанный фактор приводит к осложнениям при бурении, обусловленных катастрофическим поглощением и уходом в пласты буровых растворов. Геологический разрез нефтяных месторождений Апшеронск. полуострова в основном представлен продуктивной толщей. По мере углубления скважин крепость горных пород возрастает, что существенно влияет на скорость бурения скважин. За длительный период буровых работ на Апшероне использовались в наклоне роторный и турбинный способы бурения. Роторным способом бурятся в основном вертикальные скважины, бурение же наклонно-направленных скважин осуществилось роторно-турбинным способом.

Однако использование турбобура по мере истощения пластов стало сокращаться, т.к. создавались дополнительные гидродинамические давления, приводящие к поглощениям и уходам буровых растворов. Поэтому по мере бурения электробурением объемы его из года в год возрастали и в 1982-1986 годах достигли до 60-70 тыс. метров проходки в год. Преимуществами электробурения на Ашероне являются:

1. высокие скорости бурения связанным с наибольшей частотой вращения двигателю с долотам достигающие 600-650 об/мин.

2. С целью увеличения рейсовых скоростей электробурения широкое применение использование долот типа ИСМ и алмазных. Средняя проходка на эти долота составляет 500-600м против 50-60м при роторном бурении с использованием 3х-шарошных долот.

3. Бурение дренированных интервалов с АНПД осуществляется применяется при максимальной производительности буровых насосов, что обеспечивает наименьшие гидродинамические давление в кольцевом пространстве. Совокупно с добавками наполнителей (опилки, резиновая крошка и т.д.). В основном предотвращается поглощения и уход раствора пласты. Использование наполнителей при турбинном способе бурение не возможно, ввиду засорения турбины, турбобура,

11. В Апшероне УБР используются следующие типы электробуров:

Э-240 D=240 м

Э-190 выпуск 1970 года 676 об/мин

При электробурении используются 3-шарошечные долота типа Т-349,3 С, ТЗ-295,3 СГВ, ТЗ-244,5 СГВ, ТЗ-215,9 СГВ; СЗГВ; МГВ, ТЗ-190,5 СГВ, СЗГВ, и долота типа ИСМ, ИСМ-295,2 МС; ИСМ-242,1 МС; ИСМ-214,3 МС ИСМ-188 МС.

При использовании редуктора ИСМ-295,3 РГ, ИСМ-269,9 РГ, ИСМ-214,3 РГ, ИСМ-188 РГ, Наиболее оптимальное

долот и электробура: дол 349,3, 295, 269,9 с Э-240

долот 244,5, 215,9 с Э-190

долот 190,5 с Э-164

К недостаткам электробурения следует отнести;

1) пробои в кабельных секциях, в основном по причине недостаточной очистки стержней.

2) нежелательность использования смазывающих добавок в раствор - нефти и сиш которые разъедают резиновые части кабеля (муфта).

3) при наличие в растворе пузырьков газа и газопроявлениях, газ проникает в стыки секции и приводит к пробоям.

4) ограниченность применения эл. бурения в зависимости от глубины скважин. (температура раствора).

5) невозможность проведения геофизических работ через бурильные трубы при авариях.

Тип ЗКБ и ХН. з. 24 т. 10 т. 87 г.

4. При бурении наклонно-направленных скважин непрерывно поступает информация о траектории ствола (кривиз., азимут) посредством телеметрической системы (ТС) установленной над электробуром. Регулирование траектории ствола скважины осуществляется механизмом искривления (МИ-1,5÷2), расположенной над шпинделем электробура, что обеспечивает гарантие попадания в цель. Проводка же наклонных скважин турбобурам безпрерывно информации о координатах забоя не имеется ввиду отсутствия телеметрической системы на забое.

5. Подача электроэнергии на электробур осуществляется кабельными секциями, заключенными в бурильных трубах. Электрическое напряжение в кабельных секциях регулируется от 1200÷1800 вольт в зависимости от глубины скважины трансформатором 6 кВа, расположенном на электроподстанции.

6. В процессе электробурения нагрузка на долота корректируется 3-мя датчиками силы тока, установленными над индикаторами, показывающими в любой момент силу тока в каждой из трёх фаз электродвигателя. На нефтяных промыслах Апшерона учитывать плотность скважин на карте

разработки неподволяет во многих случаях проводить вертикальные скважины из-за наличие промысловых вышек.
Использование же кустового бурения электробура наиболее эффективно.
Для уменьшения числа оборотов вала двигателя применяется редукторные вставки над шпинделем что позволяет иметь число оборотов до 200÷250 об/мин.
Это даёт возможность использовать широкой гаммы 3-х шарошечных долот в основном высокооборотных. Для сравнение электробурения и турбобурения основными критериями является:
1) скорость бурения коммерческая, механическая, рейсовая м/ст-мес, м/час.
2) Цикл строительства скважины, сутки
3) скорость 1 м проходки
4) затраты на цикл строительства скважины
5) ремонт и тех. обслуживания турбобуров и электробуров, затраты времени и стоимость
6) износ буровых насосов (ремонт гидравлических элементов)
турб. —
электробур —
7) Износ бурильных труб
турб —
электробур —

Копирование, инв. и отчество
АВТОЗАПРАВКА

ОСНОВНЫЕ ХАРАКТЕРИСТИКИ ЭЛЕКТРОБУРОВ, ПРИНЯТЫХ К ВЫПУСКУ В 1970-1980 ГОДАХ

Тип эл.буров	Диаметр мм	Длина, м	Мощность КВт	Ток А		Скорость вращения об/мин	Момент вращения кгм		КПД %	COS φ	Вес,т	Напряжение В
				Рабочий	Холостой		Номин.	Максим.				
Э 240-8	240	13,4	210	144	107	690	297	760	75,0	0,66	3,6	1700
Э 185-8	185	12,5	125	130	93	676	180	360	67,5	0,66	2,05	1250
Э 164-8М	164	12,305	75	87,5	80	685	110	240	61,0	0,625	1,65	1300

ТЕХНИЧЕСКИЕ ДАННЫЕ ЭЛЕКТРОБУРОВ С РЕДУКТОРАМИ - ВСТАВКАМИ

Тип эл.буров	Диаметр мм	Длина, м	Мощность КВт	Ток А	Скорость вращения об/мин	Момент вращения кгм		Вес,т	Напряжение В	Передаточное число редукторов вставки
				Рабочий		Номин.	Максим.			
Э 240-8Р	240	14,78	145	112	230	615	1200	3,9	1400	2,0
Э 185-8Р	185	14,4	70	90	240	300	700	2,3	1100	2,92
Э 164-8МР	164	13,186	45	65	220	200	400	1,80	930	3,13

Основные характеристики электробуров принятых к выпуску в 1970-1980 гг.

Тип электробура	Диаметр мм	Длина м	Мощность номинальная кВт	Напряжение номинальное в	Ток. ск. Расчетное	Ток. ск. Холостого хода при номинальном	Скорость вращения об/мин	Момент кр.м. Номинальный	Момент кр.м. Пусковой	К.П.Д. %	Cos φ	Вес т.
Э240-8	240	13,4	210	1700	144	107	690	297	760	75,0	0,66	3,6
Э185-8	185	12,5	125	1250	130	93	676	180	360	67,5	0,66	2,05
Э164-8М.	164	12,305	75	1300	87,5	80,0	685	110	240	61,0	0,625	1,65

(13)

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Ахадов Р.А.

Технические данные электробуров с редукторными вставками.

Тип эл/бура	Диаметр мм	Длина м	Мощность кВт	Напряжение в	Ток рабочий номинальный а	Скорость вращения об/мин	Момент вращения номинальный кГм	Момент вращения пусковой кГм	Вес т	Передаточное число редуктора вставки
Эл240-8р	240	14,78	145	1400	112	230	615	1200	3,9	2,0
Э185-8р	185	14,4	70	1100	90	240	300	700	2,3	2,92
Э164-8р	164	13,186	45	930	65	220	200	400	1,8	3,13.

Исполнил Ахадов Р.А.

Таблица выбора напряжений бурового трансформатора.

№ п/п	Тип электробура	Номинальное (В), (а).	Глубина бурения (см). 0		500		1000		1500		2000		2800		3000		3500		4000		4500	
			в	а	в	а	в	а	в	а	в	а	в	а	в	а	в	а	в	а	в	а
1	Э164-8М	1300в, 87,5а.	1355	73	1355	71	1547	93	1547	91	1547	89	1547	87,5	1547	86	1547	85	1547	84	1680	100
	Э164-8МР	1000в, 67,5а	1085	49,7	1085	43,5	1085	49,2	1085	49,2	1220	57	1220	56,2	1220	55,5	1220	54,7	1355	63	1355	62
2.	Э185-8	1250в, 130а	1547	135	1547	1335	1547	132	1547	130	1680	147	1680	147	1680	144,5	1680	142,5	1810	1515	1810	151,5
	Эл185-8Р.	1100в, 90а.	1220	78	1220	77	1220	76	1355	92,5	1355	91	1355	89	1547	112	1547	111	1680	127	1680	127
3.	Э240-8	1700в, 144а	1810	107	1810	106	2000	120	2000	119	2000	118	2000	117	2270	143	2270	140	2270	137	2270	134
	Э240-8Р.	1500в, 124а	1680	118	1810	111	1810	109	1810	108	1810	107,5	2000	136	2000	133,5	2000	131	2000	128	2000	128

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Ассесс

Исходов В. Д. А

(П)

Russian Document Translations

Introduction

The drilling on the Apsheron peninsular has been carried on for 150 years. During this period the present Apsheron oil fields become very exhausted due to the prolonged exploitation of the formations. Due to the drainage the formation pressure decreased considerably that led to the abnormally low formation pressure. This leads to the complications during the drilling due to the catastrophic drilling mud loss in the formations. Geologic cross section of the Apsheron oil fields is mainly represented by the productive strata. As the depth of the wells increases the strength of the rock increases as well which effects the rate of drilling. During the drilling operations on the Apsheron peninsular the rotary and turbine motor drillings were used in the beginning. The rotary drilling was used in the vertical wells while rotary-turbine drilling was used in the inclined directionally drilled wells. However, the usage of the floating shaft turbodrill declined with time due to the exhaustion of the formations, since additional hydrodynamic pressures led to the drilling mud losses. Therefore, the drilling with electric downhole motor started to grow from year to year. In 1982-1986 the electrodrilling reached the mark of 60-70 thousand meters of penetration per year.

There are the following advantages of the electrodrilling on the Apsheron peninsular:

1. The high drilling rate due to the higher drilling bit rotations per minute, which could reach 600-650 rotations per minute.

2. In order to increase the bit run rate of the electrodrilling the diamond drilling bits and the bits of the type ISM are widely used. The average penetration for such drilling bits is 500-600 meters compared to 50-60 meters when the rotary drilling with three-cone rock drilling bit is used.

3. The drilling of the drainage intervals with abnormally low formation pressure is done under the conditions of the minimum operating efficiency of the mud pumps, that guarantees the minimum hydrodynamical pressure in the annular space. As the filling agents (sawdust, rubber crumb) are added the drilling mud losses are prevented. The filling agents can not be used during the turbine drilling due to the clogging of the turbine.

4. During the drilling of the inclined directionally drilled wells the information about hole trajectory (curvature, azimuth) is continuously obtained with the help of the telemetry system which is installed above the electric motor. The hole trajectory can be controlled by the "bending device" (I could not find how to translate this) situated above the spindle of the electric motor. This guarantees the precision of the drilling.

5. The electric power is delivered to the electric motor by the cable sections which are attached to the drill pipes. The voltage in the cable sections is controlled by the transformer 6 KVA (probably Kilovolt-ampere) situated electric power sub-station. The voltage varies from 1200 to 1800 Volts depending on the depth of the well.

6. During the electrodrilling the load on the bit is corrected by 3 current intensity sensors which are installed above the indicators showing all the moments of the current intensity in each of the three phases of electric motor. Due to the high density of the wells and due to the presence of derricks the vertical drilling is often impossible in the Apsheron oil fields. The usage of the elctrodrilling in cluster drilling proved to be very effective. In order to reduce the number of rotations of the shaft of the motor the reducer insertions are used above spindle. This keeps the number of rotations in the interval of 200-250 rotations per minute. It allows to use a wide variety of different three-cone rock drilling bits, mainly high-rotating.

The comparison of electrodrilling and turbodrilling is done according to the following criteria:

- The rate of drilling: commercial, mechanical and bit run: meters/month, meters/hour.
- Cycle of well construction, days
- The cost the cycle of well construction
- Repairs and maintenance of turbodrill and electric motor, the cost and time
- The wear of the mud pumps (repair of the hydrolic elements)
- The wear of the drilling pipes

The shortcomings of the electrodrilling include:

- Spark-overs in the cable sections, usually due to insufficient cleaning of the rods
- The usage of the lubricating additions in oil solutions is undesirable since it softens the rubber parts of the electric motor.
- The presence of the gas bubbles in the solution leads to its penetration into junctions and sections. This leads to spark-overs.
- The electrodrilling is restricted by the depth of the drilling.
- It is impossible to conduct the geophysical work through the drilling pipes when failure happens.

The following types of the electric downhole motors are used on Apsheron:
E-240, D=240 mm
E-190, made in 1970, 676 rotations per minute
During the elctrodrilling the following types of three-cone rock drilling bits are used:
III-349.3 S; III-295.3 S; III-244.5 SGV; SZGV; MGV; III-190.5 SGV; SZGV
During the elctrodrilling the following bits of type ISM are used: ISM-295.2 MS; ISM-242.1 MS; ISM-214.3 MS-6; ISM-188 MS.
When the reducer is used: ISM-295.3 RG; ISM-267.7RG; ISM-188RG; ISM-214.3RG.

The main characteristics of the electric downhole motors made in 1970-1980

Type of the motor	Diameter, mm	Length, m	Capacity, Kilowatt	Current, A		Rate of rotation, rotations / min	Torque, Kilogram meter		Efficiency, %	cos φ	Weight, ton	Voltage, V
				working	idle		nominal	maximum				
E 240-8	240	13.4	210	144	107	690	297	760	75.0	0.66	3.6	1700
E 185-8	185	12.5	125	130	93	676	180	360	67.5	0.66	2.05	1250
E 164-8M	164	12.305	75	87.5	80	685	110	240	61.0	0.625	1.65	1300

Technical data for the electric downhole motors with reducer insertions

Type of the motor	Diameter, mm	Length, m	Capacity, Kilowatt	Current, A	Rate of rotation, rotations/min	Torque, Kilogram meter		Weight, ton	Voltage, V	Gear ratio of reducer insertions
				working		nominal	maximum			
E 240-8R	240	14.78	145	112	230	615	1200	3.6	1400	1700
E 185-8R	185	14.4	70	90	240	300	700	2.05	1100	1250
E 164-8MR	164	13.186	45	65	220	200	400	1.65	930	1300

Table of the voltages of the drilling transformer

# ?	Type of the motor	Nominal Data (v), (a)	Depth of the drilling, meters											
			0		500		1000		1500		2000		2500	
			v	a	v	a	v	a	v	a	v	a	v	a
1	E 164-8M	1300v, 87.5a	1355	73	1355	71	1547	91	1547	91	1547	89	1547	87.5
	E 164-8MR	1000v, 61.5a	1085	49.7	1085	43.5	1085	49.2	1085	49.2	1220	57	1220	56.2
2	E 185-8	1250v, 130a	1547	135	1547	133.5	1547	132	1547	120	1680	147	1680	147
	E 185-8R	1100v, 90a	1220	78	1220	77	1220	76	1355	92.5	1355	91	1355	89
3	E 240-8	1700v, 144a	1810	107	1810	106	2000	120	2000	119	2000	118	2000	117
	E 240-8R	1500v, 124a	1680	118	1680	111	1810	109	1810	108	1810	107.5	2000	136

# ?	Type of the motor	Nominal Data (v), (a)	Depth of the drilling, meters					
			3000		3500		4000	
			v	a	v	a	v	a
1	E 164-8M	1300v, 87.5a	1547	86	1547	85	1547	84
	E 164-8MR	1000v, 61.5a	1220	55.5	1220	54.7	1355	63
2	E 185-8	1250v, 130a	1680	144.5	1680	142.5	1810	1515
	E 185-8R	1100v, 90a	1547	112	1547	111	1680	127
3	E 240-8	1700v, 144a	2270	143	2270	140	2270	137
	E 240-8R	1500v, 124a	2000	123.5	2000	131	2000	128

Electric Downhole Motor

1.4. Electric downhole motor (see Figure 2) is a submersible downhole unit which rotates a drilling bit when drilling oil and gas wells. It consists of electric motor and spindle.

Electric motor and spindle are connected by tapered thread. Their shafts are connected by gear-type coupling (clutch) 24 and hinged bush (sleeve) 23 with rubber rings. The top part of electric downhole motor has a sub 2 with a neck for elevator gripping. At the end sub has a tool joint pin for drilling pipes connections.

1.5. A unit has induction, three-phase, oil-filled electric motor with short-circuited rotor . It consists of the following main components: stator, rotor, compensator, upper and lower packing boxes.

1.6. A stator 13 is a cylinder with packages of magnetic and non magnetic sheets pressed in it. Packages of magnetic sheets serve as a magnetic circuit while packages of non magnetic sheet metal serve as a support for intermediate rotor bearings.

A stator has a pivot winding, with coiled scheme. Every pivot of winding consists of several separate isolated copper conductors with rectangular cross section. The winding is connected as $\curlyvee$, zero is soldered inside while three other leading-out ends are connected to a cable inlet by a plug.

1.7. A rotor of an electric motor consists of hollow shaft 11, with separate rotor packages 16 on it and radial bearings 15 in between them. A rotor axial support 18 consists of two ball bearings at the lower end of the shaft. Rotor packages are assembled of steel sheets, cage is filled by aluminum or welded with copper rods with short-circuited rings.

1.8. In order to provide a normal functioning of the electric motor winding and rolling supports the existing electric downhole motors require protection from the penetration of washing fluid into them. In order to do that upper and lower ends of electric motor's shaft are sealed with packing boxes 8 and 19. Sealing elements of packing boxes are represented by face rings which are in contact with each other. Contact between the rings is provided by a spring and difference in pressure. One of the rings is attached to the shaft and rotates with it, the other one is stationary and attached to frame.

1.9. Compensator 6 provides an excess of internal pressure over external due to the fact that spring acts on piston in addition to surrounding pressure. Compensator has oil in it, this allows it to expand when an electric motor is working, thus preventing an excessive pressure inside and also compensating the loss of oil through moving and stationary seals. An inside chamber of an engine is filled with transformer oil. Rubber rings with round cross section are used in order to seal moving and stationary joints in an electric motor.

1.10. A spindle 22 of an electric downhole motor is used to transfer an axial load which is created by the part of the weight of a drill pipe running string on a drilling bit through a frame of an electric downhole motor by-passing a rotor of an electric motor. It also transfers the torque from an electric motor to a drilling bit. Spindle consists of a hollow shaft 34 mounted on rolling bearings in frame 22. An upper radial support consists of two roller bearings 27, a lower radial support consists of three roller bearings or one three-row roller bearing. A multi-row vertical journal consisting of thrust bearings 28 with rubber dampener is used as an axial support. Rubber dampeners allow an axial load to spread evenly on among bearings. To carry an axial load which appears when the unit is lifted or while reaming the hole ahead there is a reverse vertical journal in the form of thrust

ball bearing 26. An internal chamber of a spindle is filled with aircraft oil MS-20. To create excessive pressure (compared to surrounding pressure), to compensate a possible oil loss through the seals and to compensate an oil fault during thermal expansion while operating, there is a compensator in the middle part of a spindle which works in the same way as a compensator in an electric motor. To seal a spindle an upper end of a shaft has a joint seal 23 and a lower end is sealed by a face packing box 32.

The technical data for electric downhole motors are given in appendices 2 and 3.

1.11. Electric current supply of an electric downhole motor is used to transfer the electrical energy from the surface to an electric downhole motor which is run into a hole in a drill pipe running string. Electric current supply consists of separate double-contact (double-wire) cable sections assembled in drill pipe running strings (see Figure 4) which are used as electric wire (system "two wires-pipe").

When an electric downhole motor is run into a hole, cable sections, connecting in series, create a continuous electric power transmission line. Cable section (see Figure 5) consists of hose flat twin cable section, double-contact rod, double-contact coupling (clutch) and supports for fastening. It is possible to use two single-core cables instead of twin cable (according to drawing SKTBE 5TSch.540.907).

A current collector is used to transfer an electric energy from a stationary system - electric cable, to a rotating system - electric current supply in the drilling pipes. It is also used to transfer from a three-phase system to a system "two wires-pipe" by grounding a lower contact ring. A current collector TE (Figure 6) consists of slanting shaft 1 with current collecting contact rings 18 and leading-in head mounted on it, housing 8 with an electric current supply device which has a continuous contact with contact rings due to brushes 5. The ends of a cable head are connected to brushes by lugs. A body of a cable head is made of rubber with armoring and has a thickening which when squeezed by flange forms a seal in a side hole of a shaft. Second ends of a cable head are soldered to contact arm of contact cable coupling (clutch) mounted in the center of a shaft. When a current collector is being screwed on a leading square kelly, a contact coupling (clutch) is connected to a contact rod which is mounted in the nipple of the leading square kelly. An electrical contact with contact rings is provided continuously by brushes which are placed in brush holders 6. Brush holders are screwed to metal sheets. Brushes with brush holders and metal sheets are mounted in housing. A shaft is carried in bronze bearings of housing. There are oil cups for bearing oiling. A current collector is connected to a power line by three-core cable KTShE 3x50.

1.12. Submersible device of type UKI (see Figure 7) or submersible contactor of type KEP (see Figure 8) are designed to control resistance of insulation of a double-wire power supply and resistance of electric downhole motor winding relative to frame (ground) when drilling pipes are not connected.

1.13. The main element of the insulation control of type UKI is represented by noncontacting semiconductor commutating unit. This unit represents the ???-parallel closing of controlled and non-controlled rectifiers in order to gain control. A connection of insulation control UKI provides normal current in all three phases of the electric motor when it has the working voltage. At the same time it introduces a considerable amount of resistance (close to circuit break) into a grounded phase when there is no working voltage on a motor. This allows to measure a resistance of electric motor and current supply relative to the ground. The device does not completely break the circuit of the grounded phase but changes it from fractions of ohm (when there is a working current) to tens of megaohms during an insulation control cycle.

1.14. Submersible contactor KEP, as well as submersible device UKI, is designed for the connection of one phase of an electric motor winding to a drilling pipe and disconnection of it from a drilling pipe during insulation resistance control of a double-wire power supply and resistance control of electric downhole motor winding relative to the ground. An electrical contact between electric motor winding and drilling pipe is implemented by two pairs of open contacts connected in parallel. A closure of these contacts is done by attraction forces of two electric magnets which magnetic fluxes act upon a system. Closure of contacts is done by a linear contactor located at the surface after an electric downhole motor is turned on. Disconnection of electric motor winding from drilling pipes is done by contactor after linear contactor turned on the whole system "electric power supply - electric downhole motor". Thus, unlike UKI device, the loading contactor breaks a disconnected circuit.

1.15. Without KEP or UKI operations are allowed if lower conductor is grounded.

1.16. It is necessary to use automatic feeding controller for a drilling bit when drilling a borehole. It is recommended to use AVT-2 as an automatic feeder. It can feed a drilling bit in the following modes:

a) according to penetration rate;
b) according to axial load on drilling bit;
c) according to active component of current and axial load on drilling bit (mode AVT)

The set AVT-2 includes:

Power unit AVT-1 consisting of drive motor P-82 and reduction gear box RV-1000 with i=115;
Motor-generator consisting of induction engine and generator;
Control station (RPDE-3 PGA 4905-53A2), weight indicator (DER-2b);
Control panel (BGA 9051-02A1);
Unit for electric drilling (PEB-1).

Power units AVT-2 (do not confuse with sets AVT-2) have to be jointed with drilling rig's winches "Uralmash-6E" and "Uralmash-4E". However, power units AVT-2 are not included in AVT-2 set and have to be delivered separately. Also separately, if a customer wants so, plant UZTM delivers sprockets (Z=47 for 4E installation). Sprockets are used for connection of power set AVT-2.

1.17. An oil-filled reduction gear insertion of planetary type (see Figure 9) is mounted between engine and spindle of electric downhole motor in order to reduce rotational speed and therefore increase torque of electric downhole motor. Reduction gear insertions have diameters corresponding to electric downhole motors and have i = 2 and i = 3.

To restrict a maximum torque of electric downhole motor according to mechanical strength of construction nominal (rated) voltage of electric motor should be reduced when applying reduction gear insertion. Power data for electric motors with reduction gear insertions are given in Appendix 4.

1.18. Telemetric system TSE is used to control geometry of borehole (angle of inclination and azimuth) and location of deflector when drilling a borehole with electric downhole motor. It consists of submersible and surface devices.

A submersible part is enclosed into separate non-magnetic frame (box). It has a set of measuring and electronic devices (see Figure 10) and mounted right above electric downhole motor which may or may not have a deflection mechanism. A surface set consists of receiving panel with displaying and registering devices and a filter for hooking up a receiving panel to power feed line. A filter also separates power line frequencies (50

hertz) from system frequencies. A receiving panel may be located right by a borehole at a drilling station and also in operator's booth.

A power feed line serves as a information channel through which information travels from bottom elements to surface measuring devices.

A cable section of system has a three-point spindle in the top part and three-point coupling (clutch) in the bottom part of a frame. A circuit receives power from a middle phase of cable inlet. Second end of a circuit is grounded.

Limits of the measurements of bottom parameters are:

well inclination	0-60°	±1.5°
well azimuth	0-360°	±7.5°
angle of deflector	0-360°	±7.5°

1.19. Deflection borehole mechanism (MI) (see Figure 11) is intended for a drilling of controlled directional wells, sidetracking, control and prevention of well curvature. They have diameters corresponding to electric downhole motors diameters (MI-164, MI-170, MI-185, MI-215 and MI-240) and have 1, 1.5 and 2 degrees models. Deflection mechanism is mounted between engine and spindle of electric downhole motor.

1.20. The coring during electric drilling is done by a special device SK-164/80 (see Figure 12). This device is represented by a retrofitting version of core sampler SK-164/80 3d which was designed by VNIIBT and is manufactured by Pavlovsk machine-building plant. In this modification hook-up subs are changed and valve is added. A core sampler is manufactured in one section design but may be converted into two or three sections by rolling on an addition frame section and core receiver. The length of core receiver is 8200, 16400 and 24600 mm for one, two and three sections design accordingly.

A core sampler should work with reduction gear insertion so that drilling bit rotation rate is below 200-230 rotations per minute.

1.21. The service and maintenance of electric downhole motor and power supply requires a set of special devices which include:

a) Device to control an amount of oil in engine, spindle and reduction gear insertion of electric downhole motor and pump up oil into these parts. Such a device is represented by T-joint one end of which is screwed into engine or spindle valve (by the thread M10x1). Two other ends are connected with pressure gage to measure oil pressure and to a hose of hand-operated pump.

b) Buckets with hand-operated pump and electric heating for pumping transformator oil into an engine of electric downhole motor and MS-20 oil into spindle and reduction gear insertion.

c) Device for heating and filtration of castor oil which is powered by 220 volts through transformer.

d) Brushes for cleaning and oiling of contact connections (couplings and spindles) of power supply.

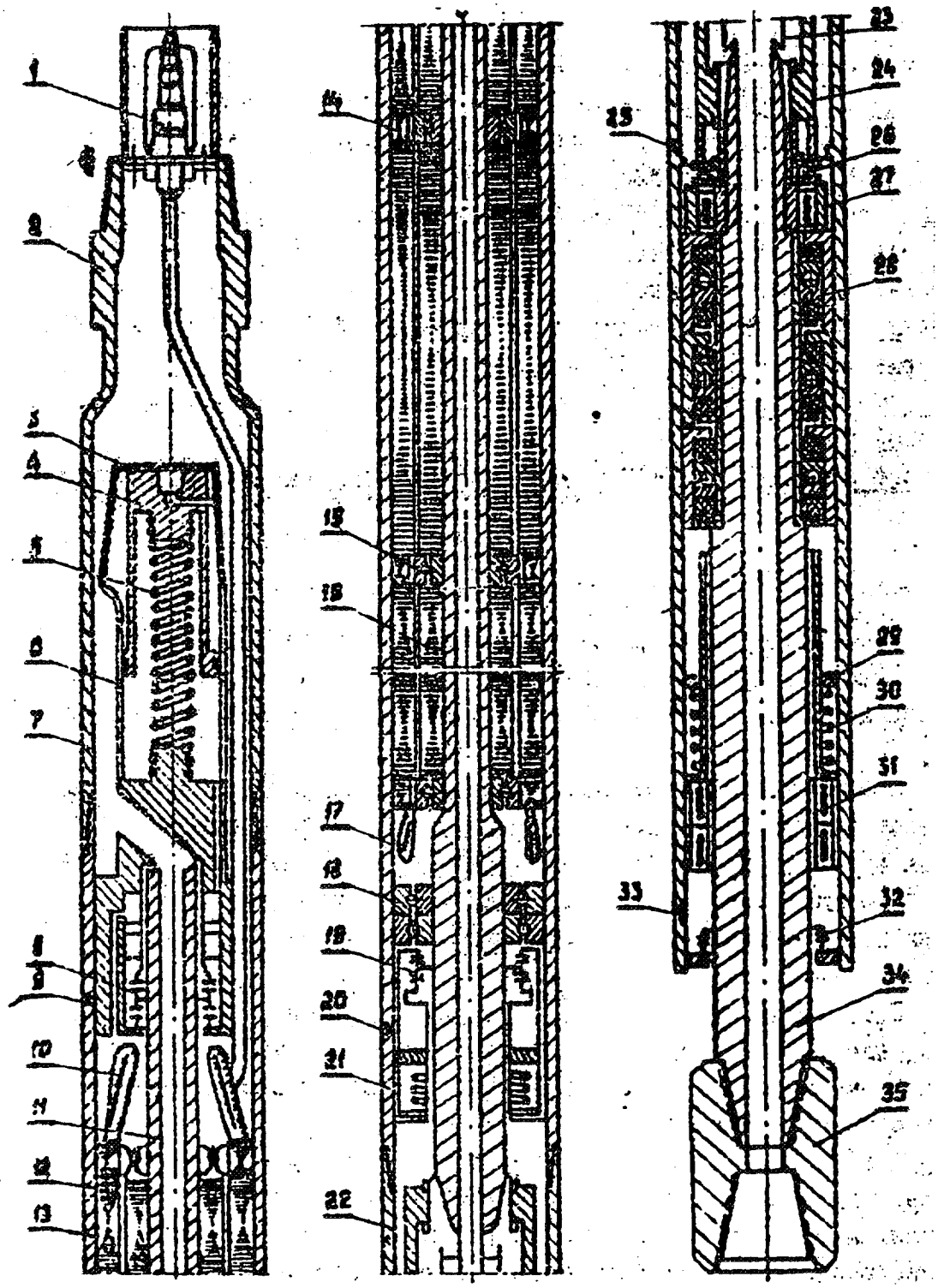


Figure 2. Electric Downhole Motor

1-Contact rod of cable inlet, 2-sub for elevator, 3-rubber diaphragm of engine's compensator, 5-compensator's piston, 6-compensator's cylinder, 7-upper connecting frame of engine's stator, 8-upper packing box of an engine, 9-upper engine's valve, 10-upper frontal part of stator winding, 11-engine's shaft, 12-package with magnetic steel, 13-stator frame, 14-intermediate package of non magnetic material, 15-intermediate engine's bearing, 16-rotor section, 17-lower frontal part of stator winding, 18-rotor axial support, 19-lower packing box of an engine, 20-plug, 21-upper connecting frame of engine's stator, 22-spindle's frame, 23-joint seal, 24-gear-type clutch (coupling), 25-plug, 26-thrust ball bearing, 27-upper radial bearing, 28-section of ball journal, 29-compensator's piston, 30-compensator's spring, 31-radial bearing, 32-packing box (seal), 33-valve, 34-spindle's shaft.

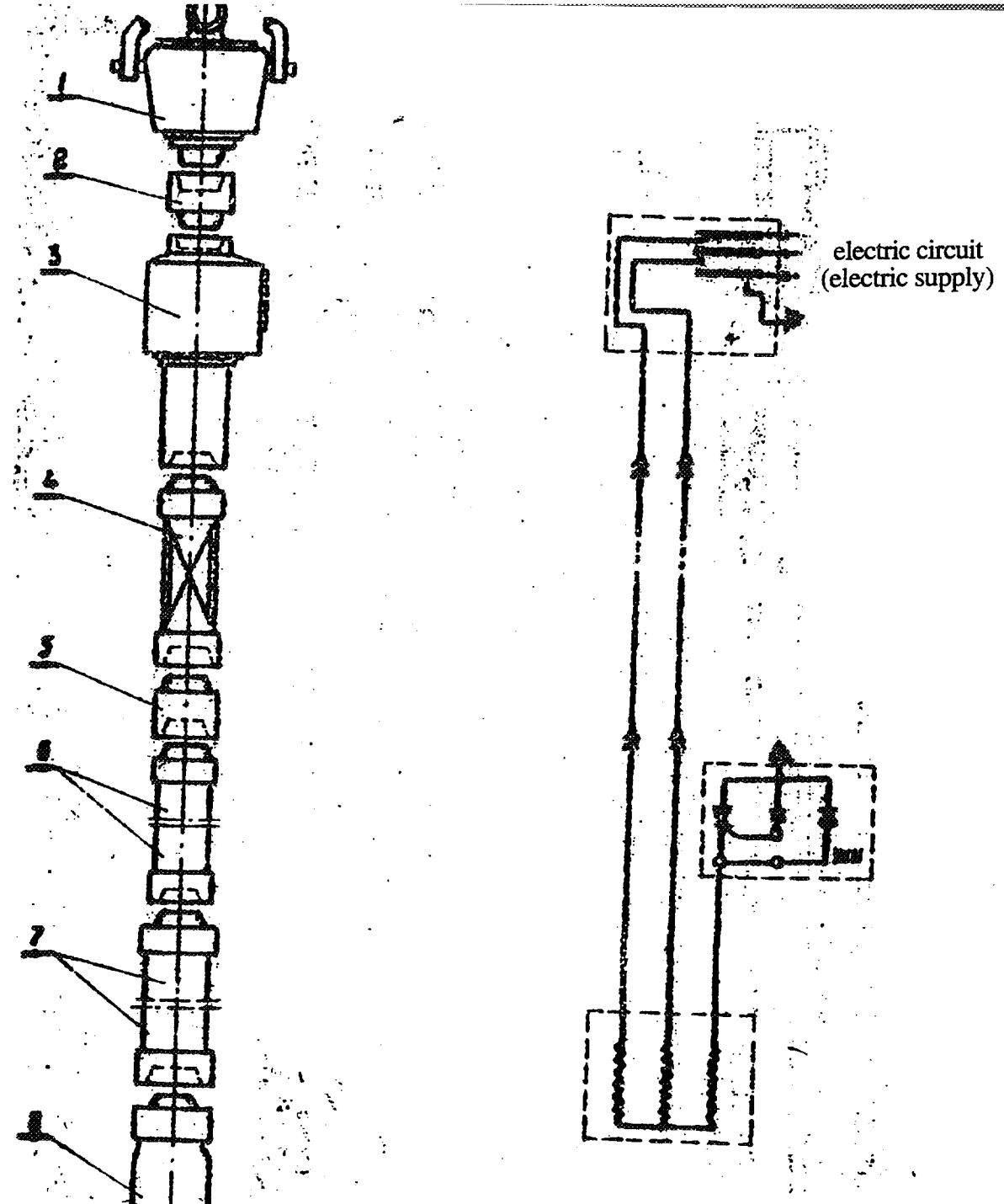


Figure 3. Drilling tools layout for electric downhole motor drilling
1-swivel
2-sub
3-current collector
4-square kelly
5-safety sub
6-drilling pipes
7-drill collar
8-device for insulation control
9-electric downhole motor
10-bottom collar sub
11-drilling bit

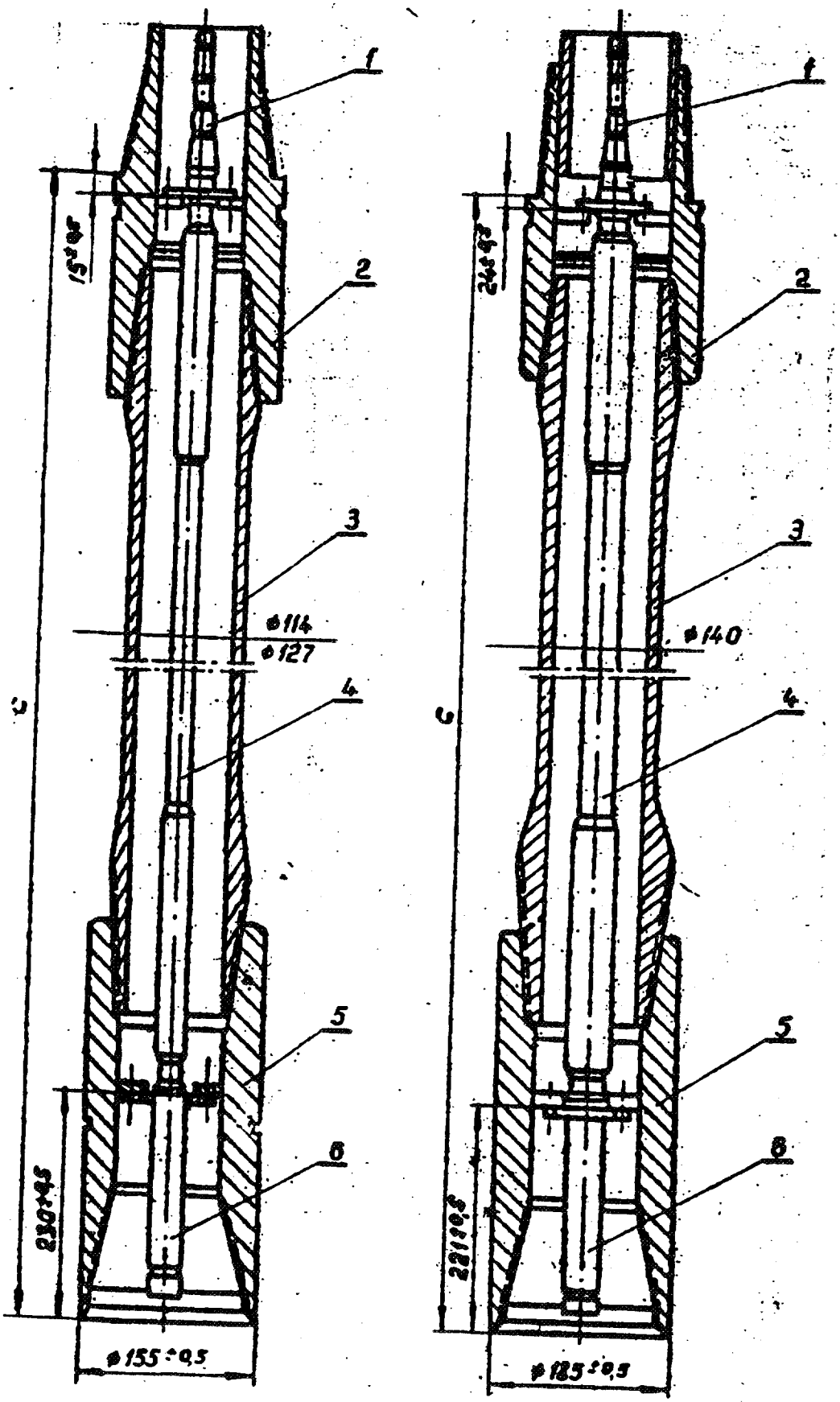


Figure 4. Drilling pipes with cable sections of electric current supply

1-double-contact rod
2-tool-joint pin
3-pipe
4-cable section
5-tool-joint clutch (coupling)
6-double-contact clutch (coupling)

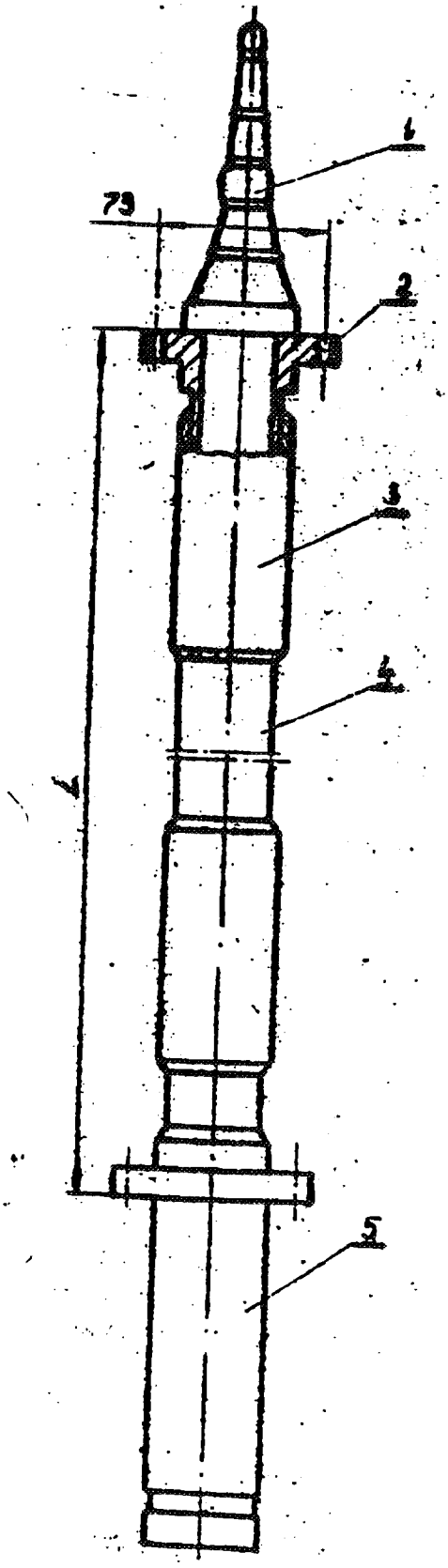


Figure 5. Cable section TBTE-1sb
1-double-contact rod
2-support
3-jointing
4-cable
5-double-contact clutch (coupling)

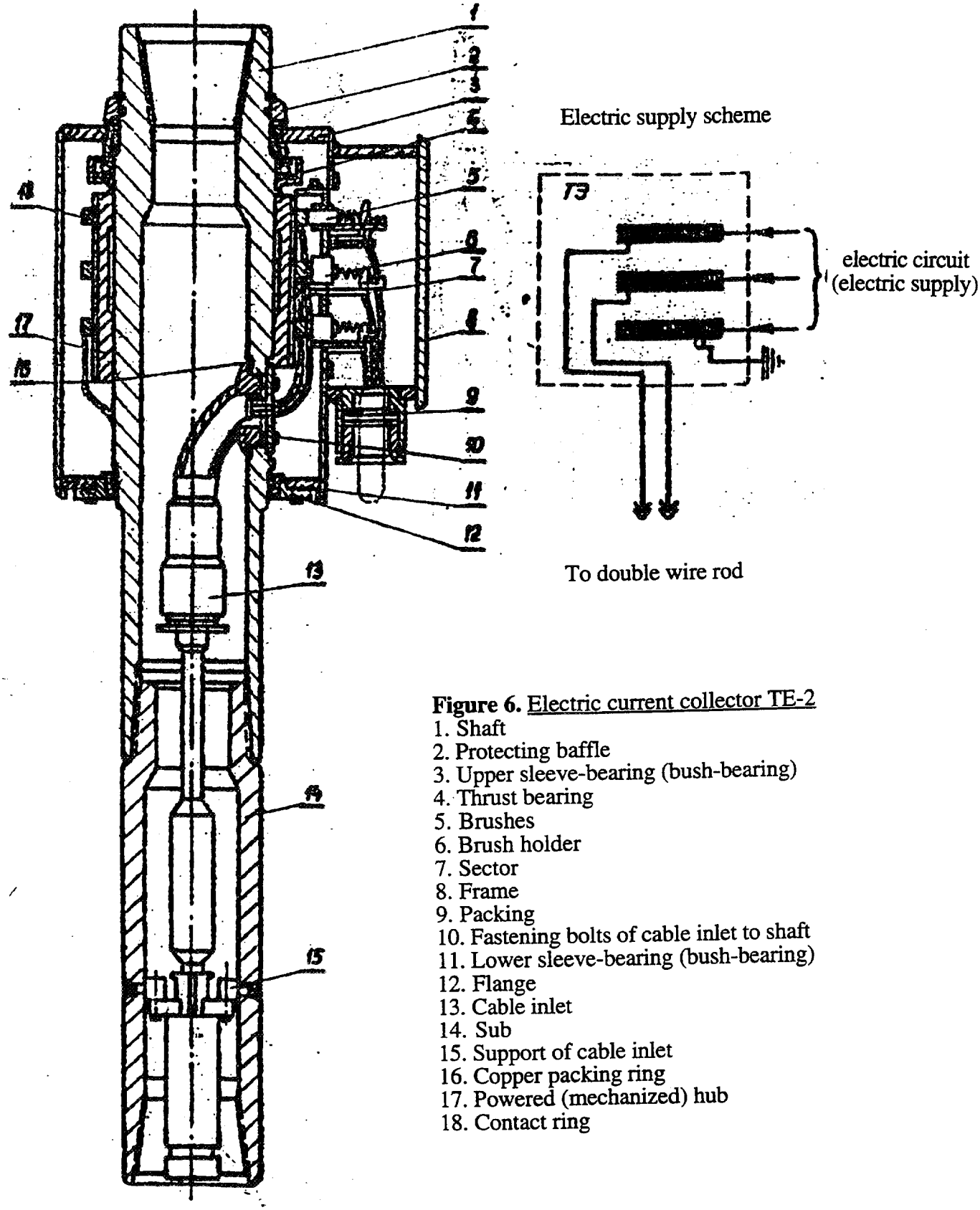
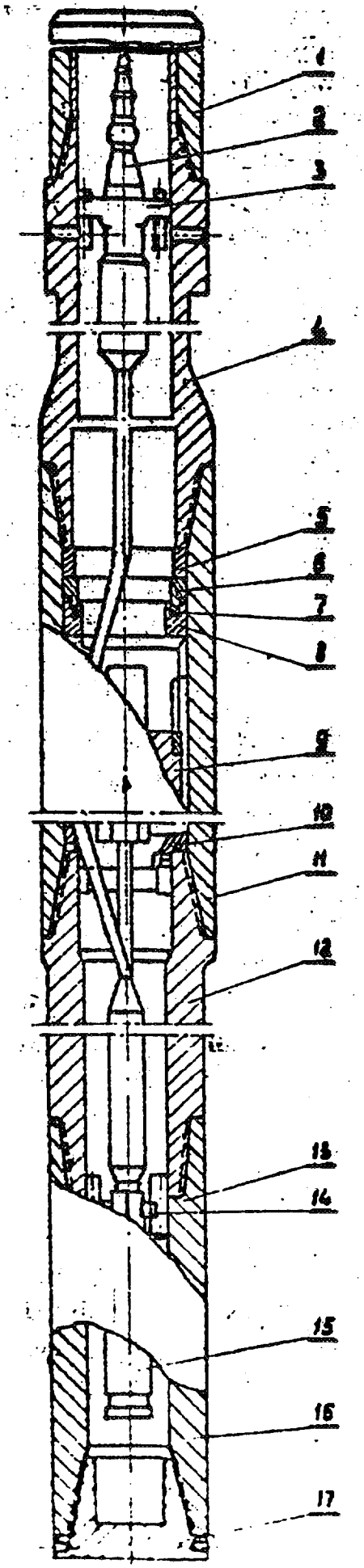
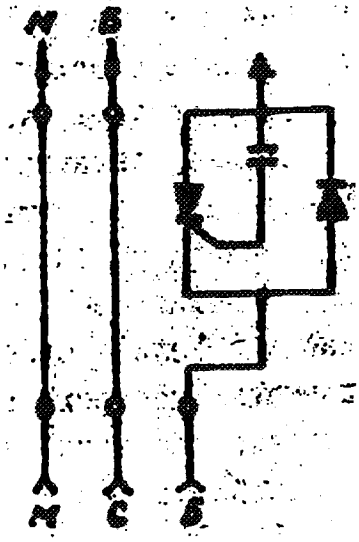


Figure 6. Electric current collector TE-2

1. Shaft
2. Protecting baffle
3. Upper sleeve-bearing (bush-bearing)
4. Thrust bearing
5. Brushes
6. Brush holder
7. Sector
8. Frame
9. Packing
10. Fastening bolts of cable inlet to shaft
11. Lower sleeve-bearing (bush-bearing)
12. Flange
13. Cable inlet
14. Sub
15. Support of cable inlet
16. Copper packing ring
17. Powered (mechanized) hub
18. Contact ring



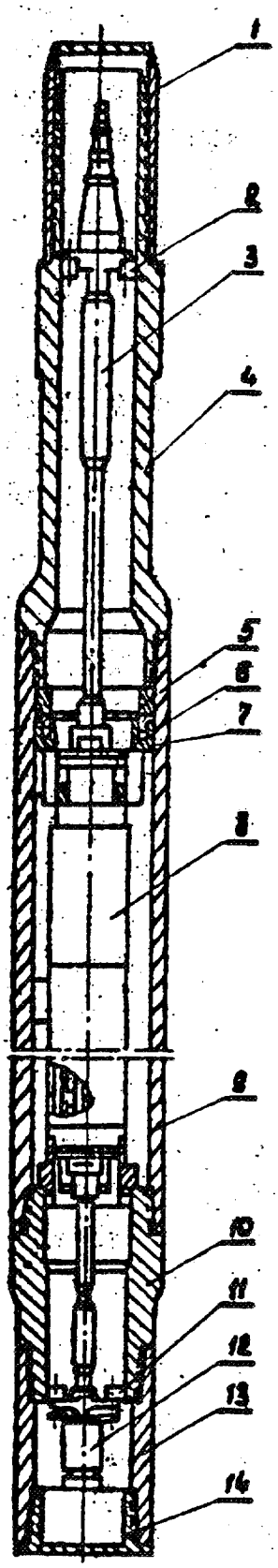
To clutch (coupling) of double-wire current supply



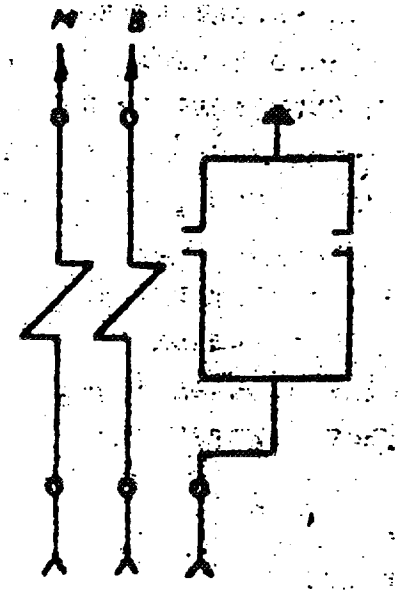
To triple contact rod of electric downhole motor inlet

Figure 7. Device for insulation control

1-Cap
2-double-contact rod of cable inlet
3-upper support
4-sub
5-bush (sleeve)
6-ring
7-damping (shock absorbing) ring
8-ring
9-container
10-thrust bush (sleeve)
11-frame
12-intermediate frame
13-demountable support of current supply
14-lower support
15-triple-contact clutch (coupling) of cable inlet
16-lower sub
17-plug



To clutch (coupling) of double-wire current supply



To rod of triple wire inlet of electric downhole motor

Figure 8. Submersible electromagnetic contactor
1-plug
2-upper support
3-double-contact rod of cable inlet
4-sub
5-remote bush (sleeve)
6-damping (shock absorbing) ring
7-support
9-electromagnetic mechanism
10-intermediate frame
11-lower support
12-triple-contact clutch (coupling) of cable inlet
13-lower sub
14-plug

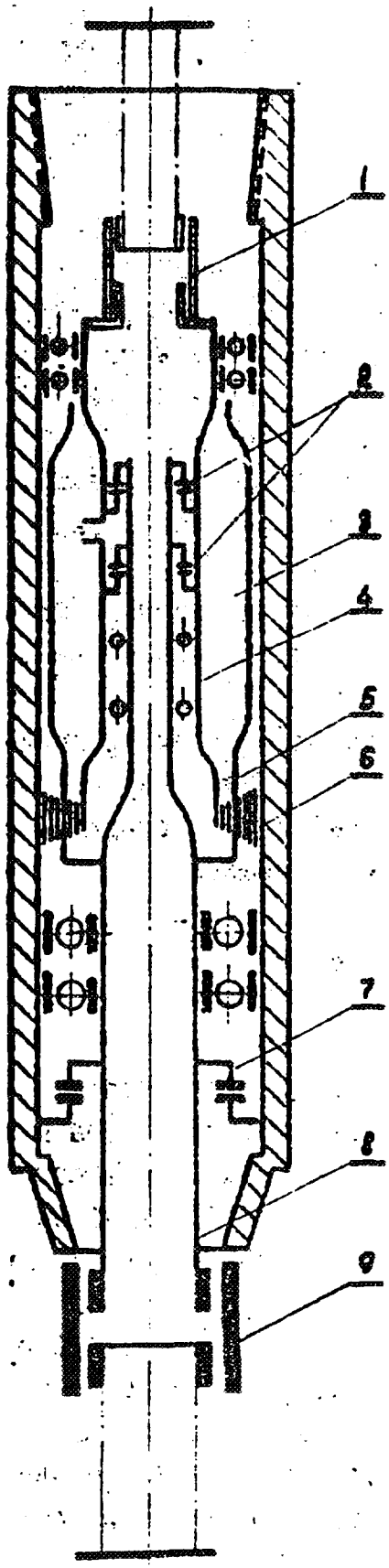
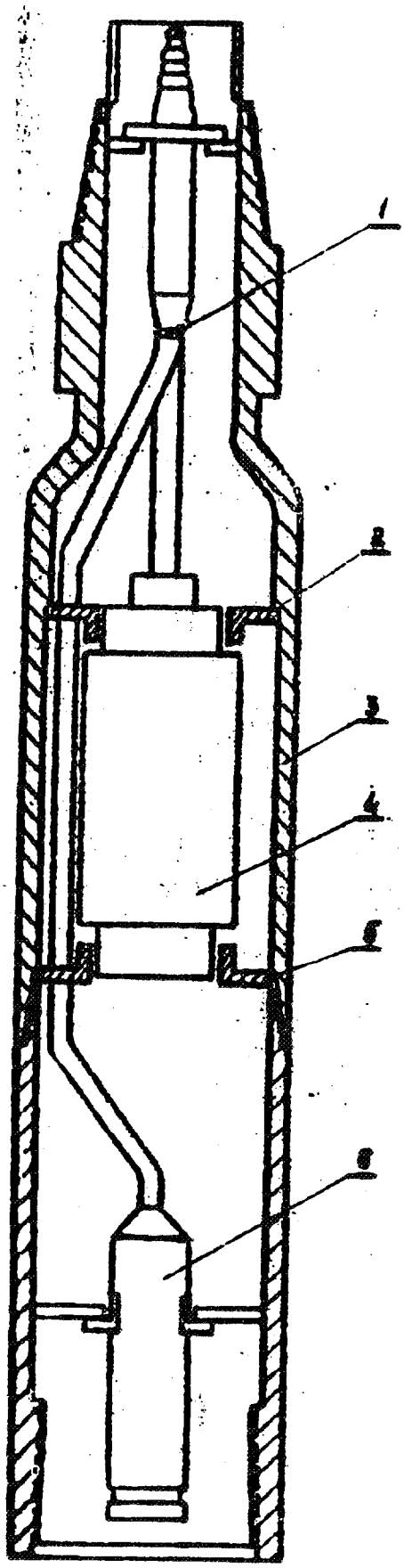
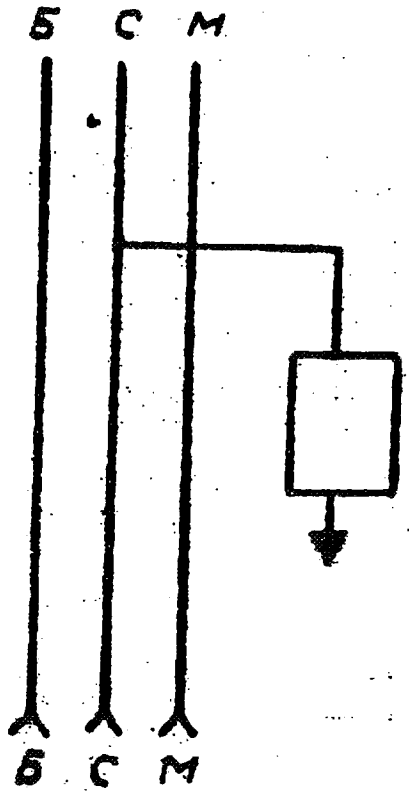


Figure 9. Reduction gear insertion
1-connecting coupling
2-upper packing box
3-compensator
4-driving shaft-gear (wheel)
5-carrier
6-static gear (wheel)
7-lower packing box
8-driven shaft
9-connecting coupling



Triple-contact rod



Triple-contact coupling (clutch)

Figure 10. Telemetric system TSE
1-triple-contact rod of cable section
2-upper support
3-frame
4-sealed container with measuring devices (angle of inclination, azimuth, angle of deflector)
5-lower support
6-triple-contact coupling (clutch) of cable section

Chart of shaft connections

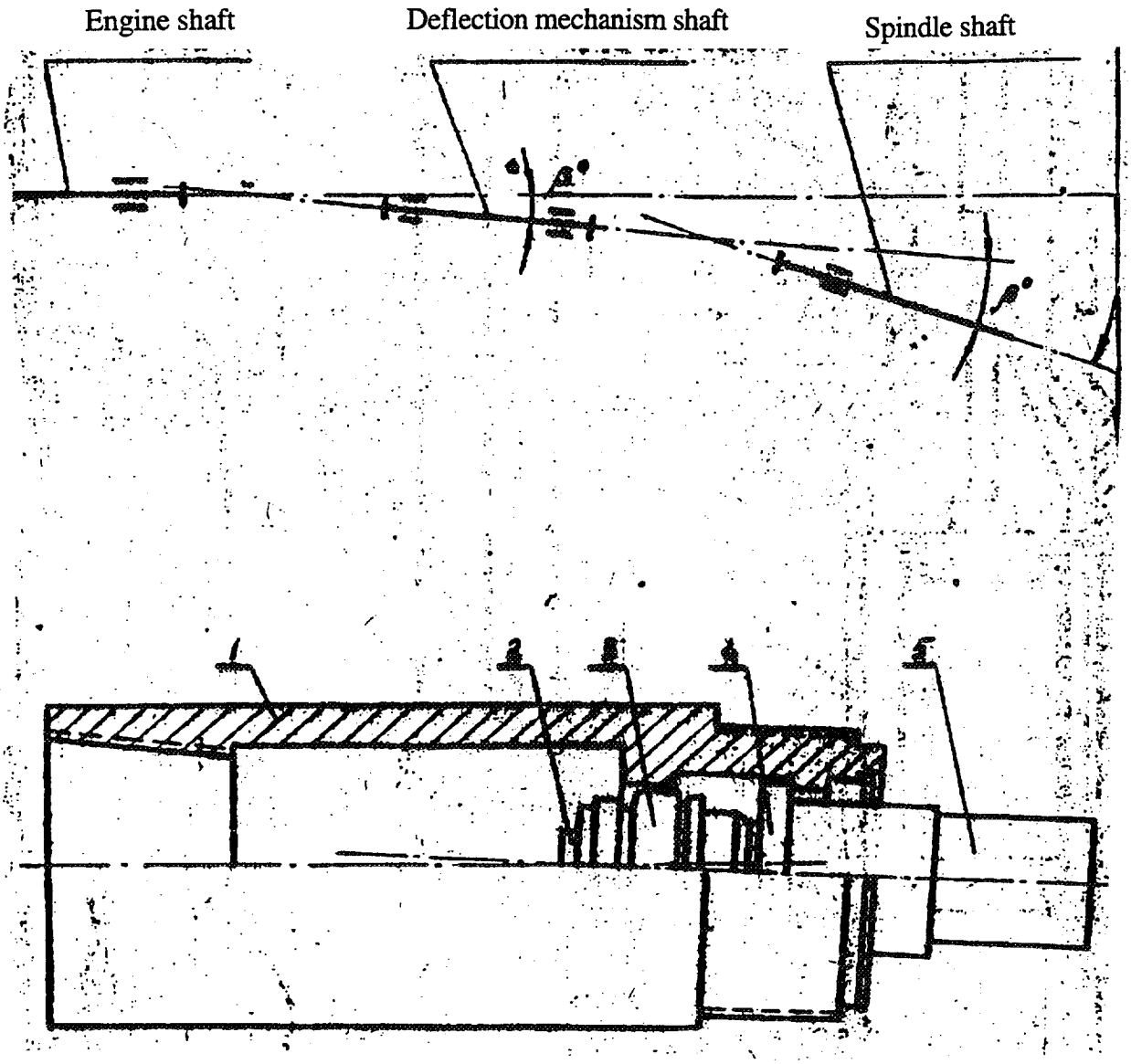


Figure 11. Deflection mechanism
1-frame
2-nut
3-coupling half
4-bearing
5-shaft

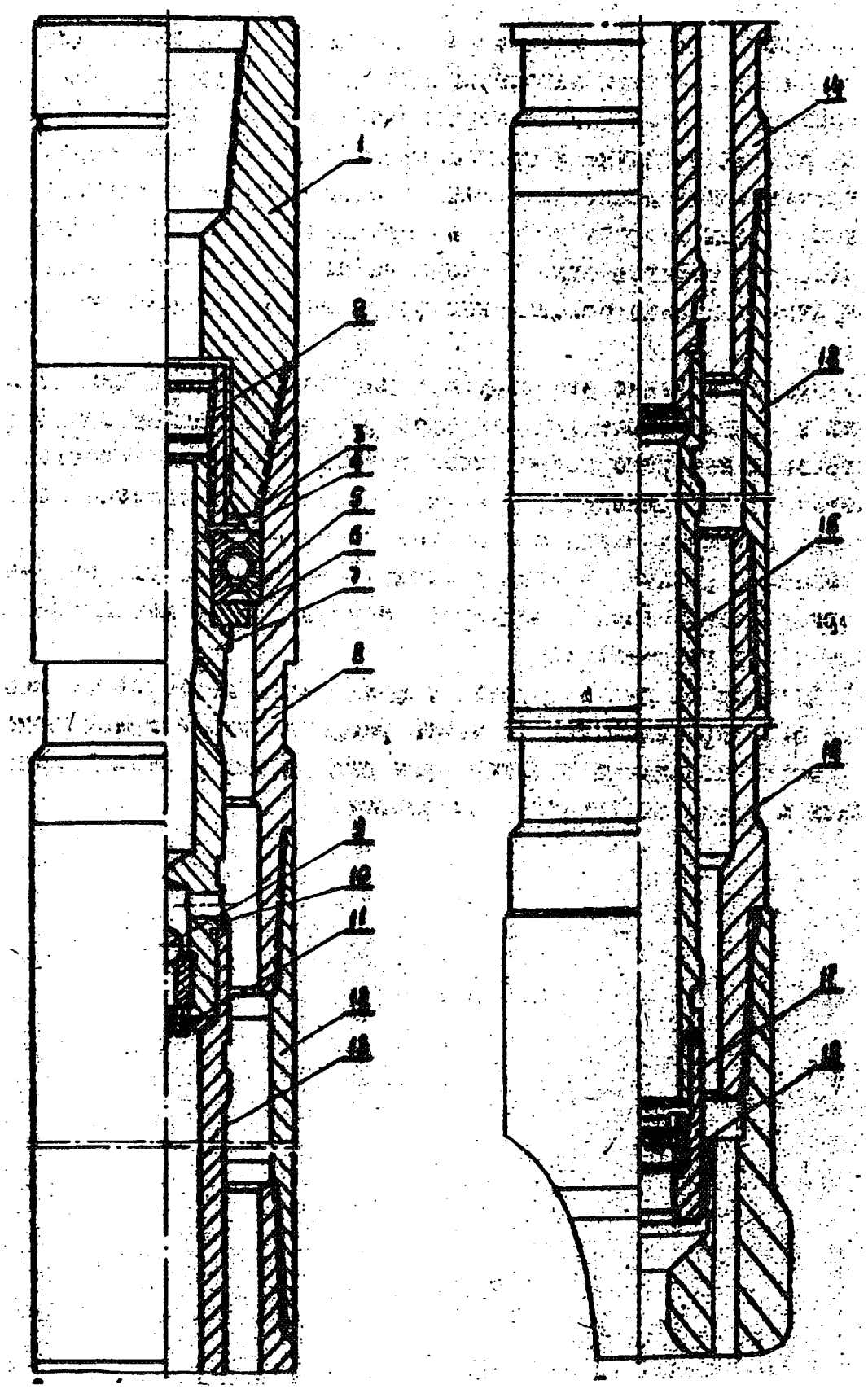


Figure 12. Device for coring

1-Upper sub
2-Nut
3-Washer
4-Washer
5-Ball bearing
6-Regulating ring
7-Valve's frame
8-Bearing's frame
9-Ball
10-Retainer washer
11-Wire
12-Frame
13-Core receiver pipe
14-Intermediate sub
15-Core receiver pipe
16-Lower sub
17-Support (stop)
18-?? (could not see what it says)

Electrodril Documents

322,355

THIS IS A PREPRINT — SUBJECT TO CORRECTION

THE GENERAL ELECTRIC ELECTRODRIL SYSTEM

By

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and
P. D. Taylor

The paper contained herein was presented at the 1980 Drilling Technology Conference of the International Association of Drilling Contractors March 18-20. Permission to reprint or abstract is granted by the International Association of Drilling Contractors, P.O. Box 4287, Houston, TX 77210, provided: (1) The authors' name and company affiliation is stated. (2) Acknowledgement is made of its presentation at the above Conference.

I. ABSTRACT

The Electrodril system is described. The DOE Field Test Demonstration Program is outlined and Test/Demonstration results are presented. Projected operational and economic benefits are discussed.

Electrodril is an advanced oil, gas, and geothermal well drilling system. The downhole system includes an electric drill motor and electronic sensor and telemetry package linked to the surface with a cable/connector conductor system. Surface elements include power generation and regulation equipment and electronics to process and manage uplink and downlink data and commands from and to the downhole motor and sensor and telemetry package.

The General Electric Company has been engaged, under contract, with the United States Department of Energy in a Field Test Demonstration Program. Under this program, a controlled demonstration of the technical and economic viability of the Electrodril system is being conducted. The program includes subsystem and system demonstrations in both test and operational wells.

The Field Test Program has been contracted on a cost sharing basis with financial participation from General Electric and from major elements of the petroleum industry as well as the Department of Energy.

The Electrodril system is expected to provide greatly improved drilling performance through significant increases in penetration rates, reduction in tripping requirements and enhanced hazard protection. The pay off from this improved drilling performance is greater application of expensive capital facilities - more wells per year per dollar of drilling budget.

II. INTRODUCTION

The Electrodril System is unique among the many new drilling and MWD (Measurement While Drilling) systems currently undergoing development and demonstration. The system is characterized as "unique" because Electrodril combines a powerful downhole electric drill motor with a high capacity, real-time electronic sensor and telemetry (MWD) package.

The concepts incorporated in the major Electrodril subsystems have been under development for ten years or more. Since mid-1976, General Electric has been engaged, under a cost-sharing contract with the United States Department of Energy, in a Field Test Program designed to provide a controlled demonstration of system functional and operational viability. The objective is to assess the drilling performance which can be expected from Electrodril in terms of improved penetration rates, reduced tripping, and the ability to utilize effectively the realtime formation, operational and system data obtained from the downhole electronic sensor and telemetry subsystem.

The Field Test Program has been sponsored by the Department of Energy with cost sharing by Industry and General Electric. Amoco, Chevron, Dresser, Gulf, Mobil and Union have contributed financially to the program. In addition, Brown Oil Tools, Exxon, Hughes, NL Industries and Shell have supported the program with facilities, equipment and personnel.

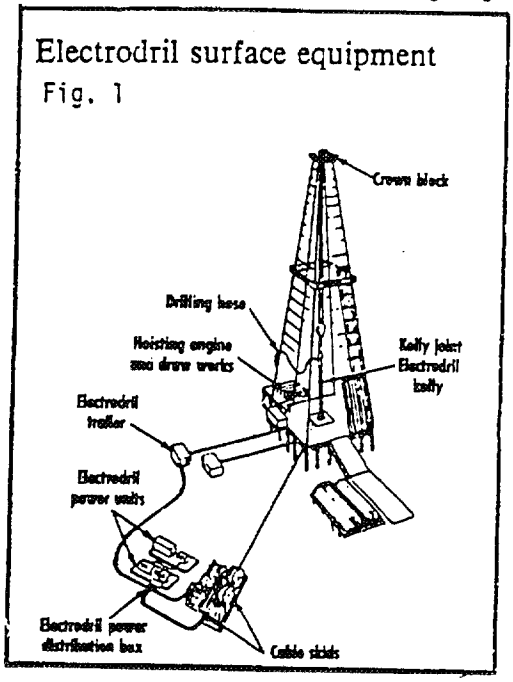
Phase I of the DOE Field Test Program was completed in August 1977. During the Phase I Program, tests of critical component and subsystems, together with system level demonstrations of the 60 HP Directional Drilling System in both test and operational wells, was accomplished.

The Phase II Program, which was initiated in August, 1977, is directed towards the operational demonstration of the Deep Drilling System. A complete deep drilling system has been designed, fabricated, tested at the component subsystem and system level and demonstrated in a test well and at two active drill sites.

The problems encountered in the drilling demonstrations have been the subject of extensive analysis and test. New hardware which is the product of some design modifications and more rigorously controlled process, inspection and test procedures will be available for evaluation and qualification late in the first quarter of 1980.

III SYSTEM DESCRIPTION

The Electrodril system is designed as a modular add-on to conventional drilling rigs.

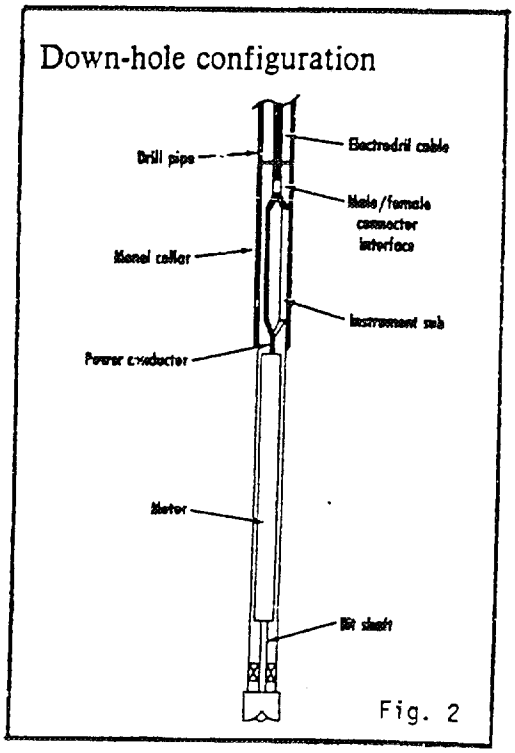


Electrodril is a family of drilling systems. This Electrodril family features a commonality of basic design philosophy and design approach. Each of the drilling systems includes a downhole electric drill motor and real-time electronic sensor and telemetry package linked to the surface with a cable/connector conductor system. Each drilling system includes surface equipment to handle the conductor system, power generation, and regulation equipment and surface electronics to process, display and otherwise handle uplink and downlink data and commands from and to the downhole sensor and telemetry package. The Electrodril family includes the following drilling systems.

- 20 HP Slimhole System
- 60 HP Directional Drilling System
- 285 HP Deep Drilling System

Characteristics of these drilling systems are depicted in Table I.

A generalized overview of the Electrodril system deployed at a typical well site is shown in Fig. 1 and the downhole portion of the system is depicted in Fig. 2.



The Deep Drilling System is depicted in schematic form in Fig. 3.

TABLE I

ELECTRODRIL SYSTEMS CHARACTERISTICS

	20 HP	60 HP	285 HP
PHYSICAL			
Downhole System			
Length Motor/Electronics	25' 6"/45'	36'/45'	51'/45'
Diameter	$4\frac{1}{2}$"	$7\frac{3}{4}$"	$7\frac{3}{4}$"
Weight	2400 lb	4150 lb	5875 lb
Cable			
Diameter	0.6"	0.9"	1.2"
Weight	0.4 lb_{ft}	1.0 lb_{ft}	1.8 lb_{ft}
OPERATING			
Motor			
Horsepower at Bit	20	60	285
Bit Rotational Speed-RPM	200-800	40-400	40-400
Torque -ft.-lbs.	500-150	1500	3500
Weight on Bit-lbs.	10,000-5,000	25,000	70,000
Electronics			
Channels	16	16	16
Bit Rate	500_{sec}	500_{sec}	500_{sec}
Sample Rate	33_{sec}	33_{sec}	33_{sec}
ENVIRONMENTAL CAPABILITY			
Pressure	20,000 psi	20,000 psi	20,000 psi
Temperature	125°C* 257°F	125°C*	125°C*
Shock	20 G	20 G	20 G
Vibration	5G - 2_{200Cy}	5G - 2_{200Cy}	5G - 2_{200Cy}

* 232°C capability in development

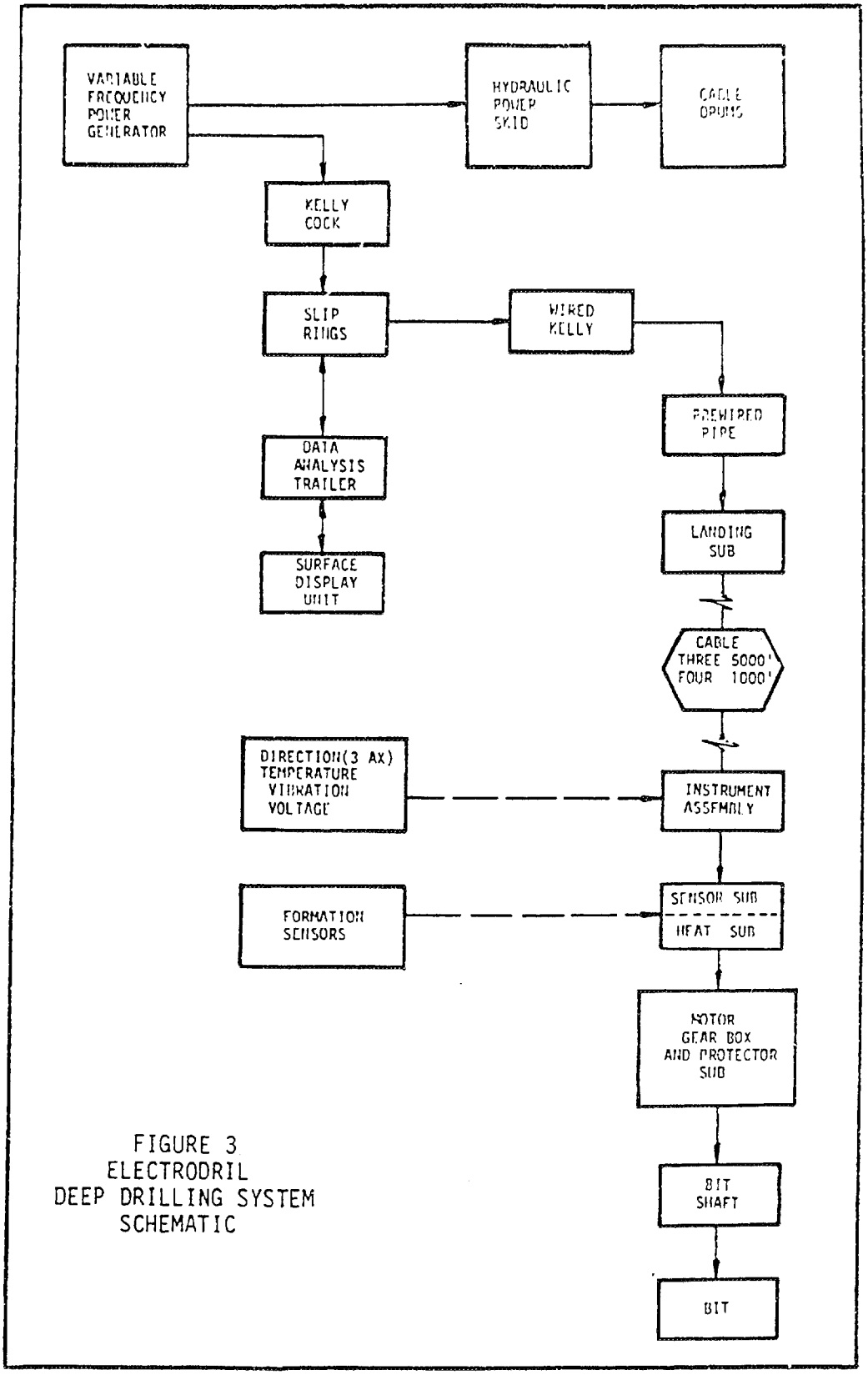


FIGURE 3
ELECTRODRIL
DEEP DRILLING SYSTEM
SCHEMATIC

The Electrodril System has been designed to permit its addition in modular fashion to standard rotary drilling rigs. Electrodril installation and operating procedures are compatible with conventional drilling operation. The Electrodril System consists of the following subsystems.

Electrodril is deployed with an independent, self-contained Power Generation and regulation capability. In addition to providing variable frequency power for the Electrodril motor, this subsystem provides auxilary electrical power (DC and AC) including all controls, inverters, converters, and safeguards.

The Cable and Cable Handling Subsystem consists of the cable, connectors, cable reels, slip rings and devices for the deployment and control of same. Design of this subsystem must incorporate the flexibility necessary to accommodate variations in the detailed layout and make-up of various drill rig floors and derricks and to accomplish specific drilling programs. The number of cable reels used, for example, is dictated by how deep the well is at the time of Electrodril deployment and the depth to which the system will be required to drill.

The Instrumentation Subsystem includes all data acquisition, processing, transmission and display functions. The downhole instrumentation package includes a solid state 3-axis directional sensor, formation and other downhole sensing capability and the electronics necessary to acquire, format and transmit sensed data to the surface. The surface equipment receives the downhole data; demultiplexes, processes, and displays this data, and transmits commands to the downhole equipment.

The Motor Subsystem includes the downhole drilling elements such as the bit shaft, electric drill motor, gearbox and shock absorber. The correct preparation of this subsystem prior to downhole deployment is key to its operational life. The adjustment of pressure compensation bags and gearbox seal lubrication, for example, have marked effects on the motor's downhole life prior to withdrawal and refurbishment.

IV. SUBSYSTEM DESCRIPTIONS

The several Electrodril subsystems are described in detail in this section. The descriptions are specific for the Deep Drilling System.

Power Generation

The following power requirements have been established for the Deep Drilling System:

Primary Power:

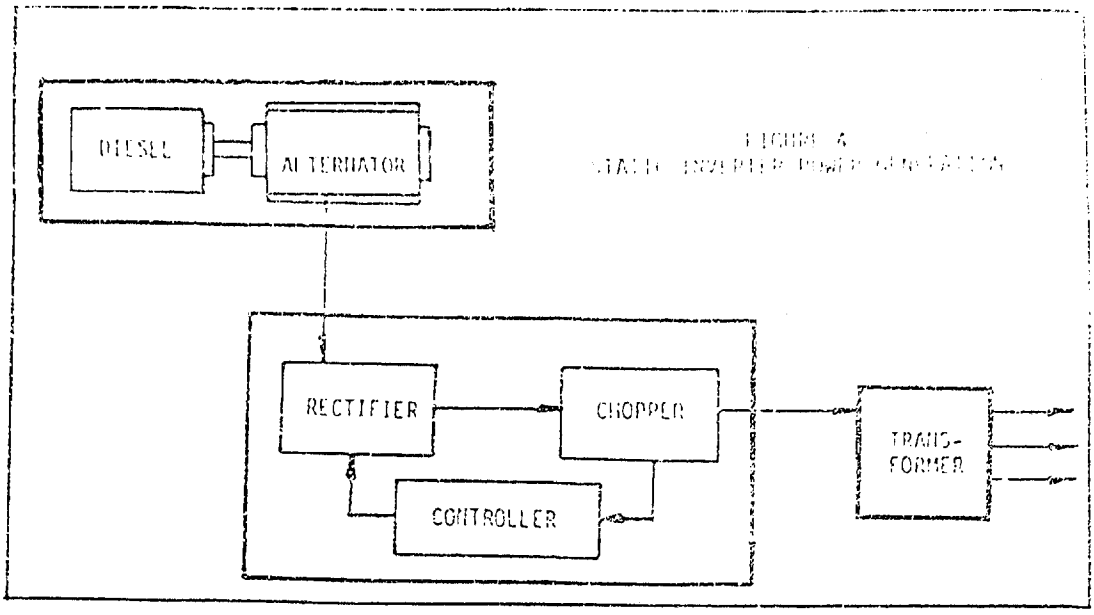
240V to 3300V, 3Ø, with variable AC frequency ranging from 12 to 120 Hz. Continuous current rating from 22 to 75 amps.

Secondary Power:

208V, 3Ø, 60Hz AC
110V, 1Ø, 60Hz AC

The satisfaction of these power requirements is accomplished by the use of a diesel prime mover driving an AC alternator to produce 440V, 60 Hz. The 440V AC output is then applied to a static inverter which converts the AC to DC and "chops" the DC output at varying rates, upon demand, to create variable frequency "pseudo" AC. Control for the DC "chopping" is developed from inputs from the downhole current and voltage sensors. A schematic of this power generation approach is presented in Figure 4.

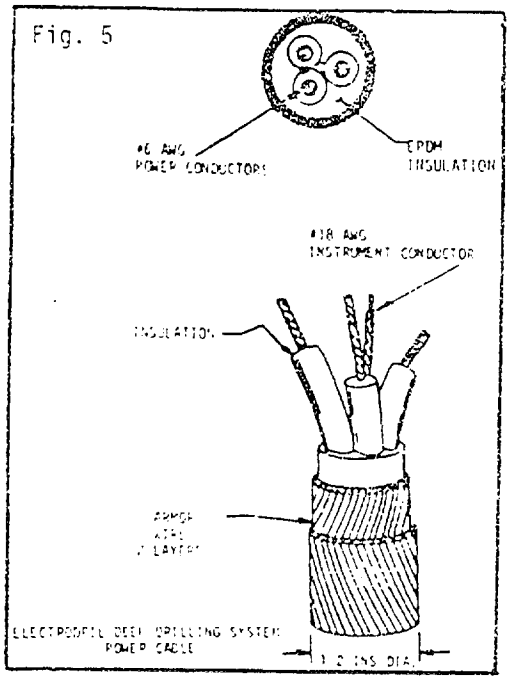
This is a demand response system with the capability of sensing and responding quickly to the power requirements of the downhole drill motor. In an operational situation the power demand can fluctuate rapidly. The static inverter system is capable of responding to these fluctuations, but the supporting downhole sensory system and surface controllers must be capable of sensing demand and switching frequency levels at a high response rate. Downhole voltage at the motor interface is measured and transmitted to the surface. Current is measured at the surface downstream of the power converter and the rate of change of these two parameters, together with their phase relationship provides the basis for modulating the static inverter power controller.



Cable and Cable Handling

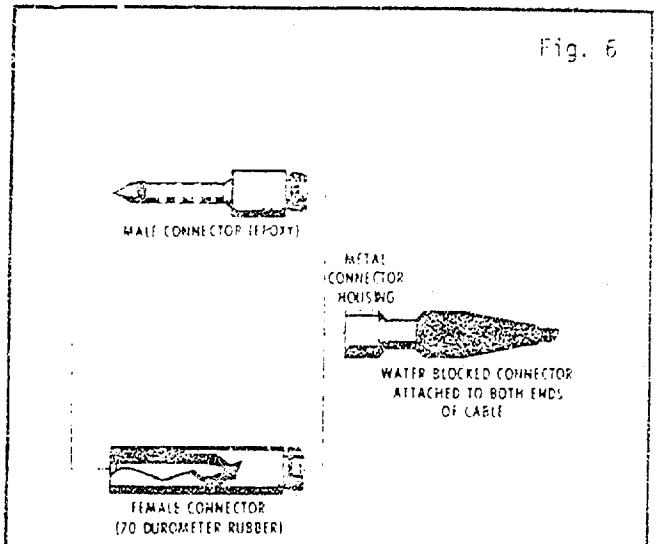
Cable and Connectors. The Electrodril cable includes four conductors as shown in Figure 5. Three No. 6 AWG conductors supply downhole electrical power to the motor.

Fig. 5



The No. 18 AWG center conductor is used for instrument power and data transmission. The cable is composed of multistranded conductors to assure cable flexibility. The double layer of torque balanced steel armoring carries the weight of the cable and provides a return for the instrument power. The cables are connected through specially designed field replaceable connectors (Fig.6) which allow easy assembly of the cable sections while providing high electrical reliability. The cable is supported in the drill pipe by cable hangers which provide cable stability during drilling operations. The hanging weight of the suspended cable is less than 20% of the cable breaking strength.

Fig. 6



Field Replaceable Connector

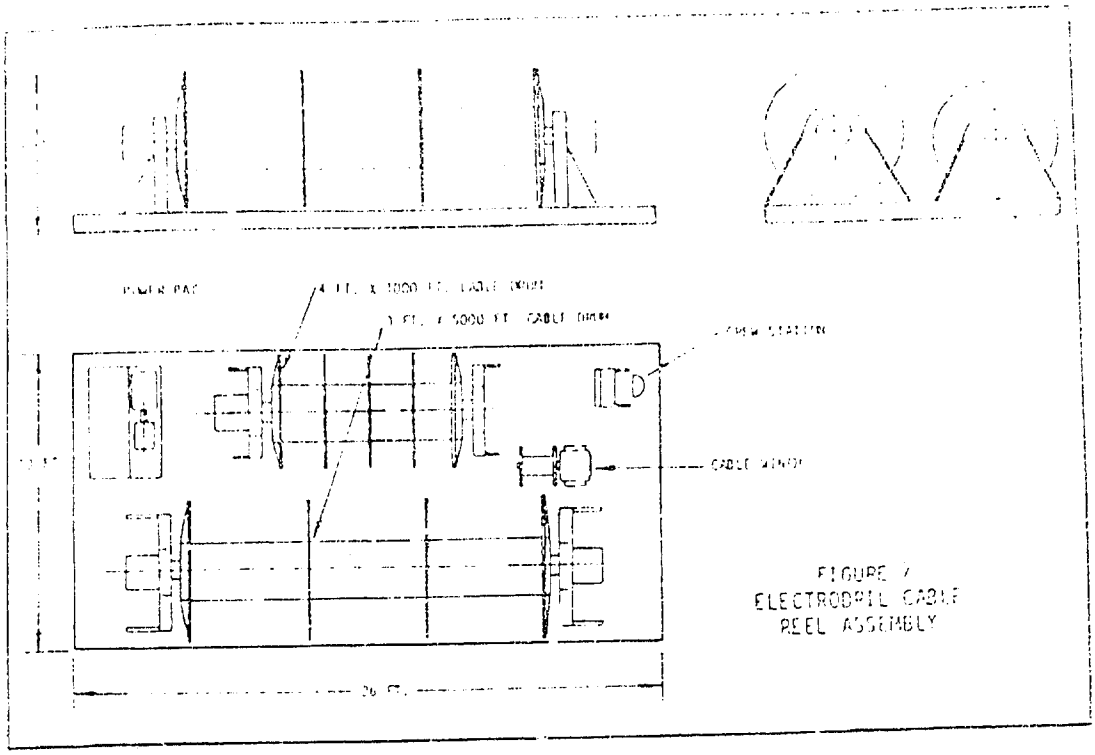


FIGURE 7
ELECTRODRIL CABLE
REEL ASSEMBLY

Cable Reels. The Deep Drilling System Cable Reels accommodate a total of 19,000 feet of cable. The cable reel skid is shown in Fig.7. A total of five reels are required to hold the 19,000 feet of cable; three 5,000 foot cable reels, and two duplex 1,000 foot reels. The cable reels can be operated up to 500 ft/min. This speed appears to be the maximum practical before hydraulic horsepower and cable strength requirements became prohibitive. Cable bedways on all the reels drums have been incorporated to minimize lower cable tier crush load.

The selection of hydraulic power for the reels was made after trade studies indicated that from a skid weight, safety and economic viewpoint an AC or DC electric system would not be as efficient. The hydraulic system chosen operates at 1500 psi and incorporates automatic fail safe (lockup) features.

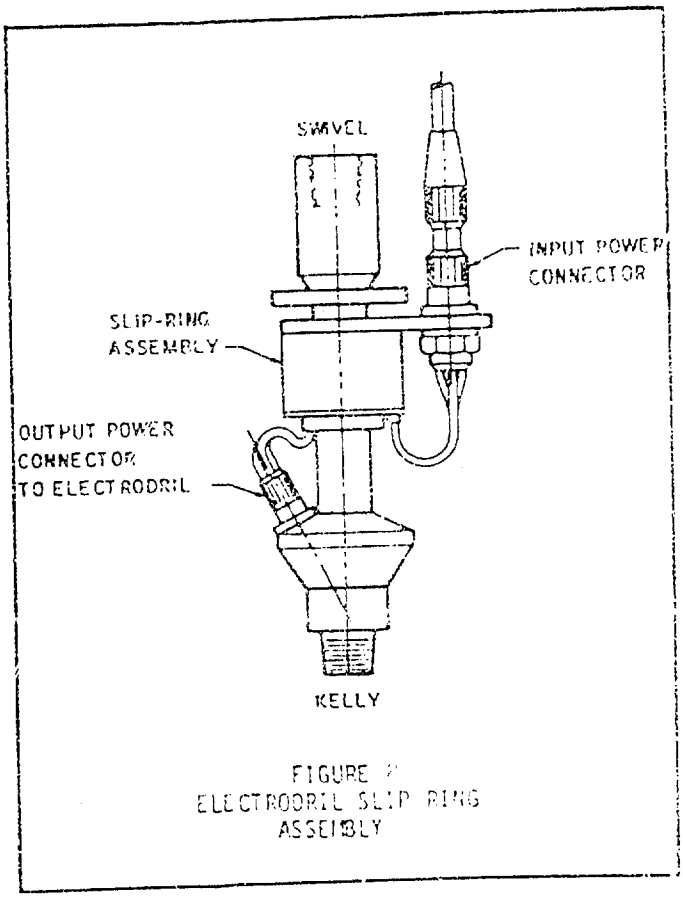


FIGURE 8
ELECTRODRIL SLIP RING
ASSEMBLY

Rig Floor Assembly

In deploying the deep drilling system cables and connectors, drill pipe rotation must be maintained to obviate the potential for differential sticking. Pipe rotation is maintained using the conventional rotary table/kelly combination. Electrical connection to the downhole cable (rotating) and the surface cable (non-rotating) is made through a slip ring assembly located below the rig swivel (Figure 8). Mud circulation is made

in the conventional manner through a circulating head above the swivel. A kelly cock is located between the circulating head and slip ring assembly to provide hydraulic safety.

The hole is drilled ahead 90 feet, utilizing two prewired dedicated joints of drill pipe and the prewired kelly. These are then removed and replaced with a 90-foot stand of prewired pipe. This sequence is repeated 10 times (a total depth of 1000 feet) at which time the pre-wired pipe is withdrawn and substituted with standard drill pipe and 1000 feet of cable. This prewired pipe is utilized in place of standard drill pipe for the first 1000 feet to maintain electrical continuity with the deployed downhole lengths of Electrodril cable during drilling operations. Each succeeding 1000 feet of hole is drilled in a similar manner until a total of 5000 feet has been drilled. At that time the prewired pipe is replaced with standard drill pipe, the four 1000 feet lengths of cable are withdrawn, and a 5000 foot length of Electrodril cable is mated downhole with the previously deployed cable. An electrical crossover sub located below the slip ring assembly allows transition of electrical power from inside the drill pipe bore to the outside of the slip ring assembly.

Instrumentation

The downhole instrumentation unit (Figure 9) includes equipment, formation, and solid state directional sensors. This sensor package combined with downhole data handling and telemetry and surface processing, display and command provides the capability to control and optimize drilling performance and safety as a function of real-time knowledge of downhole parameters.

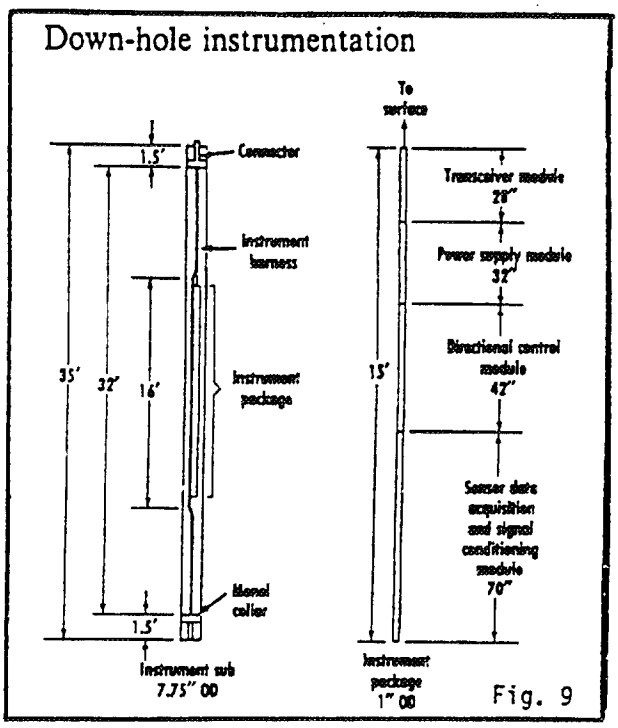


Fig. 9

The system operates at 500 bits/sec. Relatively slow 32 samples/sec uplink and one command/sec downlink rates were established as system requirements. The instrumentation system has been designed to monitor up to 15 analog plus 11 digital downhole parameters and send the combined data to the surface. It can send up to four commands downhole for execution and simultaneously carry downhole instrument power, downlink commands, and uplink data over a single No. 18 AWG conductor. It will process and display received downhole data on the surface.

The downhole instrument package performs the following functions:

1. Receives from the surface 115 VAC 60 Hz electric power and converts and distributes same to support the downhole instrumentation.
2. Monitors up to 15 analog plus 11 digital downhole parameters and processes (multiplexes) this data.
3. Sends to the surface processed data in pre-established digital formats.
4. Receives up to 4 commands from surface equipment for execution by downhole auxiliary units.

The surface equipment receives the downhole data, establishes bit and frame synchronization, checks parity, decides on the data acceptability, performs data transformation, routes and displays data.

The surface equipment transmits commands to the downhole equipment utilizing frequency shift keying of the power source to transmit the data. The correct voltage level downhole is also commanded by the surface equipment and maintained by varying the surface voltage level in proportion to the surface power signal level.

The surface equipment includes two data display stations:

1. The display control unit, located on the rig floor in the driller's Dog house, displays the three axis hole direction data and has one other display window for other selectable data.

2. The data analysis trailer, where a second microprocessor has been added so that raw downhole data can be decoded, converted, and displayed independently from the rig floor display and control unit.

The following measurements are made, processed and displayed while drilling:

From the downhole directional sub:

Instrument voltage
Instrument temperature
Vibration
Hole position (drift, azimuth, and tool face)
Command received response

From the downhole sensor package:

Motor temperature
Motor voltage
Differential mud pressure
Annulus mud temperature
Gamma count

From surface sensors:

Depth of hole and penetration rate
Mud pressure
Mud flow rate
Motor current

The Instrumentation Subsystem is shown in block diagram form in Figure 10.

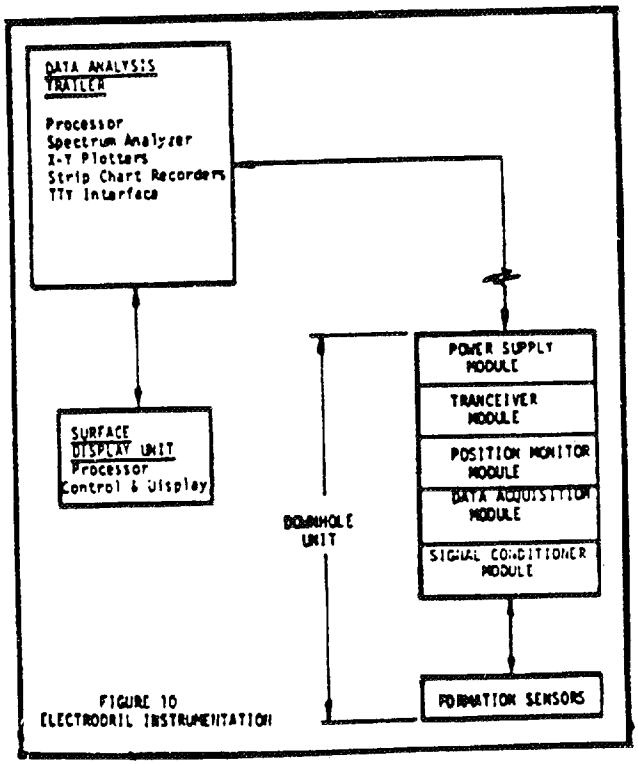


FIGURE 10
ELECTRODRIL INSTRUMENTATION

Downhole Motor Assembly

The Electrodril motor subsystem is a total of 51 feet in length, and 7-3/4" in diameter. A cutaway of this assembly is shown in Fig. 11.

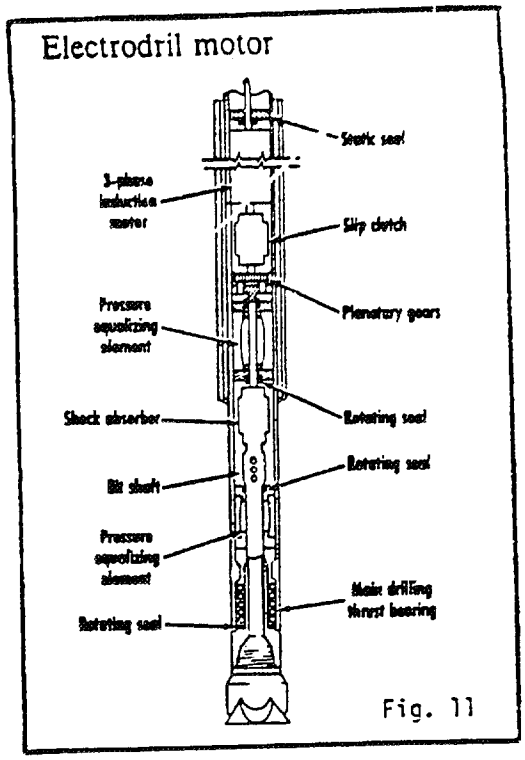


Fig. 11

The motor subsystem is electrically protected at the surface. In the event of an overload situation, current sensors trip the power generation circuit breakers to prevent motor damage. Motor temperature is sensed downhole and displayed at the surface.

The Electrodril motor is a standard industrial REDA type 540 submersible pump motor rated at 150 HP at 1150 volts 60 Hz. At this rating the motor has a speed of 3200 rpm. The output of the motor is put through a 16 to 1 gear reduction so that when the motor is operated through its planned range, the effective bit speed range will be from 40 to 400 rpm. Motor speed is varied by changing excitation frequency, which for this system will range from 12 Hz (35 HP) to 12 Hz (285 HP).

A normal Electrodril Start-Up will begin at 12 Hz depending upon length of cable deployment. This low frequency start is made to minimize the motor inrush current. The motor is then brought up to speed as dictated by the bit type and formation to be drilled.

The motor gearbox is a double train planetary reduction unit designed and tested to with-

stand weights on bit of up to 70,000 lbs. and torques in excess of 3,500 ft lbs. A shock absorber unit is included to isolate the motor from the shock loads produced by the drilling operation. A slip-clutch unit, designed to safeguard the motor in the event the bit is suddenly stopped is also included. Internal oil pressure compensation bags are also provided in this assembly to assure that the internal oil pressure is the same as the mud pressure in the mud tube thus maintaining an almost zero pressure drop across the lower motor seals. The oil leakage over the lower motor seal is thus held to a minimum and the seal surface wear characteristics are idealized. Pressure compensation bags have been designed with a capacity to accommodate more than 200 hour downhole deployment.

The bit shaft has been designed with metal-to-metal seals capable of withstanding pressure differentials in excess of 2,000 psi and bearings rated to accommodate weights on bit of up to 70,000 lbs. and the more severe downhole environment. In addition, the pressure compensation bag has been designed with sufficient oil capacity to assure that lubrication is maintained at least for 200 hours. The oil is replenished each time the drill string is tripped.

The seal and bearing design chosen has been utilized extensively in downhole water pump applications. A special internal flush feature assures positive oil to mud leakage to minimize the potential for mud intrusion. In addition, a grease packed labrynth seal is incorporated into the seal housing to act as a mud barrier.

V. SYSTEM DEPLOYMENT

There are two basic activities that are necessary to activate Electrodril at a drilling site. System elements must be deployed in the vicinity of the rig and modifications and additions to the rig must be accomplished. These two basic activities can be carried out independently.

Most Electrodril equipment will be deployed more than 100 feet from the rig. However, 1000 feet of Electrodril drill pipe is stored on the pipe rack and, in addition, an electric power cable is run from the Electrodril power generating equipment to the base of the rig, up a derrick leg and along the standpipe and mud hose to the rig swivel. This cable will eventually be mated to the slip ring assembly which will be located above the kelly.

Two primary assembly tasks must be accomplished in the rig before Electrodril is deployed:

1. Eleven 90 foot stands of drill pipe must be assembled and electrified with standard Electrodril cable and connectors.

2. The kelly must likewise be electrified with standard cable and connectors and the slip ring assembly must be installed between the kelly and swivel.

Assembly of the eleven 90 foot stands of dedicated (prewired) drill pipe is accomplished using the 1000 feet of drill pipe delivered with the Electrodril equipment. The use of this drill pipe is necessitated because the length of each joint has been carefully measured and the mating cable lengths have been cut and terminated to suit a particular three joint combination. This 1000' of pipe is run in the hole as part of the conventional string during normal drilling operations. As the drill string is pulled, 90' stands of the Electrodril pipe are isolated and electrified by suspending the mating cable/connector lengths and securing them into each stand. Each completed prewired stand is then stood back in the rack.

The electrification of the kelly is accomplished by threading an electrical cable through the kelly bore. The upper end of the cable is brought out of the bore by a special crossover sub and terminated at a connector. The slip ring assembly is mounted on this crossover sub and electrical connections made between the connector and slip ring. The top of the slip ring is mated with the power cable which runs from the power generation sub system up the derrick and along the mud hose.

To minimize the time consumed, the preferred cadence is to stand back the eleven electrified dedicated drill pipes and to then electrify the kelly, set it in the rat hole and place the motor subsystem in the slips ready to be run in the hole.

Electrodril is then ready for downhole deployment. The motor subsystem is picked up, and placed in the slips and run in. The instrumentation subsystem is then mounted to the top of the motor and the combined Electrodril downhole assembly is lowered until the top of the non-magnetic collar is in the slips. An electrical check is made at this time to assure the system is in functional order.

Upon successful completion of these electrical checks, approximately 5000 feet of rig drill pipe is run in the hole on top of the motor/instrumentation assembly. During this

process, an accurate tally must be kept as the length of drill pipe run in the hole must match that of the cable which is to be installed in it. The Electrodril system inventory includes sufficient pup joints of various matching lengths to facilitate drill string and cable length matching. A special landing sub is added to the drill string to facilitate suspension of the power cable.

The rig floor and traveling sheaves are then installed in a similar manner to that used for conventional wire line logging operations. In addition, a prewired sinker bar is set in the drill pipe on special slips, and the Electrodril power cable is brought over from the cable skid and mated to it.

With the power cable and sinker bar mated, this assembly is run into the hole. Cable deployment can be accomplished at up to approximately 500 feet per minute although towards the end of the cable run-in procedure care must be exercised utilizing a fairly slow cable speed to provide greater control. At the point where the cable is about to be run off the cable reel, the reel is stopped so that the cable end can be removed from its reel attachment. The cable is secured in the drill pipe using special cable slips. These cable slips allow the cable end to be slackened off, removed from the reel and attached to a wire rope. The wire rope which is mounted on a stinger winch controls the final deployment of the cable over the sheaves into the landing sub. At this point the downhole male connector and the female connector at the end of the cable length being deployed are mated. Just prior to seating the cable, the slips are used to permit the attachment of the cable landing shoes and male connector.

This cable deployment process is repeated depending on depth until the bit is on bottom and a cable/connector string connecting the Electrodril downhole assembly (motor assembly and instrumentation subsystem) is deployed, landed and checked electrically. Electrodril power cable is provided in lengths of 5000 feet and 1000 feet and shorter lengths are available by using prewired 90 foot stands and 30 foot joints. Once the system is fully deployed, the prewired kelly is attached with its bushing and the downhole motor is turned on using the driller's console.

After the kelly has been drilled down, a conventional mouse hole connection is made first with one and then with the second of the prewired Electrodril 30 foot joints and drilling is continued. When 90 feet has been drilled with the kelly and two prewired 30 foot joints, the kelly is set in the rat hole and two joints are laid down and replaced by one of the prewired 90 foot stands. The kelly is then picked up and drilling is continued. When 1000 feet has been drilled, all eleven 90 foot lengths of prewired pipe and the two prewired 30 foot lengths are set back from the hole and 1000 feet of conventional drill pipe is run into the hole. A landing sub and pup joints are used to make the pipe tally fit the length of cable to be deployed. A 1000 foot length of Electrodril cable is then deployed in a similar manner to that previously described. Drilling again proceeds using the kelly, the two prewired joints and the prewired 90 foot stands until another 1000 feet has been made. When 5000 feet of hole has been drilled, four 1000 foot cables and eleven 90 foot prewired stands will have been deployed. These are all removed and 1000 feet of rig drill pipe is run in. A 5000 foot length of Electrodril cable is then deployed, landed and checked electrically. Drilling then continues as before. It should be noted that to minimize time, bit trips will be used as much as possible to facilitate these pipe manipulations. At any time the 1000 foot and 5000 foot lengths of cable can be removed from the pipe with a wire line fishing tool. To accommodate this requirement, the 90 foot stands of prewired pipe are run in the hole on top of a safety joint.

VI. THE ELECTRODRIL TEST AND DEMONSTRATION PROGRAM

During the past year and one half, three demonstrations were conducted:

- Systems Verification tests were conducted in a test well during September and October 1978 with the aim of testing key system elements and demonstrating the integrated system on a "wet dry run" basis.
- The initial operational demonstration was held at an Exxon well near Beaumont, Texas during April 1979.
- The second operational demonstration was conducted in South Texas at a Shell well near McCook in late June and early July 1979.

SYSTEM VERIFICATION TESTS

Verification tests designed to check out the Deep Drilling System first at the subsystem level and then as an integrated system were carried out at a 3400 foot section of a test well at Brown Oil Tools facility in Houston, Texas. The purpose of these tests were to provide the maximum level of assurance

possible that the system could, with reasonable confidence, be deployed at an operational well for an active drilling demonstration.

Tests of each subsystem and of the integrated system were designed to add elements on a progressive basis so that problems, if encountered, could be isolated accurately and quickly.

The full test program was accomplished without major problems. All of the newly designed Deep Drilling System equipment was exercised successfully. Numerous downhole connector mateups were made. The integrated system functioned well and was meshed with the rotary rig and deployed readily by a standard crew.

BEAUMONT DRILLING SITE DEMONSTRATION

The first operational drilling demonstration was conducted at the Exxon I.C.H. Matthews well Number 1 located near Beaumont, Texas. Transportation of the Electrodril Deep Drilling System to this Beaumont site began on April 4, 1979. Initial plans called for the deployment of Electrodril at the 5876 foot depth after 2000 feet of surface casing had been set. A 9 7/8" bit was used.

Surface deployment of Electrodril was completed April 7. The downhole assembly was then tested electrically on the surface. During this surface system check, a problem was diagnosed in the voltage control unit which necessitated return of the instrument sub to Houston for repair. While this repair was being effected, Exxon continued rotary drilling.

Electrodril was subsequently deployed at 6973 feet with 6000 feet of cable (one 5000 foot and one 1000 foot length) and eight 90 foot stands of prewired drill pipe. This drill string with the Electrodril downhole system was checked electrically and found to be operationally ready. The motor was started and shut down five times to calibrate the motor control servo loop. At the time the drilling demonstration was to begin, the motor failed to start. An electrical short was isolated in the downhole assembly connection between the instrument package and the motor. This short did not involve the cable/connector system. The Electrodril demonstration, was, consequently, discontinued.

The electrical short was later located in the lower instrument sub power connector. The failure was in the connector harness rather than in the field replaceable connector. The probable cause of this connector failure is centered around a mechanical interference in the multipin mating connector adaptors which impaired complete makeup of the connector.

MC COOK DRILLING SITE DEMONSTRATION

The second Task C drilling demonstration was conducted at the Shell Martinez Number 4 well in their La Copita field near McCook Texas. Transportation of the Electrodril Deep Drilling System to this well site began on June 25, 1979. Plans were to deploy Electrodril at the 5180 foot depth after surface casing had been set. Bit size to be used with the Electrodril was 9 7/8 inches with three 11/32 diameter jets.

Surface deployment of the Electrodril was completed June 27 and a surface test of the downhole assembly was successfully concluded June 28. The voltage control servo loop was also successfully exercised at this time using the static inverter, the downhole sensing unit and 5000 feet of cable.

Electrodril was deployed downhole on June 29 at the planned depth of 5180 feet. Initial makeup of the drill string was the bottom hole assembly comprising the motor and instrument assemblies, seventeen drill collars (including two Electrodril collars), and sufficient drill pipe to land 5000 feet of cable. The electrified kelly was made up on this assembly and drilling commenced at 12:30 am July 1. The remainder of the kelly was drilled down (21 feet) with the motor running at 60 rpm and with 8000 lbs weight on bit. During this process all aspects of the downhole instrumentation subsystem functioned properly. Real time data was received, displayed and recorded in the instrumentation trailer.

After the kelly was drilled down, a prewired 30 foot joint was added to the drill string. The first 30 foot prewired joint of pipe and a section of the kelly was drilled down before an electrical problem in the connectors of this prewired pipe was encountered. A total of three 30 foot prewired joints were subsequently rejected (one being damaged by the rig hands). At this point it was decided to rotary drill an additional 60 feet. This would permit drilling with Electrodril to continue by using a 90 foot prewired stand of pipe and the electrified kelly.

The process of drilling ahead 60 feet utilizing the Electrodril string and rotary power was successfully completed and a 90 foot stand of prewired pipe was added and 30 feet of the kelly was drilled down using Electrodril. Real time data from the downhole instrumentation subsystem was again received, displayed and redorded in the instrument trailer.

During this drilling period, the connectors on the prewired 30 foot joints were replaced and made ready for reuse. However, none of these reworked prewired joints were successfully mated electrically in the drill string. The decision was subsequently made to again drill ahead 60 feet using conventional rotary power with the Electrodril drill string. This process was accomplished without incident.

A second 90 foot stand of prewired pipe was then added to the string. This process was not successful, however, due to indications of electrical leakage to ground. A replacement 90 foot prewired stand was also unsuccessfully introduced and after a third unsuccessful attempt to obtain electrical continuity the Electrodril demonstration was discontinued on the afternoon of July 1, 1979.

VII. CONCLUSIONS AND PLANS

The predominate effort since the McCook demonstration has been to establish on as positive basis as possible the reasons for the electrical problems encountered there. Initial trouble shooting procedures established that the problems were isolated in the field replaceable connectors.

An exhaustive test program was then implemented to define the exact nature of this connector malfunction. One of the major problems associated with the development of downhole systems is the impossibility of trouble shooting while the system is operational. This impossibility is matched by the extreme difficulty of duplicating or even providing a realistic simulation of the downhole environment. At the conclusion of the investigation it did appear that the problem was related primarily to faulty process control, inspection and acceptance test techniques and procedures.

Some minor design modifications to the connectors were incorporated and an initial lot of new connectors were fabricated and tested. These connectors failed in acceptance test on a random basis and additional design modifications were made.

A second connector lot is in process at this writing. Delivery is expected in February. Assuming success in acceptance test, the cable/connector system will be tested exhaustively in a test well, probably in late March. The objective of this test series will be the requalification of the connectors for use in an Operational Demonstration.

A salient point to be made is that the problem has been in the integrity of the connector hardware. It has been possible to achieve a downhole mating of the female/male connectors and establish electrical continuity on a repeatable basis. One further point, reliable connector hardware was made in the engineering model shop during the Phase I Program in 1977 and it appears that the transition from the model shop to the factory was not properly planned.

It is important to place the connector problem to one side and establish a perspective on what has been learned:

When this test and demonstration program is considered as an entity, a number of positive conclusions may be drawn with respect to system deployment at the drill site:

1. The integrated 285 HP Electrodril Deep Drilling System has been fully implemented in hardware and software and is completely feasible as a system.

2. Electrodril is compatible with existing rig equipment and operating methods and can be readily assimilated by standard rig crews.

3. The Electrodril system can be activated at a drill site while rotary drilling is in process and can be brought to the point of actual downhole deployment with no interference with the ongoing drilling operation.

4. Electrification of the prewired 90 foot drill pipe stands can be accomplished quickly with additional time expended in the order of two minutes per stand.

5. Necessary modifications and additions to the rig (i.e., electrifying the kelly, securing the power cable, installing crossover sub and slip ring assembly, emplacing driller's console, emplacing cable sheaves and completing electrical power and instrument connections) can be accomplished within a reasonable time. There is, however, a definite need to incorporate improved equipment and methods, particularly with respect to electrifying the kelly.

Verification tests and system demonstrations have resulted in a number of conclusions with respect to Deep Drilling System Hardware:

1. The power generation scheme selected for Electrodril; an AC alternator and static inverter with downhole demand sensors and surface controllers is capable of providing necessary power levels in response to fluctuating downhole torque requirements.

2. The cable reel and drive provides the capability to deploy and retrieve cable with the necessary speed (300/500 ft/min) reliability, sensitivity and safety.

3. The instrumentation (sensor, telemetry, display and control) subsystem is fully functional and provides broad range (16 channels), high speed (32 samples/sec), real time measurement while drilling.

4. The downhole power/instrument cable is functional, appears to be sufficiently rugged and can be handled effectively. The cable/connector combination is likewise effective, however, at the McCook demonstration an anomaly in connector make-up (female-male combination) was encountered. Preliminary indications are that this is traceable to process and quality control problems. Rework and retest will be required.

5. The Electrodril motor assembly is functional and over the range of testing accomplished thus far promises to provide a reliable source of downhole power. That portion of the assembly above the bit shaft exhibits no problems, however, post test tear down subsequent to the McCook demonstration revealed fractures in the upper bit shaft face seal and a hole in the bit shaft pressure compensation bag. These failures are under investigation. However, it seems certain that problems can be resolved through one of a number of possible approaches. This view is supported by the fact that both the lower motor and lower bit shaft face seals, which are designed for more demanding service, exhibited no problems.

Finally, the limited operational experience achieved to date makes it impossible to draw definitive conclusions relative to Electrodril drilling performance. However, on a preliminary basis the following comments appear valid:

1. Tripping the motor assembly and instrument package downhole and then making up the cable connections can be accomplished smoothly. This operation (with 5000' of cable) will require 30 to 40 minutes more than a conventional trip.

2. Making connections with the prewired elements (90 foot stands, 30 foot joints and the kelly) works smoothly and with a very minor expenditure of additional time over that required for standard rotary drill pipe connections.

3. The active Electrodril drilling accomplished at McCook was very limited (50 feet). In addition, power provided downhole was about one quarter of rated levels, due to problems with the diesel generator set. Even with these limitations, a penetration rate of 94 feet per hour was achieved with motor output of 38 HP. Drilling immediately before and after Electrodril, Shell achieved penetration rates of 55 and 60 feet per minute with the rotary system. The conclusion to be drawn from this admittedly sparse data is that with full 150 HP (@200 rpm) very dramatic improvements in penetration rates could have been expected.

4. The sensor and telemetry system functioned perfectly. All sensors provided valid data, and there is no question but that the real time measurement while drilling capability is functional.

VIII. PROJECTED OPERATIONAL AND ECONOMIC BENEFITS

Through the integration of the capabilities embodied in the several system elements, the Electrodril system promises to provide greatly improved drilling performance. Improvement is projected in three areas of major significance:

°High horsepower at the bit and high rotational speeds will provide significantly increased penetration rates. The ability to sense downhole conditions in real time and optimize speed and weight on bit while balancing mud hydrostatic pressure with formation pore pressure as a function of changing conditions will also contribute to increases in the rate of penetration.

°Real time formation sensing and the directional control afforded by the downhole instrumentation and telemetry package will result in reduced tripping. This will be possible because better control of drilling operations together with expanded application of diamond bits will result in extended bit life and optimize the ability to sense the point at which a bit trip is required. In addition, fewer trips will be required for logging and surveys.

°The ability to sense blowout conditions as they are encountered at the bit face will contribute greatly to safer drilling operations since killing a blowout or controlling a kick will be much simpler and safer with a continuous surface readout of bottom-hole pressure and other formation conditions.

In combination, these benefits are expected to provide a reduction in the overall time during which the very expensive facilities required for drilling are used at a given well. The payoff from this improved drilling

performance expected from Electrodril is greater application of expensive capital facilities - more wells per year per dollar of drilling budget.

It is difficult, and perhaps unrewarding, to attempt to quantify the effect on operational economics which may be expected to result from the operational benefits outlined above. However, a number of drilling logs have been analyzed and the change in results achieved in the actual drilling operation assuming the substitution of Electrodril for rotary drilling has been projected. The assumptions utilized in these analyses were quite conservative with respect both to improvements to be expected in drilling performance and the value of the savings resulting from this improved performance. It appears that in the correct applications; deep, tough formations, fifteen percent savings in direct costs budgeted for drilling would be accompanied by reductions in capital and other indirect costs assessed against each well. Moreover, these operational savings will be accomplished with a system which provides a high capacity MWD capability.

In addition to the quantifiable direct costs, economic benefits are projected from a number of other important factors:

- Increased drill pipe life may be expected because with Electrodril the pipe will be rotated at very low rpm.
- Better hole conditions may be expected to result because the drill pipe, operating at low rpm and with very little torque, will not disturb the mud cake build up on the hole wall.
- The ability to log while drilling will provide greatly improved well-to-well correlation.
- Earlier initial production will be realized.

Finally in situations where very heavy capital outlays for rigs are planned, the capability to accomplish twenty-five to thirty percent more drilling with each rig is of extreme significance.

BERC/TPR-77/4
Distribution Category UC-92a

247,887
99pp.

ELECTRODRIL SYSTEM FIELD TEST PROGRAM PHASE I—FINAL REPORT, MAY—DECEMBER 1976

By

General Electric Company
Space Division
March 1, 1977

Prepared for the Energy Research and Development Administration Under Contract No. EY-76-C-02-4033

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Date Published—October 1977

U.S. DEPARTMENT OF ENERGY
TECHNICAL INFORMATION CENTER

FOREWORD

The Electrodril System Field Test Program - Phase I, as described herein, is a cooperative, cost-sharing venture between the Energy Research and Development Administration (ERDA) and the petroleum industry with the prime contractor being General Electric Company (GE). The work was performed under ERDA Contract Number EY-76-C-02-4033 (formerly Contract Number E(11-1)-4033). Other industry participants are as follows:

AMOCO Production Company
Brown Oil Tools Company
Chevron Oilfield Research Company
Dresser Industries
Roy H. Cullen Research
Union Oil Company of California

The Electrodril concept is to provide a method to drill with a downhole electric motor that uses a retrievable power cable and employs a telemetry system which makes downhole measurements of various drilling and safety parameters and transmits them to the surface. The successful development of Electrodril should provide a significant addition to drilling technology.

The objective of Phase I was to test the Electrodril Directional Drilling System under actual drilling conditions and to test the Electrodril Major Drilling System (for straight hole drilling) under drilling conditions in a cased well. Both systems utilize a wireline retrievable electric cable for a power source but use different methods of deployment. Both systems require downhole mating of electrical connectors in a drilling mud environment but the Major System also requires prewired drill pipe which makes the electrical connection as the pipe is screwed together.

This report describes the work performed and the results obtained. The actual achievements fell far short of what had been planned or predicted; however, enough satisfactory results were obtained to indicate that the Electrodril System is a viable drilling method. The problems encountered pointed out the areas where improvements and modifications were needed.

The subject contract was extended and improvements have been made which will make the Directional Drilling System ready for an oilfield demonstration.

C. Ray Williams
Technical Project Officer

ELECTRODRIL SYSTEM FIELD TEST PROGRAM
PHASE 1

FINAL REPORT

ABSTRACT

Phase 1 of the Electrodril System Field Test Program was set up to establish the technical viability of two Electrodril System configurations, the Directional Drilling System and the Major Drilling System. Both Electrodril configurations consist of an electric drill motor located directly above the bit, a downhole telemetry-control instrument designed to monitor hole position and other downhole parameters while drilling; a cable deployed through the drill string and remotely mated to the motor/instrument downhole in drilling mud and associated power conversion, cable handling, and data processing equipment on the surface.

The Directional Drilling System used a 60HP drill motor, small 3/4" diameter downhole cable connectors, and a "Yo-Yo" type cable deployment system. It is designed to drill deviated holes to depths of 10,000 feet or less.

The Major Drilling System used a 285HP drill motor, large 1" diameter downhole cable connectors, cable suspended in the drill pipe by a special sub, pre-wired pipes, and slip rings. It is designed for deep, tough drilling under hostile conditions.

Both configurations were shown to be compatible with existing rig equipment and procedures. A deviated hole was drilled using the Directional Drilling System with a bent sub. A straight hole was drilled through a concrete plug set in a cased well using the Major Drilling System. The Downhole Telemetry/Command instrument was used to monitor hole position, temperature, downhole voltage, and vibration while drilling. The Field Test did establish the technical viability of the Electrodril System.

ELECTRODRIL
PHASE 1
FIELD TEST
FINAL REPORT

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ELECTRODRIL

PHASE I

FIELD TEST

FINAL REPORT

1.0 INTRODUCTION

The Electrodril Phase I Field Test was performed at the Brown Oil Tool (BOT) test site located on the Katy Freeway in Houston, Texas. Testing was accomplished during the period of September 20, 1976 through December 17, 1976. Testing was performed in accordance with the Phase I Test Plan (Reference 2), and the Phase I Task A and Task B Test Procedures (References 3 & 4).

The Task A portion of the Phase I Field Test demonstrated the compatibility of the Directional Drilling System (consisting of 60 hp motor, Downhole Real Time Telemetry/Command System, a "Yo-Yo" deployed Electrodril cable, and small 3/4" O.D. cable connectors) with existing rig equipment and procedures. Actual directional drilling was also accomplished during Task A testing.

The Task B portion of the Phase I Field Test demonstrated the compatibility of the major drilling system (consisting of 285 hp motor, cable fully deployed into hole, pre-wired pipe, slip rings, and large 1" O.D. cable connectors) with existing rig equipment and procedures. Straight drilling through a concrete plug was also accomplished during Task B testing.

This report is to document the results of the Electrodril Phase I field tests, to identify problem areas, and to recommend what should be accomplished next to expedite the commercial use of Electrodril.

2.0 SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

2.1 SUMMARY OF RESULTS

2.1.1 Drilling Mud Pressure Drop Through Electrodril System

Drilling mud was circulated through five downhole configurations to determine the mud pressure drop due to each Electrodril component. The drop through the motor varied from 16 to 110 psi with flow rates from 200 to 420 gallons per minute. The deployed Electrodril cable (2000 feet) contributes from 20 to 70 psi drop over the same flow rate range. The downhole Electrodril instrument assembly adds a 16 to 24 psi drop.

At 2000 feet, drilling with the Electrodril system requires a 50% increase in mud pump pressure when compared to that required to drill conventionally.

A projection of the Electrodril pressure drop data indicates that drilling at 20,000 feet with Electrodril requires a maximum of 28% increase in mud pump pressure capability over that required for conventional drilling at the same depth.

2.1.2 Electrodril Cable and Connector Performance

2.1.2.1 Cable

The Electrodril armored cable was deployed downhole a total of 48 times. The deployment time ranged from 55 ft/min to 180 ft/min while the retrieval time ranged from 95 ft/min to 250 ft/min. No noticeable wear was found on the cable exterior (armor). The electrical properties of the cable did not degrade during the test.

The cable armor was physically damaged five times without compromising the electrical properties of the cable. Four of the five events resulting in damage were caused by human error. The fifth event was a result of incorrect retrieval procedure and has been corrected.

2.1.2.2 Connectors

Three types of Electrodril cable connectors were utilized during the test. The first, a 3/4" O.D. straight connector designed to mate downhole under mud, was used for all Task A testing. The second and third, a 1" O.D. straight connector similar to the first type and a tapered connector to be mated in air, were demonstrated during Task B testing.

Seventeen successful connector matings were made downhole in mud with the Task A connector system. A total of 41 downhole matings were attempted to achieve the 17 successes. The mating failures were caused by: 1) connector failures, 2) inability of the dielectric grease (put into the female connector to keep mud out) to escape quickly enough during mating, and 3) misalignment of the male,female connectors while attempting to mate. After identifying the causes of mating failures, appropriate corrective actions were taken. After taking these corrective actions, reliable downhole mating was achieved.

The planned usage of Task B connectors was not as extensive as that of the Task A connectors. However, both the straight and the tapered 1" connectors were used successfully to drill with the 285 hp motor. Procedural difficulties resulted in mud or moisture being introduced into both types of connectors while adding a pre-wired section of pipe. This moisture caused arcing between conductors which ultimately resulted in the connectors failing. The procedural difficulties have been documented and will be alleviated prior to using again.

2.1.3 Electrodril Motor Performance

A total of three motors were used during the field test. One was a 285 hp motor used in Task B testing. The other two were 60 hp motors used in Task A testing. It was observed that motor current varied proportionally to the weight on the bit. Data is being accumulated to allow a direct correlation between bit torque and motor current.

2.1.3.1 285 hp Motor

- Total run time = 51 minutes
- Run time in mud = 48 minutes

  Maximum mud pressure on surface = 800 psi
- Total drill time = 45 minutes
- With surface voltage = 1220 volts

  Idle current = 30 amps

  Max drill current = 45 amps (8000# wt. on bit)
- Motor performed as required with no failures

2.1.3.2 60 hp Motor #1

- Total run time = 275 minutes
- Run time in mud = 266 minutes

  Maximum mud pressure on surface = 450 psi (compatibility test)
  = 100 psi (directional drilling test)
- Total drill time = 85 minutes
- With surface voltage = 1230 volts

  Idle current = 11.5 amps

  Max drill current = 25 amps (6000# wt. on bit)
- Use of motor for test terminated when lower face seal (mud to oil) on output shaft failed, allowing mud to enter the protector section of the motor

2.1.3.3 60 hp Motor #2

- Total run time = 122 minutes
- Run time in mud = 121 minutes

  Maximum mud pressure on surface = 100 psi (directional drilling test)
- Total drill time = 89 minutes

- With surface voltage = 1230 volts

  Idle current = 11 amps

  Max drill current = 25 amps (10,000# wt. on bit)

- Use of motor for test terminated when lower face seal (mud to oil) on output shaft failed, allowing mud to enter the protector section of the motor.

2.1.4 Drilling Performance

Drilling was accomplished with each of the three Electrodril motors (one 285 hp and two 60 hp).

2.1.4.1 Task B Drilling

The 285 hp motor was used to drill a straight hole through a hard concrete plug in a 3600 foot cased well. An 8-15/32" diamond bit was used to drill the concrete. A total of eight feet were drilled. For the first two feet the drill rate was 7 to 10 minutes per foot. As we became more familiar with the drilling system, the rate went to 4 minutes per foot. After drilling the 8 feet, drilling was stopped to allow a 30 foot section of pre-wired drill pipe to be added to the drill string. Drilling mud or moisture was inadvertently left in the tapered Task B connector at the lower end of the pre-wired pipe. The moisture caused arcing between conductors which rendered the connector unuseable. The protective fuses blew thus preventing any damage to any other portion of the Electrodril system. Drilling was not resumed due to a schedule conflict with BOT use of the 3600 foot cased well.

2.1.4.2 Task A Drilling

The two 60 hp motors were used in conjunction with the Electrodril directional instrument, a 1° bent sub (located immediately below the motor), and a 9-7/8" tricone rock bit to drill a controlled directional hole. A total of 142.5 feet were drilled, 50 feet with 60 hp motor #1

and 92.5 feet with 60 hp motor #2. Both motors achieved approximately a 1.3 ft/min drill rate while turning the bit at 200 rpm in shale with sand lenses. The bent sub, located 11 feet above the bit provided an average deviation of 3.5°/100 ft. The downhole directional instrument measured drift, azimuth, and tool face orientation while drilling (see discussion in Section 2.1.5). The ability to control hole azimuth by measuring while drilling, then rotating the rotary table when adding drill pipe was demonstrated while drilling the 142.5 feet of hole. The procedure for controlling hole direction will be refined based on lessons learned during this test.

2.1.5 Well Survey Basic (WSB) Performance

The WSB consists of a downhole instrument package, surface equipment and a data analysis trailer.

2.1.5.1 Downhole Instrument Performance

The downhole instrument system is composed of a real time telemetry and control system and several sensing elements including a position measuring package designed to function continuously while drilling.

2.1.5.1.1 Telemetry and Control System

Two downhole telemetry and control systems were operated for 188 hours and 177 hours respectively with only typical electronic equipment problems. When deployed downhole, the instrument performed flawlessly. Both uplink telemetry and downlink controls were consistently transmitted and received simultaneously over the same conductor, with the motor running, and with no errors detected. Measurements indicated that the telemetry link was operating with a signal-to-noise ratio margin of 45 db even when the motor was intentionally turned on and off to create current surges.

2.1.5.1.2 Downhole Sensing Elements

A total of 15 analog inputs plus one 16 bit digital input can be accepted by the downhole telemetry system. The configuration tested used nine (0V calibration, 4V calibration, vibration frequency, vibration amplitude, downhole instrument voltage, downhole temperature, and three position measurements - drift, azimuth, and tool face orientation) of the analog channels and five digital channels (Command 1, Command 2, Command 3, Command 4, and a discrete from the vibration sensor). The temperature sensor, voltage sensor, calibration voltage generators, and the received command indicators performed as specified. The vibration sensor appeared to be functioning normally; however the formations in which the drilling test was run did not provide enough bit vibration to adequately demonstrate the vibration sensor.

The position monitor made drift, azimuth, and tool face orientation measurements which were sent to the surface, converted to engineering units, displayed, and recorded. Processing the position monitor data to yield closure information similar to that obtained by multishot surveys has shown that the instrument did yield a hole trajectory that followed a 2-1/2° multishot survey (Sperry Sun) trajectory within six inches. Note for reference that a 10° Eastman Whipstock multishot survey provided a trajectory that differed from the Sperry Sun trajectory by up to 11 inches. The instrument itself is designed to operate at higher deviation angles (up to 90°) than were obtained while drilling 142 feet. As a result of the low deviation angles of 2 degrees or less, the instrument did have trouble obtaining reliable azimuth readings.

Two identical position monitor instruments were used during the test. The first was run a total of 44 hours while the second was run 28.5 hours. No equipment failure occurred while drilling.

2.1.5.2 Surface Equipment

The WSB surface equipment consists of a power source and a Control/ Display unit. Both units were designed to operate in an outside oil field environment of moisture, temperature, and drilling mud. Operation of both units was completely satisfactory. There were no failures during operational use.

During the course of testing the surface units accumulated a total run time of 313 hours. They were subjected to bright sunlight, rain, drilling mud and temperatures down to 30°F and performed satisfactorily.

All surface cabling performed without failure while subjected to oil well environment.

2.1.5.3 Data Analysis Trailer

The Data Analysis Trailer proved to be a useful device for collecting, storing, and processing data received from the downhole instrument. Strip chart recordings of all data received while drilling were obtained. The trailer was available and was used to support all phases of testing involving the WSB system.

2.1.6 Surface Cable Handling Equipment Performance

Electrodril surface cable handling equipment consists of the hydraulic portion of the power skid, the hydraulically powered cable reels, upper sheave, lower sheave, and the load cell.

The surface cable handling equipment operated successfully during all tests However, performance can be improved through modification in several areas (particularly the hydraulic system control functions). These modifications will be accomplished before using again.

2.1.7 Surface Electrodril Power Equipment Performance

The surface power equipment consists of a tapped 3 phase power transformer, associated protective circuitry (fuses and overvoltage trips), and the drillers console used to monitor and control the downhole power.

This equipment performed its function as required.

2.1.8 Electrodril Compatibility with Existing Rig Equipment and Procedures

The Electrodril System was demonstrated to be compatible with existing rig equipment and procedures in most areas. The following problems in that area were found and resolved.

- Electrodril must use non conductive pipe joint compound exclusively while current pipe joint compounds are typically conductive.

- The fine straight threads used to mate the motor to the mud tube are unsuitable for field assembly.

- Technique for mounting upper and lower sheaves used to direct the cable into the drill pipe must be flexible enough to ensure that the cable can be deployed witnout touching existing portions of the rig setup.

2.1.9 Safety Considerations

No personnel safety problems were encountered during testing. All components of the Electrodril system that could be touched were electrically grounded before power was ever applied. "Danger High Voltage" and "Hard Hat Area" signs were conspicuously displayed in the appropriate areas. All components that hung above head level were mounted with hardware with break strength at least two times the maximum possible load. The power skid was dragged slightly while under cable load. Testing was subsequently continued after the power skid was securely anchored with two 6-foot anchors.

2.2 CONCLUSIONS

The Electrodril concept has been shown to be technically viable. Remote downhole electrical connections have been repetitively made in drilling mud. An Electrodril system has drilled a deviated hole while interfacing with conventional rig equipment. The downhole telemetry/command system performed flawlessly during the test program. The direction monitoring unit provided hole trajectory data during the directional drilling operation which subsequently correlated closely with hole trajectory provided by a conventional Sperry Sun multishot survey.

Problems were initially encountered with the downhole cable connectors but were resolved during the program. The 60 hp motors exhibited poorer seal life than anticipated. Post test evaluation indicated that incorrect pretest preparation procedures contributed to the poor seal life. Further investigation and possibly additional design effort is necessary in the oil/mud seal area of the motor protector section. This effort is currently in progress as part of the Interim Phase II Program.

Post test evaluation of the bit shaft assembly indicated higher than anticipated upper seal wear. A design reassessment of this area is also being made as a part of the Interim Phase II program.

2.3 RECOMMENDATIONS

During the course of implementing the 1976 Electrodril Phase I Field Test Program, delays were encountered due to cable/connector failures. Although fixes were instituted in time to permit the major elements of the Phase I program to be successfully completed, the consensus of the Advisory Board members contacted was that an Interim Phase be set up to fully investigate the cause of the cable/connector failures and from the lessons learned, redesign and/or modify the current cable/connector approach to assure system success in future deployments.

In addition to the cable/connector problem identified above, motor system mud/oil seal interfaces have been identified as needing investigation. The particular seal interface gave poor performance during the Phase I demonstration program and upon post test disassembly showed excessive wear. There are, however, mitigating circumstances surrounding this problem as post test investigations indicate both motors were assembled for use incorrectly. The mud/oil seal interface is too important an area to be left in an unresolved technical status and thus, it is recommended to thoroughly investigate and resolve the problem during this Interim program.

Thus, it is recommended that an interim phase of approximately 4 months duration be implemented to resolve the connector problem and the motor seal problem. In addition, it is recommended that a reassessment of the bit shaft oil/mud seal design be included in the interim phase to resolve the excessive wear problem mentioned in Section 2.2 and 4.3.

3.0 FIELD TEST DESCRIPTION

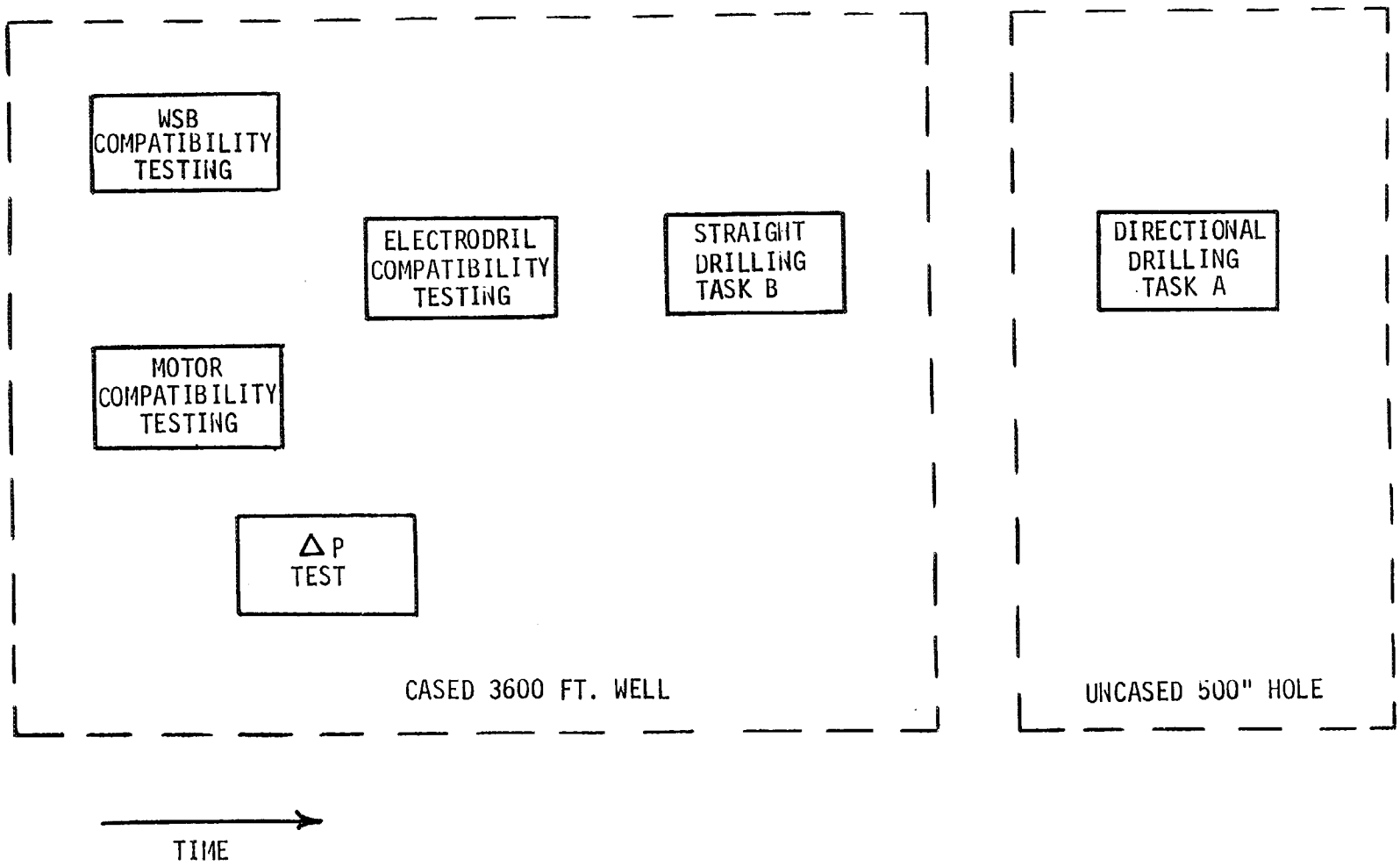
The Phase I Electrodril Field Test was accomplished in accordance with the Phase I contract, the Field Test Plan (Ref. 2), and the Task A and Task B Field Test Procedures (Ref. 3 & 4). The overall field test was divided into six relatively independent tests as shown in Figure 3-1. Note that safety testing is not specifically illustrated on the figure. A safety plan was implemented coinciding with the beginning of the field test. Verification that the equipment was indeed safe extended throughout the entire field test.

All testing except the directional drilling test was performed at a cased 3600 foot test well using an in-place rig. The directional drilling was accomplished using a portable rig and a hole drilled conventionally to 500 feet.

3.1 WSB COMPATIBILITY TEST

All Well Survey Basic (WSB) equipment (downhole instrument, power source, control and display unit, data analysis trailer, and associated cabling) were operated together in an oil well environment during the WSB compatibility test. The following functional objectives were achieved:

1) Each of the WSB components functioned as required
2) WSB connectors and cables functioned and were compatible
3) All WSB interfaces were compatible
4) The WSB system functioned with the downhole instrument deployed in drilling mud and all surface equipment exposed to an outside oil well environment
5) The interfaces with the test site were compatible
6) The downhole telemetry and command links functioned without error



MAJOR PHASE I FIELD TESTS

FIGURE 3-1

3.2 MOTOR SYSTEM COMPATIBILITY TEST

Two motor system compatibility tests were run, one for Task A equipment and one for Task B equipment. A list of the equipments involved in each test follows:

Task A	Task B
60 hp motor	285 hp motor
Downhole Yo-Yo cable/connector	Self supported downhole cable/connector
Circulating head	Electrical crossover sub
	Pre-wired drill pipe
Wireline packoff	Slip rings
Surface cable handling equipment	Surface cable handling equipment
Cable skids/reels	Cable skid/reels
Power skid	Power skid

In each case, the motor was run downhole, cable deployed and made up downhole, the system configuration completed, mud circulation established, and the motor ran. The following functional objectives were achieved:

1) Each motor system component performed its intended function. (Thoughts for improving the operability of the components were documented as testing progressed).
2) All system interfaces were compatible.
3) System connectors and cables functioned. (Several problems in the connector design were uncovered and resolved to complete the tests).
4) The motor was deployed and operated downhole on standard drill pipe using a conventional rig.
5) The entire motor system interfaced with the conventional rig as required.

3.3 ELECTRODRIL COMPATIBILITY TEST

Following the WSB and motor system compatibility tests, the entire Task A Electrodril system (60 hp motor system, WSB system, and the downhole instrument harness) was assembled and operated as a system. The motor and instrument assembly were deployed downhole and then the Electrodril cable deployed downhole until it mated with the instrument harness. Next, the downhole instrument was turned on, mud circulation was established, and then the motor was turned on and ran with the bit off bottom. The motor was turned on and off several times to determine the effect of motor start current on WSB operation. The following functional objectives were achieved:

1) All Electrodril components functioned together as a system.
2) The WSB uplink and downlink functioned without error with the motor being turned on and off and then with the motor running continuously.

3.4 DRILLING MUD PRESSURE DROP TEST

The purpose of this test was to measure the drilling mud pressure drop when the Electrodril system was deployed downhole. Five different configurations were used, starting with drill pipe alone and ending with the entire Electrodril system. The various configurations were employed to allow determination of mud flow impedance due to each downhole component of the Electrodril system. The test established that the Electrodril system does not significantly impede drilling mud flow.

3.5 STRAIGHT DRILLING TEST

The straight drilling test for Task B was accomplished by first setting a concrete plug near the bottom of a 3600 foot cased well, then drilling it out with the Task B Electrodril system. Eight feet was drilled using the pre-wired Kelley. No problems were encountered. Next, a 30' pre-wired pipe was added so drilling could continue. Apparently, some drilling mud or precipitation entered the connectors while adding the pre-wired pipe. As a result, arcing occurred between conductors in the connector when power was applied to the motor to resume drilling. The arcing destroyed the integrity of the connector which in turn delayed the test while additional connectors were molded. A scheduling conflict arose between Electrodril testing and BOT over use of the cased 3600 foot well. Task B Electrodril testing was terminated due to this scheduling conflict.

3.6 DIRECTIONAL DRILLING TEST

The Task A directional drilling test was performed on a hole drilled conventionally to a depth of 500 feet. Directional drilling was accomplished using a 60 hp motor with a 1° bent sub located below the motor approximately 11 feet above the bit. A total of 142.5 feet of hole was drilled. The following functional objectives were achieved:

1. Demonstrated that a directional hole can be drilled with the Electrodril system.
2. Demonstrated that hole position and other drilling parameters can be monitored continuously while drilling

Directional drilling performance is discussed in Section 4 of this report.

Two 60 hp motors were used during the course of the directional drilling test. The first motor was used to drill a total of 50 feet. It was replaced by a second 60 hp motor when the lower oil/mud seal on the first motor failed

and allowed drilling mud to enter the protector section of the motor. The second motor was used to drill another 92.5 feet of directional hole. Testing was terminated when the lower oil/mud seal on the second motor failed and allowed drilling mud to enter the protector section of the motor.

4.0 DETAILED TEST RESULTS

4.1 DRILLING MUD PRESSURE DROP THROUGH ELECTRODRIL SYSTEM

Tests were run to establish how much the drilling mud flow is impeded by having the Electrodril downhole assembly and cable deployed in the hole. These tests were run in the cased (9-5/8" O.D. casing) 3600 foot hole at BOT. Five different configurations were employed to allow comparison of mud pressure required to provide a fixed mud flow rate.

The five configurations all used 16.6 lb/ft, 4-1/2" X-hole drill pipe. Four configurations used a 7-7/8" tricone rock bit with the three nozzles removed. The diameter of each of the three bit openings was 7/8" which yields a total flow area of 1.8 in^2.

Mud flow rate was determined by counting the mud pump stroke rate (9.9 gal/stroke). A SWACO pump stroke counter was tried and yielded some good data but proved to be unreliable, hence pump strokes were observed and counted.

Mud pressure was monitored by recording pressure on a Geolograph and by reading pressure on a standard mud pressure gage manufactured by Cameron Iron Works.

Before each test, the mud in the tanks was stirred up and then mud circulated through the system until mud weight and viscosity stabilized (generally 1 to 2 hours). Pressures were recorded for $\approx$40, 30 and 20 strokes per minute mud flow rate in each test configuration. Approximately 30 minutes of testing was accomplished at each flow rate.

The five different configurations tested were:

1. 58-60 ft. stands of drill pipe (mud weight = 8.6 #/gal.)
2. 32-60 ft. stands of drill pipe with bit (mud weight = 9.6 #/gal.)
3. 32-60 ft. stands of drill pipe with 285 hp motor and bit (mud weight = 9.3 #/gal.)
4. 32-60 ft. stands of drill pipe with deployed Electrodril cable, 60 hp motor, and bit (mud weight = 9.3 #/gal.)
5. 25-60 ft. stands of drill pipe with deployed Electrodril cable, instrument assembly, 60 hp motor, and bit (mud weight = 8.8 #/gal.)

Figure 4-1 is a plot of input and pressure versus mud flow rate. Note that the values have all been corrected to 10 #/gal mud weight and 2000 feet of drill pipe.

The pressure drop data has been extrapolated to determine the added mud pump pressure that must be provided by a rig when using Electrodril instead of conventional drilling techniques. Figures 4-2 and 4-3 are curves comparing mud pump pressure required for Electrodril and conventional drilling at various depths and mud flow rates. Figure 4-2 assumes a 10 lb/gal mud while Figure 4-3 assumes a 15 lb/gal mud. In both figures a drill bit pressure drop of 1000 psi is assumed.

4.2 ELECTRODRIL CABLE AND CONNECTOR PERFORMANCE

All Phase I field testing was accomplished using a four conductor armored cable. Several types of connectors were used for accomplishing both Task A and Task B goals. The cable/connector interface is discussed as part of connector performance.

4.2.1 Cable

The Phase I field test cable was a 0.875" O.D. double armored cable containing three #10 AWG stranded conductors to power the 3 phase downhole motor and one #18 AWG stranded conductor for operating the downhole instrument system. The cable armor served as the return for the instrument system.

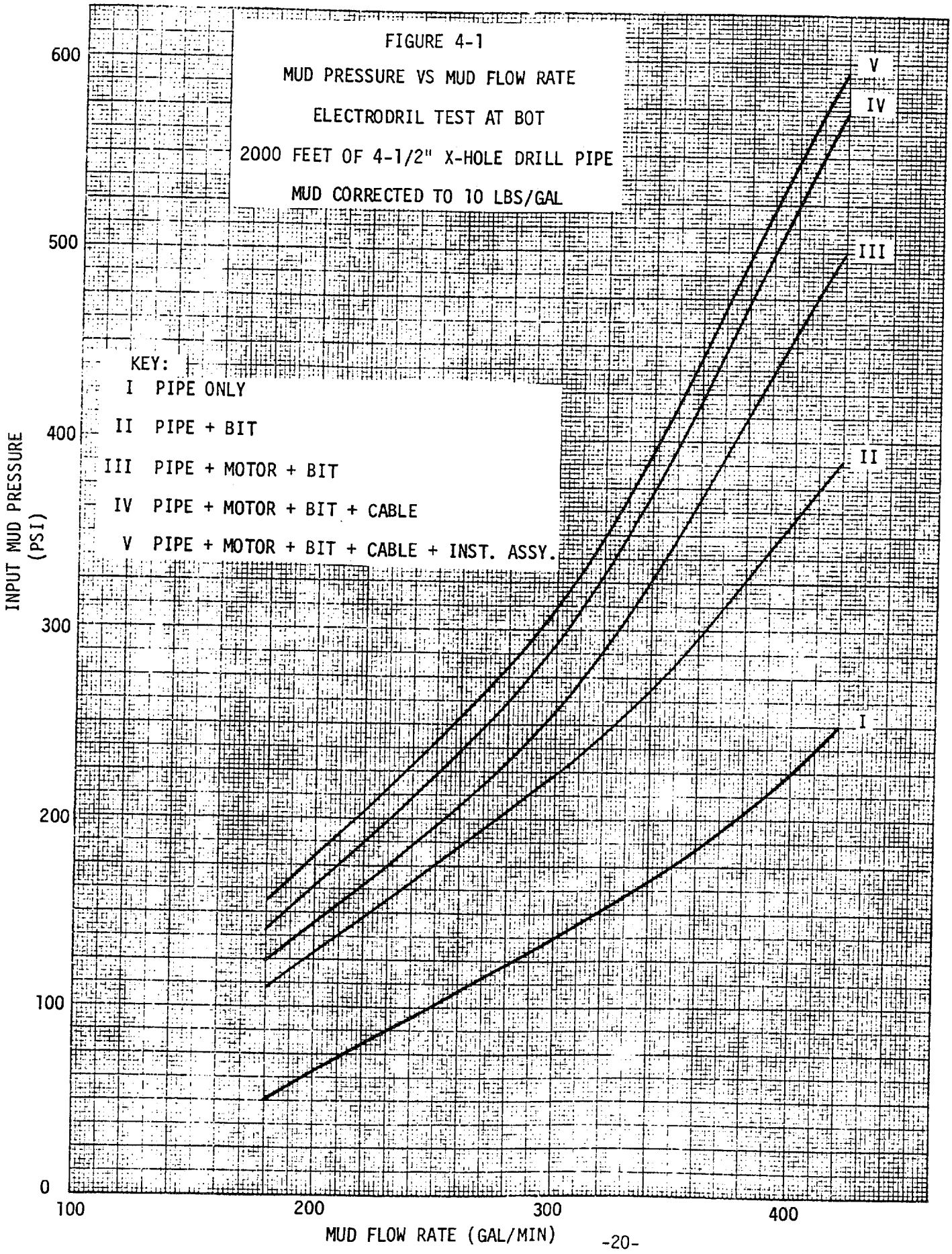


FIGURE 4-1
MUD PRESSURE VS MUD FLOW RATE
ELECTRODRIL TEST AT BOT
2000 FEET OF 4-1/2" X-HOLE DRILL PIPE
MUD CORRECTED TO 10 LBS/GAL
KEY:
I PIPE ONLY
II PIPE + BIT
III PIPE + MOTOR + BIT
IV PIPE + MOTOR + BIT + CABLE
V PIPE + MOTOR + BIT + CABLE + INST. ASSY.
INPUT MUD PRESSURE (PSI)
0
100
200
300
400
500
600
100
200
300
400
MUD FLOW RATE (GAL/MIN)
I
II
III
IV
V

FIGURE 4-2
MUD PRESSURE VS HOLE DEPTH
FOR
ELECTRODRIL AND CONVENTIONAL DRILLING
MUD WEIGHT = 10 LBS/GAL
PRESSURE DROP ACROSS BIT = 1000 PSI

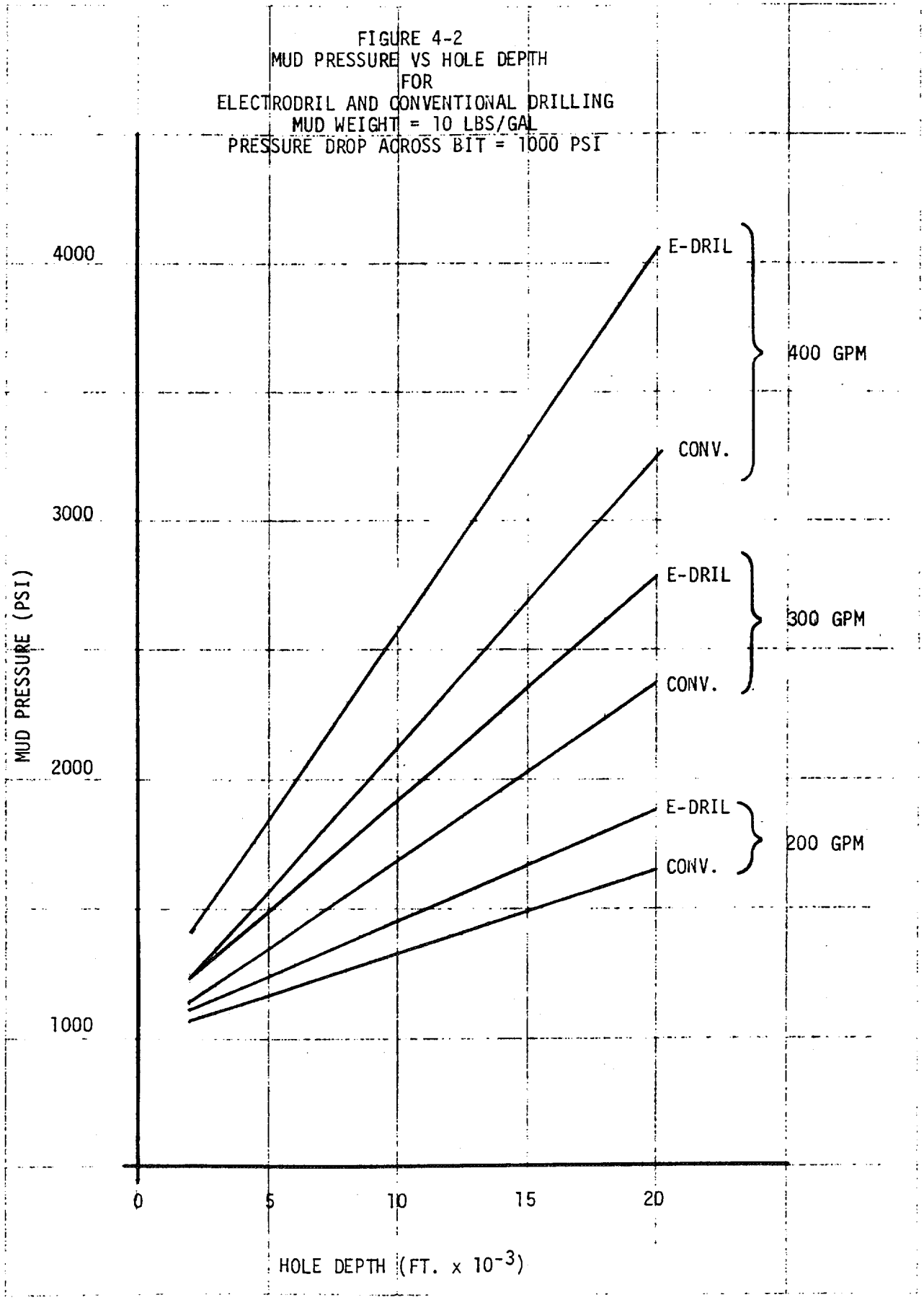


FIGURE 4-3
MUD PRESSURE VS HOLE DEPTH
FOR
ELECTRODRIL AND CONVENTIONAL DRILLING

MUD WEIGHT = 16 LBS/GAL
PRESSURE DROP ACROSS BIT = 1000 PSI

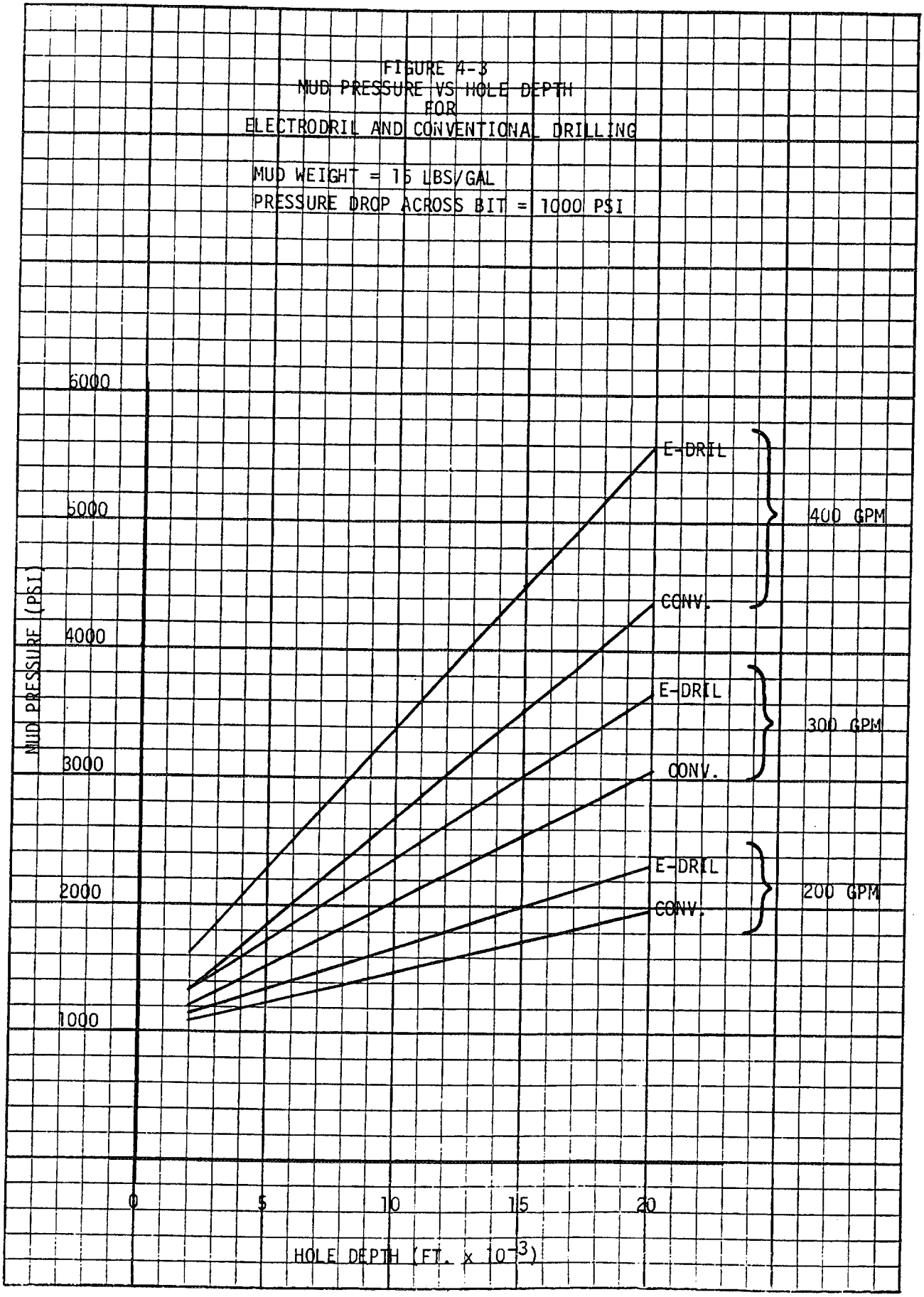


Figure 4-4 is a photograph of the male connector on the motor.

The cable was deployed downhole, using the power skid hydraulics and the surface cable handling system, a total of 48 times. The downhole motor was powered up 17 times through the deployed cable. In addition the cable was used to "bump" the motors numerous times while on the surface.

Throughtout the entire test, the electrical properties of the cable did not fail or degrade.

The armor protecting the cable was damaged several times but never failed, i.e., the strands of armor never were broken but they were moved out of position resulting in a "birdcage" effect. This did not affect the electrical properties of the cable but did cause minor problems when passing the cable through the wireline packoff.

The armor was damaged twice by repairmen working on the power skid hydraulic system. The cable was damaged two more times due to rig hand carelessness. The cable was damaged one time when the cable rode off the cable reel while retrieving, resulting in the cable starting to wrap around the reel axle.

4.2.2 Connectors

4.2.2.1 Connector Configurations Utilized

Two basic types of connectors were utilized while performing the field test, those designed to mate downhole in mud (straight) and those designed to mate on the surface in the atmosphere (tapered). Both are designed to operate in drilling mud after mating. Two sizes of straight connectors were utilized during the field test, one small (3/4" O.D. male) and one large (1" O.D. male). Figure 4-5 illustrates the cable/connector configuration used in Task A and in Task B testing. Note that in the Task B configuration, the large straight male connector on the upper end of the 3400 foot cable had the added function of supporting the cable. This was accomplished with spring loaded "dogs" on the connector base that sat on a lip in a specially designed "landing sub".

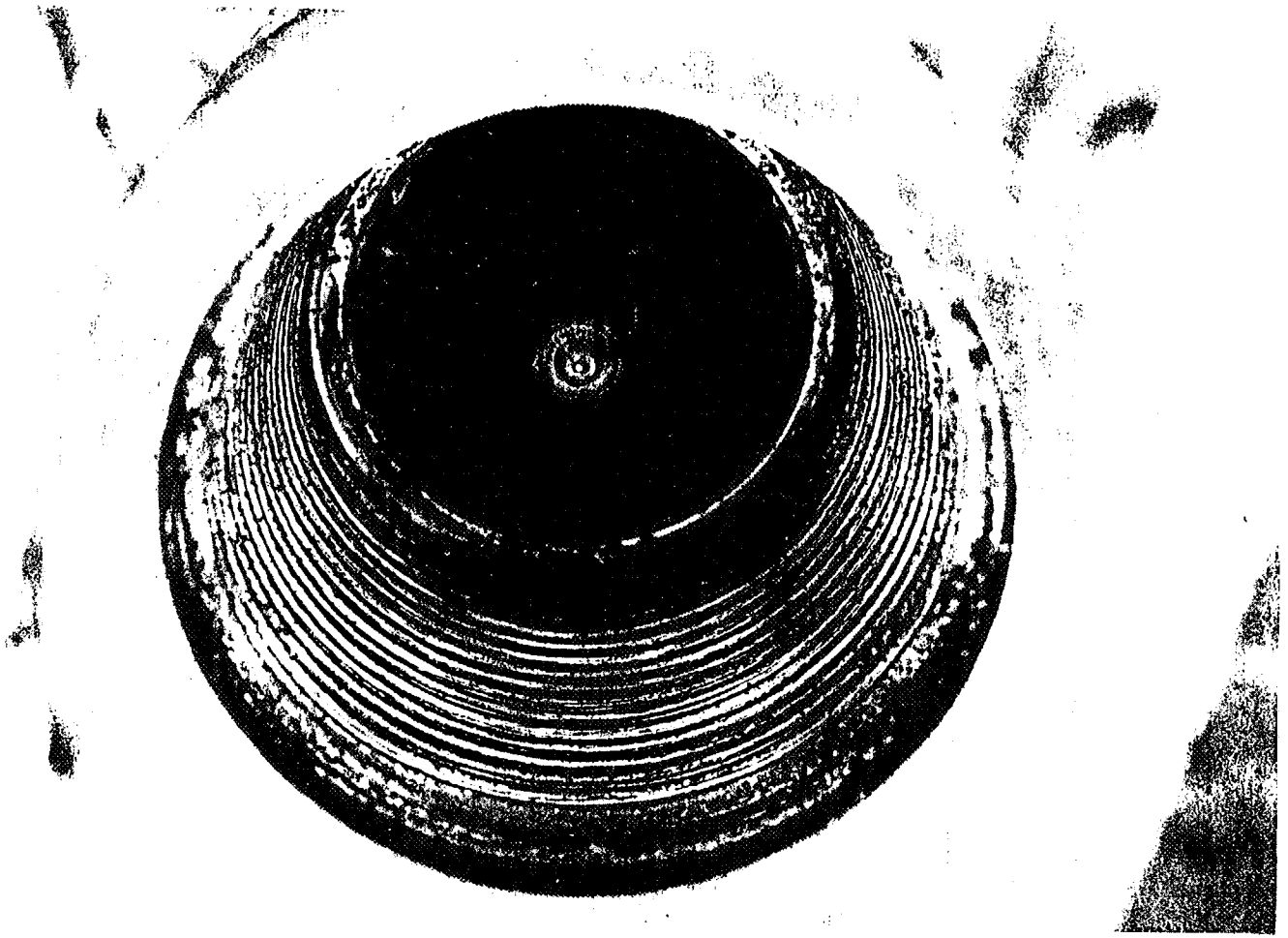


FIGURE 4-4

MOTOR MALE CONNECTOR

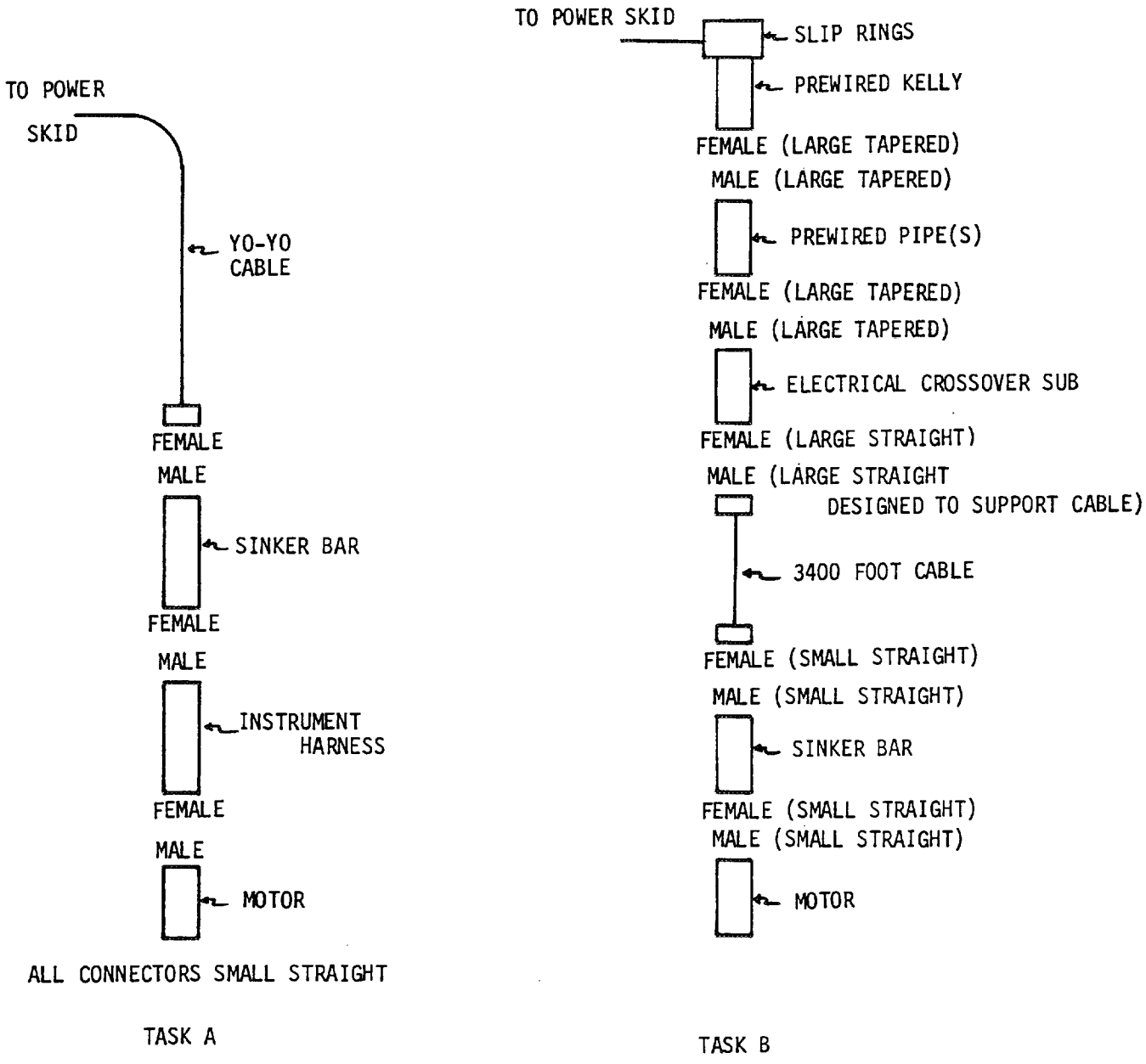


FIGURE 4-5

FIELD TEST CABLE/CONNECTOR CONFIGURATIONS

Most of the connections are made on the surface prior to being deployed. The instrument harness is mated to the motor and the sinker bar is mated to the downhole cable before deployment. Thus the only remote (downhole) connection that must be made in drilling mud is the sinker bar to instrument harness. If the motor is to be run without the downhole instrument, then the sinker bar mates directly to the motor downhole in drilling mud.

Downhole mating in drilling mud is accomplished by thoroughly cleaning the female connector on the sinker bar, filling it completely with dielectric grease to keep drilling mud out, and then deploying the cable/sinker bar downhole. Centralizer fins are located on the male connector and the sinker bar to assure that the two connectors are perfectly aligned prior to mating. The upper end of the female connector has a vent hole to allow the dielectric grease to escape as the male enters. Wiper rings are located on the male and in the female so all grease and mud is eliminated from the connection as the mating occurs. Figure 4-6 is a sketch of the connectors illustrating their important features.

The tapered connections are designed for rigid mounting inside drill pipe (prewired). Mating is accomplished automatically as the pipe joint is made up. The connector taper and physical positioning are such that the conductor rings do not touch until approximately the last 1/4 turn of the pipe joint mating (to prevent the conductor rings from excessive slipping as the mate is accomplished). Dielectric grease is not required since mating does not occur in drilling mud.

4.2.2.2 Connector Performance

Downhole mating was accomplished by deploying the sinker bar downhole while monitoring the cable weight indicator. Figure 4-7 is a photograph of the sinker bar being guided into the wireline packoff to begin cable deployment. Cable deployment rate was

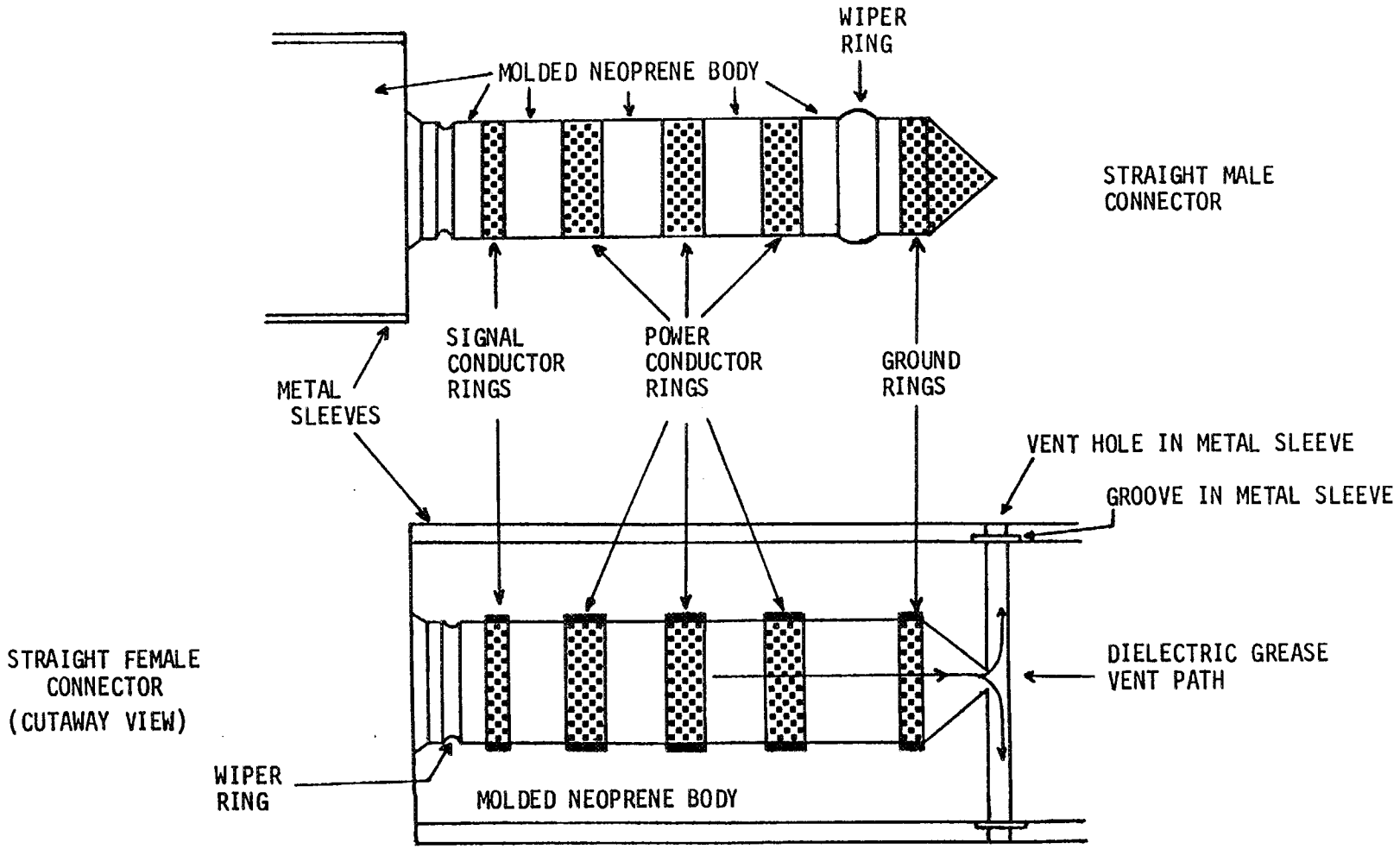


FIGURE 4-6 SKETCH OF ELECTRODRIL STRAIGHT CONNECTORS

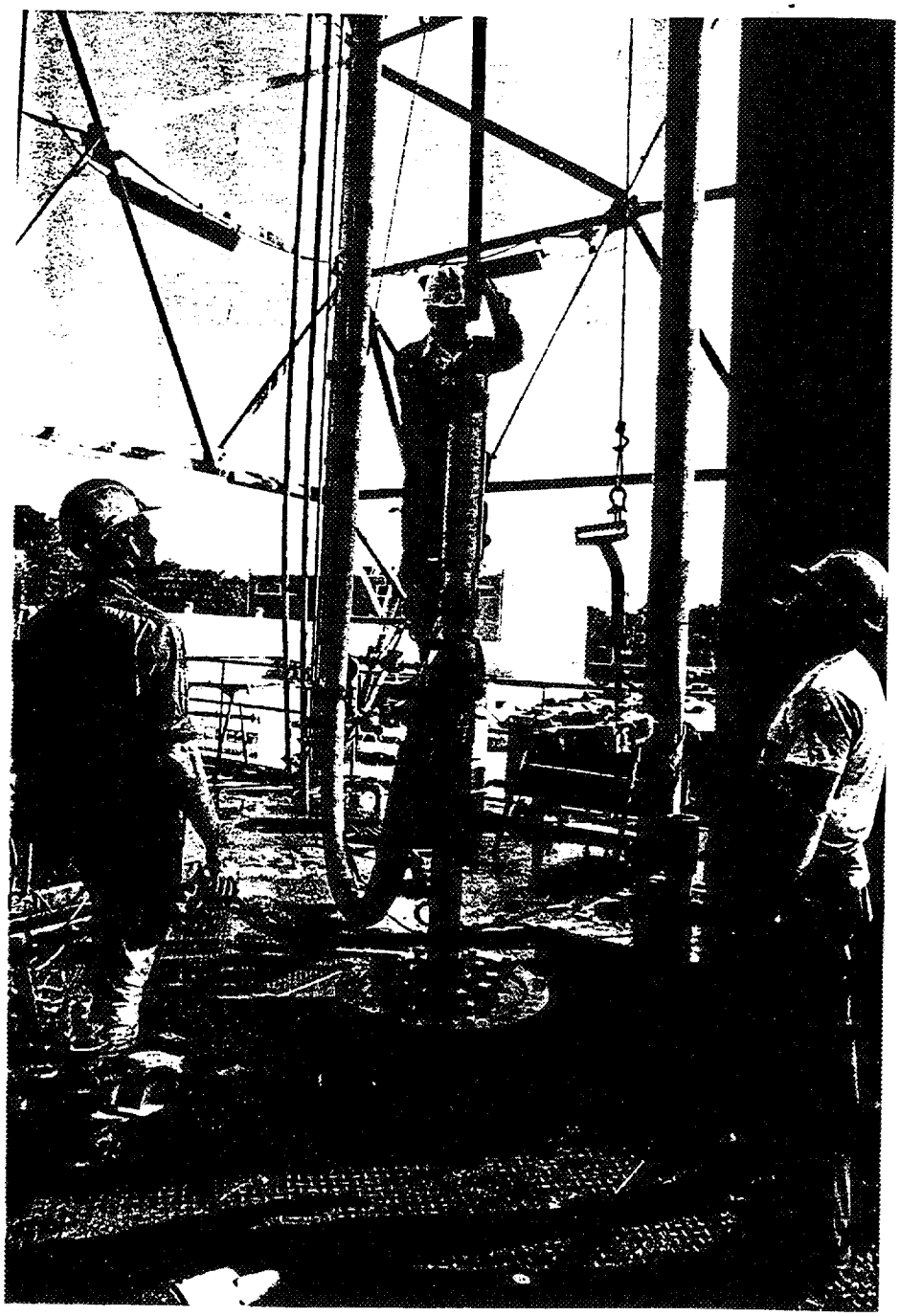


FIGURE 4-7

SINKER BAR/CABLE DEPLOYMENT

reduced as the sinker bar neared the motor or instrument harness. When a reduction in cable weight was detected, cable deployment was terminated. A typical weight of 250 to 350 pounds was allowed on the downhole connection to effect mating.

After mating, continuity and isolation measurements were made from the surface to verify that a good low loss, no leakage connection had been achieved.

A total of forty-one downhole (in mud) connections were attempted during the field test. Thirty-three of the attempts were made as described previously with dielectric grease filling the female connector. The other eight were second attempts made after failing on the initial try. The second attempts were made by pulling off approximately 15 or 20 feet, then trying again without retrieving the cable and cleaning and repacking the female. Thus the second mating attempts were made with drilling mud in the female connector.

A total of thirteen first attempts and four second attempts were successful.

A good mate was indicated by a resistive measurement of 7 to 11 ohms between power conductors (two way cable resistance plus motor winding resistance plus connector impedances), a resistive measurement of 20 to 60 ohms between the signal lead and ground (instrument input impedance plus signal cable and return resistance plus connector impedance), a leakage measurement of >1 megohm between power conductors and ground, a leakage measurement of >500 K ohm between the signal conductor and ground, and a leakage measurement of >1 megohm between the signal conductor and any of the power conductors.

The unsuccessful matings were a result of:

1) Incorrect alignment of male/female before mating
2) Connector failure
3) Inability of the dielectric grease to be expelled

4.2.2.2.1 Connector Alignment

Connector alignment throughout the downhole cable system is accomplished with three pronged standoffs designed to keep the connectors in the center of the drill collar/pipe while allowing mud to flow by unimpeded. The problem occurred at the upper end (small male connector) of the instrument harness. The male connector is located approximately one foot above the centralizer. The instrument harness itself flexed (bent) enough below the centralizer to force the male connector off center and to a non-vertical position. Note that the one foot lever arm magnified the misalignment. This problem was eliminated by tightening up on the centralizer tolerances (both those near the connector and those located further down the instrument harness).

4.2.2.2.2 Connector Failures

The following connector failures occurred during the field test.

Small male connector: Nine failures

Small female connector: Four failures

Large straight male connector: Two failures

Large straight female connector: One failure

Large tapered male connector: One failure

Large tapered female connector: One failure

4.2.2.2.2.1 Small Male Connector

Two of the nine failures were due to human carelessness. The first failure occurred when a drill pipe was attached to the motor while a rubber protector was on the male plug. The connector is designed so that it cannot be touched while adding the pipe, however if the protector is left on, the pipe can and did hit the protector/connector resulting in destruction of the connector. The second failure resulted when the cable reel was rotated without first disconnecting the cable to the power skid.

One failure was due to poor manufacturing, i.e., mechanically out-of-tolerance components were used. This allowed the entire tip of a male connector to pull off when disconnecting.

Two failures occurred when the bond between the connector molding material (Neoprene) and the conductor rings (copper) failed and allowed drilling mud to enter the connector. These failures may be due to a poor bond being achieved during molding or to the misalignment discussed previously. Both potential causes have been investigated and corrective action taken.

Four failures resulted when drilling mud leaked into the connector and shorted conductors between themselves and to ground. Factors contributing to these failures include:

1) The four conductors used in the cable were stranded with the voids between the strands filled with air. This allowed a great pressure build up between the conductors and the drilling mud.

2) The cable itself was made up by individually insulating the four conductors with EPDM then insulating the cable assembly with Neoprene. Each conductor of the connector was then electrically connected to the corresponding cable conductor. The connector

was then molded using Neoprene. Thus the molded Neoprene is required to bond to the EPDM insulation of the cable conductor and provide a watertight seal. This bond failed several times during field test. Upon analyzing the bond failures, it was discovered that the particular batch of EPDM used in cable conductor insulation had an excessive amount of wax-like material in it. The wax-like material prevented a good bond from being made.

After discovering the EPDM to Neoprene bonding problem described above, the conductors used in making up the instrument harness and sinker bars were changed to ones with a different type of EPDM used as insulator. In addition, the voids between the conductor strands were filled with epoxy. After making these changes, no leakage failures occurred (all actual drilling was accomplished with no leakage failures).

4.2.2.2.2.2 Small Female Connector

Two of the four failures of the small female connector were water leakage problems caused by failure of the Neoprene to EPDM bond. The problem was resolved as discussed for the small male connector.

The other two small female connector failures were "blowout" type failures. When the male connector enters the female, the dielectric grease packed in the female connector is forced out through two vent holes located at the top of the connector (See Figure 4-6). In both failures, a small ragged hole was discovered immediately below one of the existing vent holes. Careful measurement of the vent hole locations indicated that they were not lining up perfectly with the groove/vent holes located in the metal protector sleeve around the female connector. Thus when mating was

attempted, the vent holes in the Neoprene connector were effectively plugged. The resulting "hydraulic ram" effect caused the "blowouts". The groove in the protector sleeve was enlarged to eliminate this problem. No further problems of this type occurred after the enlargement.

4.2.2.2.2.3 Large Straight Male Connector

Two large straight connector failures occurred during the Task B testing. The first failure was a mechanical failure. When the connector was first used to support the 3400 foot cable, the weight of the cable pulled one of the power conductors loose from the connector. This problem was solved by removing excessive tension from this solder joint by increasing the support provided by the cable armor.

The second failure was precipitated by a failure in the tapered plug on the upper end of the electrical crossover sub. The connectors are designed with the signal conductor ring located near the entrance of the female connector and near the base of the male connector (See Figure 4-6). Thus when mated, the signal conductor ring is nearer drilling mud than are the power conductors. The rings are arranged this way to allow the high voltage rings to be located as far as possible from the drilling mud (electrical ground). The signal ring is located to provide sufficient insulation (path length to ground) to accommodate up to the maximum voltage expected on the signal conductor (600 VAC RMS). When the tapered connection on the upper end of the electrical crossover was made up, moisture was inadvertently left in the connection between the lower power ring and the signal ring. Thus the full high voltage (1200 VAC RMS) was applied to the signal lead throughout the cable. The easiest path to ground from the signal lead was apparently from the signal ring in the

large straight connector on the lower end of the electrical crossover sub to the drill mud. Arcing occurred between the lower power ring to the signal ring in the tapered connection and then from the signal ring to ground in the straight connection. The arcing caused a slight burn in both sets of connectors.

4.2.2.2.2.4 Large Straight Female Connector

This connector was mated to the large straight connector when the arcing described above occurred. This connector was also slightly burned.

4.2.2.2.2.5 Large Tapered Male Connector

The large tapered male and female connectors were mated on the surface under non-optimum conditions. The failure occurred a few moments after power was applied. Arc-over had occurred between the lower power conductor ring and the signal conductor ring (see discussion of 4.2.2.2.2.3). This resulted in slight burn paths in the Neoprene. Rain was falling when the connection was made, thus it is assumed that moisture was inadvertently left in the connection.

4.2.2.2.2.6 Large Tapered Female Connector

This connector was mated to the large tapered male connector when the arcing described above occurred. This connector also had a slight burn path between the corresponding two conductors.

4.2.2.2.3 Dielectric Grease

Prior to each downhole mating attempt, the female connector on the lower end of the sinker bar was thoroughly cleaned with solvent (brand name - Gamlin) and compressed air, then packed with dielectric grease (Dow Corning C-20 silicone grease) to keep mud out of the connector. During testing,

several partial mates were achieved, i.e., continuity was achieved only through two of the three power conductors, indicating that the male connector had not fully entered the female. This was subsequently confirmed when the sinker bar was returned to the surface by noting that some grease remained in the upper portion of the female connector.

Other times, the mechanical connection appeared to have been made (no grease remaining in connector) without continuity being established. This problem was most likely caused by a dielectric grease film being left on the conductor rings in the connector. The film was there either by the wiping action being insufficient or possibly by excessive pressure being built up as the grease attempted to exit through the vent hole. The excessive pressure could force the grease to "blow-by" the upper wiper ring on the male connector.

All of the probable causes of the poor matings pointed to the relatively high viscosity of the dielectric grease as the underlying problem. After noting this, the dielectric grease was mixed with castor oil to yield a dielectric mixture with a low viscosity. Matings attempted when using the mixture were more successful than before but problems still existed. The dielectric grease and castor oil did not mix well, i.e., a homogeneous mixture was not obtained. The mixture was a field "fix" and as such was not intended to be the final solution. A more suitable dielectric grease will be tested and then used in subsequent efforts. Another aid to contribute to the solution of the grease exiting problem is to enlarge the vent hole in the female connector. The vent hole was not enlarged during the Phase I test but will be enlarged on all plugs molded after the test.

Another occurrence of interest concerning connector performance is that after eight unsuccessful matings (attributed to dielectric grease exiting), the sinker bar was pulled up 10 to 15 feet and then lowered to attempt a mate. This procedure allowed drilling mud to enter the female connector. A good low loss mate was achieved on four of the eight attempts. The mud was not viscous, thus allowing it to exit easily through the vent hole. Also note that the cleaning action of the wiper rings in the connectors was sufficient to provide a low loss connection. Thus all indications are that a good low loss connection should be reliably obtained by enlarging the vent holes and using a less viscous dielectric grease.

4.3 ELECTRODRIL MOTOR PERFORMANCE

Three Electrodril motors were used during the Phase I Field Test. Task B testing was accomplished with a 285 hp motor while two 60 hp motors were used during Task A testing. These motors will be termed the 285 hp motor, #1 60 hp motor and #2 60 hp motor. Their corresponding serial numbers are listed here for reference.

285 hp motor	S/N 54-14713
#1 60 hp motor	S/N 54-35337
#2 60 hp motor	S/N 54-35336

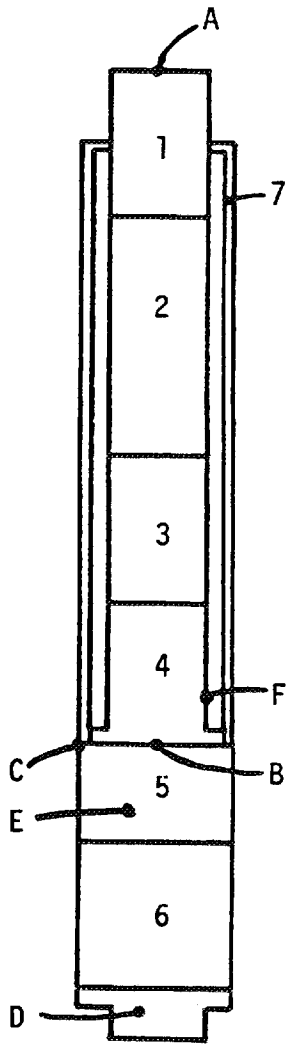
Figure 4-8 is a functional drawing illustrating the components making up a motor assembly. Figure 4-9 is a photograph of a 60 hp motor assembly ready for downhole deployment. All components except the stator/rotor sections and the mud tubes were interchangeable between the 60 and 285 hp motors.

Appendix A contains usage logs for each of the three motors.

Table 4-1 is a compilation of motor performance parameters summarized from Appendix A.

The 285 hp motor performance was exceptional in all respects.

The two 60 hp motors performed exceptionally well up to the point where drilling was terminated. Drilling with both motors was terminated when mud was found in the oil inside the protector section of the motor assembly (See Figure 4-8). In both cases, the rotating face seal designed to keep mud out of the motor had worn excessively and allowed drilling mud to enter the motor. However, there were extenuating circumstances associated with each seal failure.



Components

1. Connector Section
2. Motor (Rotor/Stator)
3. Slip Clutch/Reduction Gears
4. Protector Section (Includes Mud/Oil Pressure Compensator)
5. Bent Sub or Straight Sub
6. Bit Shaft
7. Mud Tube

Other Referenced Areas

A. Male Electrical Connector In Pipe Joint Box
B. Output Shaft (Sealed by Face Seal)
C. Mud Tube/Bit Shaft Tool Joint
D. Rotating Pipe Joint for Bit Attachment
E. Flexible Coupling in Bent Sub
F. Entry Holes for Mud to Enter Compensation Chamber

FIGURE 4-8 FUNCTIONAL DIAGRAM OF MOTOR ASSEMBLY

FIGURE 4-9

60 HP MOTOR ASSEMBLY

PERFORMANCE PARAMETER	#1 60 HP MOTOR	#2 60 HP MOTOR	285 HP MOTOR
1. Number of Time Deployed Downhole in Mud	16	1	2
2. Maximum Depth (Ft.)	3500	640	3500
3. Maximum Surface Input Mud Pressure (PSI)	450	<100	800
4. Total Run Time (Min.)	275	122	51
5. Run Time in Mud (Min.)	266	121	48
6. Drilling Time (Min.)	85	89	45
7. Hole Drilled (Ft.)	50	92.5	8
8. Maximum Weight on Bit (Lbs.)	6K	10K	8K
9. Maximum Surface Input Mud Pressure While Drilling (PSI)	<100	<100	800
10. Idle Motor Current (Amps RMS)	11	11	30
11. Maximum Motor Current While Drilling (Amps RMS)	25	25	45

TABLE 4-1 MOTOR PERFORMANCE PARAMETERS

#1 60 hp Motor Seal Failure

The male connector on this motor was rendered unusable during test on October 7, 1976. The connector section was subsequently removed from the motor, rebuilt, and then put back on the motor on October 11, 1976. The motor then was refilled with oil to replace that lost when the connector section was removed. The procedure used to fill the motor at the test site was incorrect. Specifically, any drilling mud/motor oil pressure differential that might occur is compensated for by an expansible member (bag) in the protector section of the motor. The correct filling procedure calls for filling the mud side of the compensation chamber with a fixed amount of oil prior to filling the motor. The outside cavity, with the oil drained out and vent holes opened to the outside mud, allows the motor oil to expand (against the expansible member) as heat builds up internally. This outside cavity was not filled prior to motor filling. This allowed the bag to expand until it was restrained by the outer wall of the chamber, thus leaving no room for expansion when it was needed. As a result, the motor oil expanded during normal build up of internal heat until the bag ruptured at the vent hole through which mud normally enters the compensation chamber. The rupture then allowed mud to enter the motor oil which in turn caused a premature failure of the rotating face seal.

#2 60 hp Motor Seal Failure

The rotating face seal failure on the second 60 hp motor was precipitated by failure to remove the drilling mud vent hole plugs after filling the motor as described in the discussion of the failure of the #1 60 hp motor. In this instance, the motor oil could not expand through the expansible bag

since the expansion cavity was still filled with oil. Thus when the motor heated up, pressure compensation could not occur so the motor oil was forced out around the rotating face seal. This abnormal occurrence apparently allowed mud to enter the seal which in turn caused it to wear and fail prematurely.

The face seal failures on both 60 hp motors were due to incorrect procedures being used while preparing the motors for use. Detailed motor preparation procedures and checkoff lists have been prepared and will be explicitly followed in all future Electrodril effort.

After completing the field test, the bit shaft used for all Task A drilling was disassembled to determine how the bit shaft components had held up. It was discovered that the oil/mud seals had worn more than anticipated. As a result, this design will also be reassessed during the Interim Phase II Electrodril Program.

4.4 DRILLING PERFORMANCE

Some footage was drilled during both Task A and Task B field test as called for in each of the references.

4.4.1 Task B Drilling

Task B straight hole drilling was accomplished in the 3600 foot cased well with the permanent BOT drilling rig. A 140 foot concrete plug was set between 3444 feet and 3584 in the 9-5/8" casing by Halliburton. The top of the plug was then drilled conventionally with a power swivel until the top of the plug was at 3485 feet. Approximately 41 feet were drilled using an 8-15/32" diameter Rucker Hycaloy diamond bit. The 41 feet were drilled in a 2 hour and 20 minute time period yielding an average drilling rate of 1 foot per 3.4 minutes. The concrete plug was then left to cure for a total of 19 days.

Drilling the concrete plug with Electrodril occurred on December 1, 1976. The cable configuration was as shown in Figure 4-5. The 285 motor was used with the same 8-15/32" diamond bit used previously to drill conventionally. 60 HZ downhole power was used to power the motor which yielded a bit rotation rate of 200 RPM. The BOT mud pump was used to provide mud circulation of 436 gallons/minute with surface input pressure of from 600 to 800 PSI depending on the weight on bit.

A total of eight feet were drilled before stopping to add a joint of pre-wired pipe. The weight-on-bit during drilling started at 2000 pounds and was increased up to a maximum of 8000 pounds. The times required to drill each foot are listed below:

First Foot	10 Minutes
Second Foot	7 Minutes
Third Foot	5 Minutes
Fourth Foot	5 Minutes
Fifth Foot	6 Minutes
Sixth Foot	4 Minutes
Seventh Foot	4 Minutes
Eighth Foot	4 Minutes

Note that the drilling discussed above was the first drilling accomplished by the Electrodril System. The rig operators were purposely "taking-it-easy" so they could gain familiarity with the system. The eight feet were drilled with no trouble. The Electrodril System performed exactly as planned.

The limit of drilling with the pre-wired Kelly was reached after eight feet. Drilling was stopped to add a Pre-wired pipe (30 foot) to the drill string. When the pre-wired Kelly to electrical crossover sub pipe joint was disconnected, a reverse mud flow occurred due to the extra weight of cuttings in the return mud. As a result, the tapered male connector at the top of the electrical crossover was actually under drilling mud for approximately 45 minutes. When the reverse flow stopped, the tapered connectors were cleaned, swabbed with boiling castor oil and mated. The mating was accomplished during a rain storm. When the motor was turned on to continue drilling, the motor current ammeter read erratically, i.e., normal ($\approx$30 amps), then pegged ($>$50 amps), then back to normal until the fuses on the power skid blew. Subsequent investigation revealed that moisture or drilling mud was apparently left in the tapered connector

when it was mated. This in turn caused arcing which burned the connectors and terminated drilling. Refinement of the procedure for mating large tapered connectors will eliminate this type of problem during subsequent Electrodril operation.

Further Task B drilling was not possible due to a scheduling conflict with a BOT test using the 3600 foot cased well and associated rig.

4.4.2 Task A Drilling

4.4.2.1 General

Task A directional drilling was accomplished in a hole drilled by conventional drilling equipment to a depth of 500 feet. The hole was cased with 13-3/8" casing to a depth of 200 feet. The remaining hole (300 feet) was drilled with a 12-1/4 inch rock bit. A portable rig was used during test to handle the conventional aspects of drilling with Electrodril.

The Task A downhole drilling equipment consisted of a 9-7/8" tricone rock bit, the motor assembly illustrated in Figure 4-8 with a 1° bent sub, the WSB downhole control/monitor system, and the cable/connector configuration illustrated in Figure 4-5.

Directional drilling with the #1 60 hp motor occurred on December 15, 1976. Directional drilling with the #2 60 hp motor occurred on December 17, 1976. Both motors were powered with 3-phase, 60 hz power which yielded a bit rotation rate of 200 rpm. A small rented mud pump was used to provide a flow rate of 200 gallons/minute. This mud flow rate resulted in a surface input pressure of less than 100 psi (100 psi was smallest pressure that could be gaged) at all times during the test. The formation was shale with sand lenses throughout this drilling test.

A total of 142.5 feet of hole was drilled, 50 feet with the #1 60 hp motor and 92.5 feet with the #2 60 hp motor. A summary of drilling performance is presented as Table 4-2.

TABLE 4-2

TASK A DRILLING SUMMARY

DATE	MOTOR	DEPTH	FEET DRILLED	TIME (MIN)	DRILL RATE (FT/MIN)	WT. ON BIT (LBS.)
12/15	#1 60 hp Motor	509	Oriented Prior to Drill			
			8	8	1.00	≤ 5K
		517	Stopped to Add Pipe			
			29	22	1.32	≤ 6K
		546	Stopped to Add Pipe			
			13	55*	0.24	≤ 6K
		559	Drilling Ceased			
12/17	#2 60 hp Motor	559	Oriented Prior to Drill			
			10	18	0.56	≤ 7K
		569	Stopped to Orient			
			7.5	6	1.25	≤ 6K
		576.5	Stopped to Add Pipe and Orient			
			12.5	9	1.39	≤ 7K
		589	Stopped to Reposition Rotary			
			18	15	1.20	≤ 6K
		607	Stopped to Add Pipe			
			30.5	24	1.27	≤ 6K
		637.5	Stopped to Add Pipe			
			14	17	0.82	≤ 10K
		651.5	Drilling Became Erratic, Stopped			
	TOTAL (AVG)		142.5	174	0.82	
			129.5	119*	1.09	

* The 55 minutes required to drill 13 feet is not representative since mud was balled up on the bit, preventing effective drilling. The second totals reflect the effect of deleting the non-representative data.

The last 13 feet of drilling with the #1 60 hp motor and the last 4 feet of drilling with the #2 60 hp motor produced erratic motor current readings and drill rates. In retrospect, it is believed that mud was balling up the bit due to insufficient mud pressure being generated by the mud pump.

Drilling with the #1 60 hp motor was stopped when motor current indicated that the motor was idling (11 amps) when in fact there was over 6000 pounds weight-on-bit. After pulling the motor from the hole, the flexible shaft in the bent sub was found to have come apart. This resulted in no power being transferred to the bit. The flexible shaft was not broken or damaged in any way, a retainer ring had simply slipped out. The shaft was re-assembled and the retainer ring welded in place. Before starting downhole again, the oil in the protector section of the motor was checked. Drilling mud was discovered in the oil. This ended drilling with the #1 60 hp motor. The cause of the mud-in-oil situation is discussed fully under discussion of motor performance (Section 4.3).

Drilling with the #2 60 hp motor was stopped when it appeared that mud was balling up the bit. A decision was reached to come out of the hole, replace the bent sub located below the motor with one located above the motor, and continue drilling. While exchanging the bent subs and testing the slip clutch, mud was discovered in the protector section of the #2 60 hp motor. This terminated drilling with the second 60 hp motor. The cause of this mud-in-oil situation is also fully discussed in the motor performance section.

4.4.2.2 Directional Drilling Performance

Prior to drilling with the Electrodril System, a multishot survey of the 500 foot uncased hole was made by EMCO. Directional drilling performance of the Electrodril System with a 1° bent sub located 11 feet above the bit was then monitored in real time by the WSB System. After drilling, a total of two Eastman Whipstock multishot surveys (10° maximum deviation instruments) and one Sperry Sun multishot survey (2-1/2° maximum deviation instrument) were made to provide data concerning the directional drilling capability of Electrodril and to provide hole positional data for comparison between multishot surveys and between multishot surveys and the WSB. The comparison of survey accuracies is made in Section 4.5

Appendix B is a copy of the Sperry Sun multishot survey data taken after all drilling was completed. The Sperry Sun survey is referenced because it was made using an instrument specifically designed to survey low drift angle wells ($\leq$ 2-1/2°) while the Eastman instrument was designed to survey wells with drift angles up to 10°. The test drilling did not produce a drift greater than 2-1/2°, hence the Sperry Sun survey is used because of its greater inherent accuracy.

A close look at the survey indicates that a fairly steady dog leg severity of approximately 3.5°/100 ft. was obtained while the Electrodril was drilling effectively, i.e., from 507 to 538 feet (drilling with #1 60 hp motor) and from 558 to 630 feet (drilling with #2 60 hp motor). Note that the dog leg severity dropped off significantly during the last 10 feet of drilling with #1 60 hp motor and the last 10+ feet of drilling with #2 60 hp motor. The significance of these decreases

is that the depths correspond exactly to those at which the Electrodril motor current indication became erratic and drill rate decreased indicating that mud was balling up around the bit, thus preventing effective drilling. This problem should not occur when a good high capacity mud pump is utilized.

Figure 4-10 is a plot of hole position with respect to vertical. The circular points are positional data points provided by the Sperry Sun multishot survey taken after drilling was completed. The triangular points indicate drilling log parameters added to correlate drilling actions with the positional data. A discussion of the drilling actions follows.

Prior to directional drilling, it was decided to deviate toward the Northwest, i.e., N 45° W. The EMCO survey indicated that the hole azimuth was N 27° W at a drift angle of 1.5° when conventional drilling was terminated (at foot 509). Before going downhole with the Electrodril System, the tool face was oriented approximately S 45° W (visual observation). It was decided to leave tool face in that orientation, go down, turn on the directional instrument and then orient tool face based on downhole WSB readings. When bottom was reached, the WSB instrument was found to be non-operational. As a result, the drill pipe was turned $\approx$100° CW (based on the prior visual observation of tool face). Drilling was then started. After drilling started, the WSB instrument did start functioning. It indicated that the tool face was oriented at approximately N 7° W. The decision was to keep drilling at that angle until the drift angle built up to several degrees. At a depth of 559 feet, the drift angle had increased to 2.1°. The uphole data was evaluated and a decision reached to orient the tool face to a more northwesterly direction. The drill string was lifted off bottom,

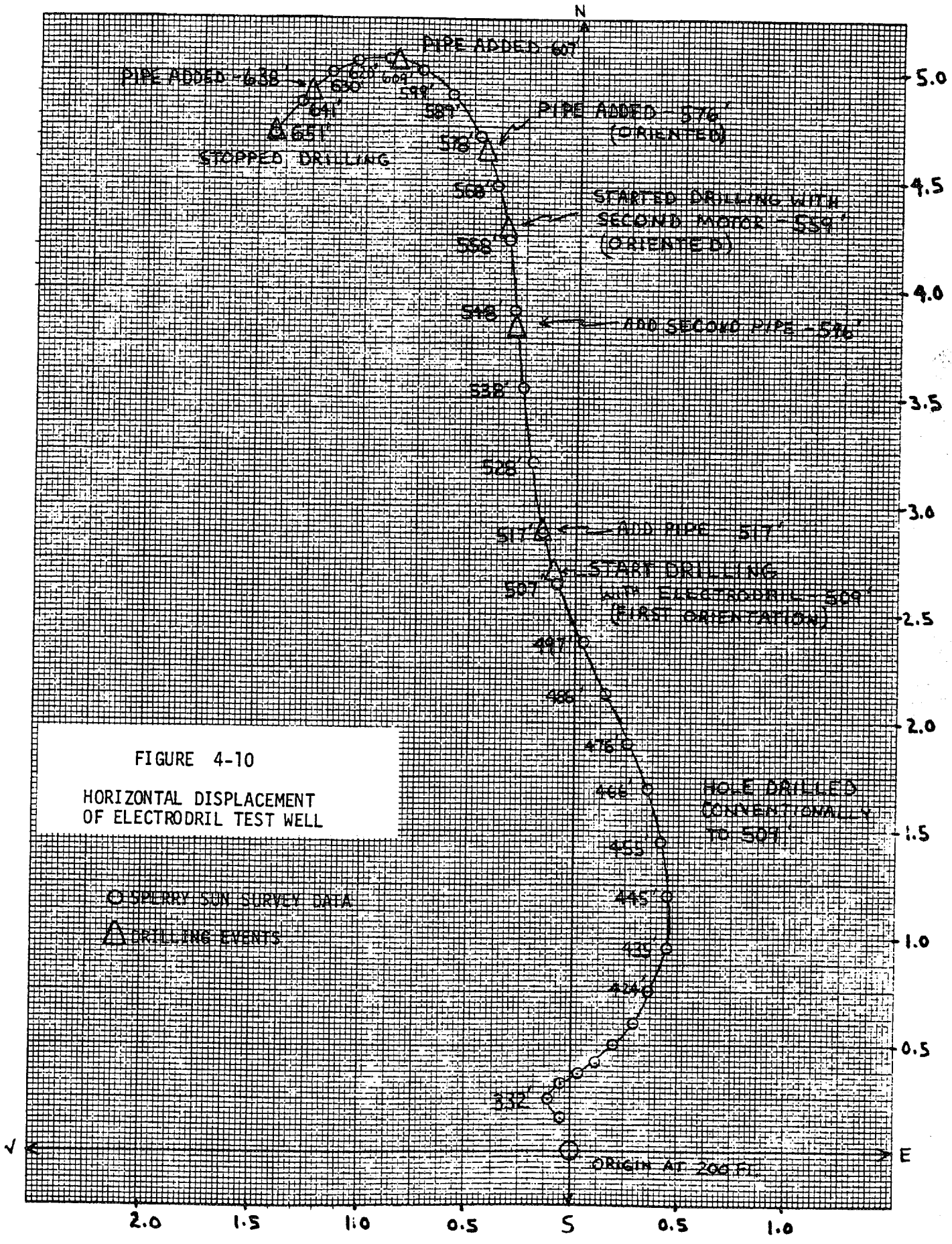


FIGURE 4-10

HORIZONTAL DISPLACEMENT
OF ELECTRODRIL TEST WELL

oriented, and returned to bottom to resume drilling. While orienting, the flexible coupling in the bent sub had parted as discussed in Section 4.4.2.1. When drilling mud was discovered in the #1 60 hp motor, the #2 60 hp motor was prepared and used to continue drilling.

The first 50 feet of drilling (#1 60 hp motor) had demonstrated that deviation of a hole could be obtained by Electrodril using a bent sub. Thus, it was decided to try to turn the hole direction while drilling with the second motor. Before entering the hole, the tool face was oriented to a SSW direction. When drilling actually began, torque build-up in the drill pipe apparently forced the tool face to a direction almost exactly opposite the hole azimuth. This resulted in little change in hole azimuth but did force the drift angle to start decreasing, i.e., the hole was bending back toward vertical. This condition was detected by monitoring the received downhole data. When drilling was stopped to add the first drill pipe (after 17.5 feet was drilled), the drill pipe was oriented 47° CW to force the hole to a SW direction. Two more pipes were added with no further orientation. The WSB and subsequently the multishot surveys indicated that the hole direction did indeed change to yield a SW azimuth. Drilling was terminated when mud was discovered in the #2 60 hp motor.

4.5 WELL SURVEY BASIC (WSB) PERFORMANCE

The WSB telemetry and command system fulfilled its basic requirements of data acquisition, downlink command transmission and execution, real time position monitoring, data processing, and data display.

One of the basic field test requirements for the WSB system was to demonstrate that the Electrodril cable center conductor could be used to simultaneously carry downhole instrument power, downlink commands, and uplink telemetry while the motor is operating under load. This requirement was demonstrated several times. In addition, measurements were made that indicated that the telemetry link was operating with a signal-to-noise ratio margin of 45 db even when the motor was intentionally turned on and off to create current surges. A storage scope was used to monitor coupling of the motor current surges to the center conductor. The coupling was so small that it could not be detected on the scope.

All downhole measurements, including hole position, were successfully made, transmitted to the surface, and displayed while drilling. Commands were transmitted downhole and verified while drilling.

Appendix C is a copy of the WSB field test results document generated by WSB field test personnel.

The WSB System consists of:

1) Downhole Instrument
   - Uplink telemetry module to input, multiplex and transmit data
   - Downlink command module to receive, decode and execute commands
   - Sensor module to measure temperature, voltage, vibration and hole position (drift, azimuth and tool face)

2) Surface Equipment

- Power source to supply electrical power to downhole instrument
- Control/display module to receive telemetry data, process and display the data in real time, accept human command inputs, format the commands, and transmit the commands to the downhole instrument.
- Data analysis trailer to record data received from the downhole instrument via the control/display module.

4.5.1 Downhole Instrument

Figure 4-11 is a photograph of the downhole instrument in its pressure housing (left), a monel drill collar and short subs to orient the instrument (center), and a sinker bar (right).

4.5.1.1 Telemetry and Control Modules

The telemetry and control portion of the downhole instrument performed exceptionally well during all phases of testing. Two telemetry and control units, S/N 001 and S/N 002, were operated for totals of 188 hours and 177 hours respectively. No failures occurred that held up testing. No errors were detected in either the uplink or the downlink during the entire field test.

4.5.1.2 Sensor Module

The sensor compliment consists of a position monitor (hole drift, azimuth, and tool face), downhole vibration sensor, downhole instrument input voltage sensor, and downhole temperature. All of the sensors functioned but with varying degrees of reliability and accuracy.

4.5.1.2.1 Position Monitor

Two identical position monitors were used during testing. The first was operated a total of 44 hours and 15 minutes. The second was operated for 28 hours and 27 minutes.

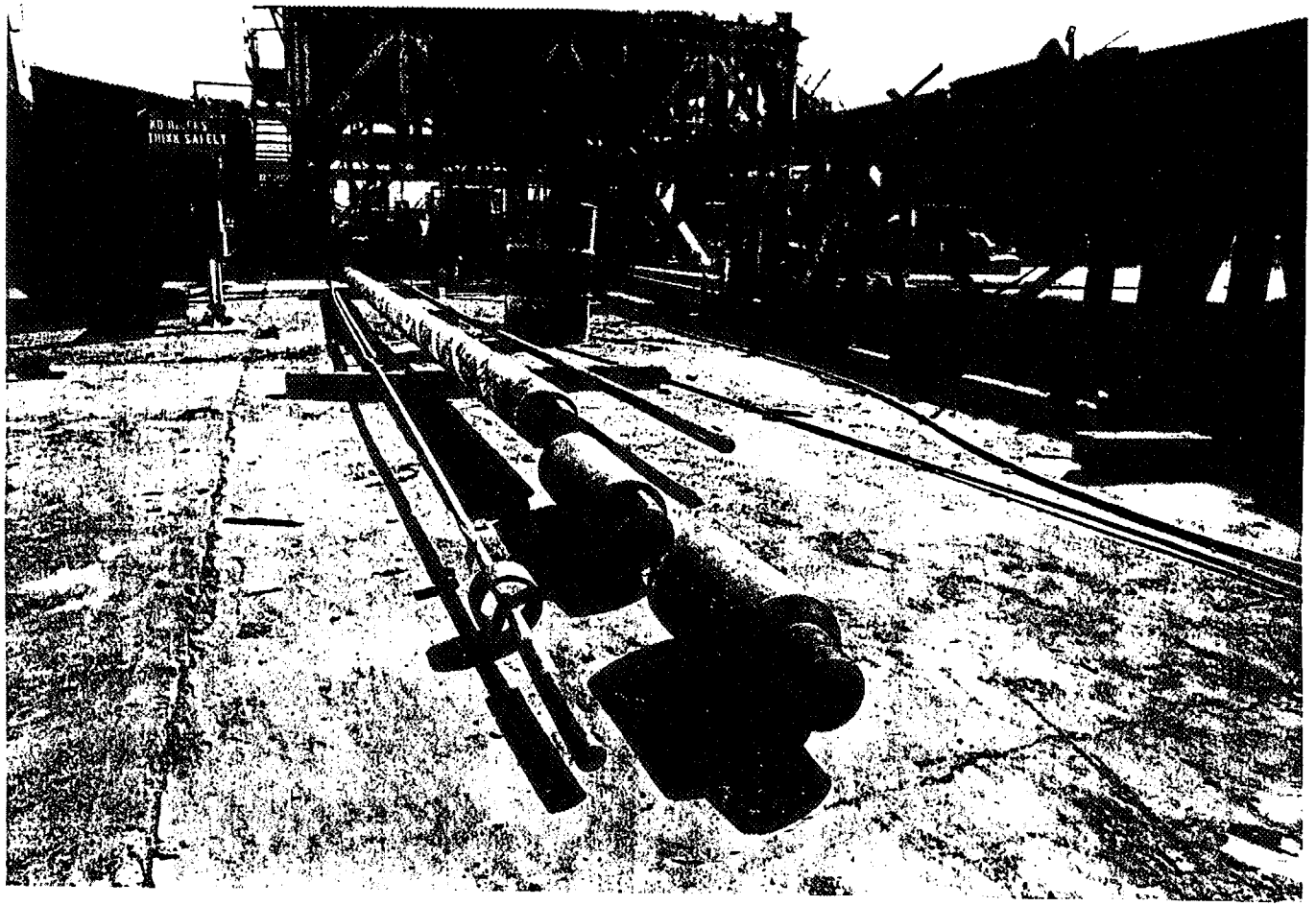


FIGURE 4-11

DOWNHOLE INSTRUMENT ASSEMBLY

The downhole position monitor functioned well enough to allow real time control of hole position. Its accuracy was disappointing. Table 4-3 itemizes the required and actual measured accuracies. In addition, it was found that the position monitor oscillated, rendering unusable data, at drift angles below 2°.

Data was obtained and processed to yield closure information similar to that obtained by the multishot surveys. The WSB closure curve is plotted with the corresponding Sperry-Sun survey for comparison (see Figure 4-12). At 528 foot depth, the WSB trajectory is within 6 inches of the corresponding point Sperry Sun trajectory. A similar plot with Eastman trajectory data indicates an 11 inch discrepancy between the Sperry Sun and Eastman surveys at the 528 foot depth.

The position monitor used during the field test had many problems. As a result of the problems encountered, several alternative monitors are currently being considered as a replacement. General Electric has implemented a program to develop a position monitor to meet the original requirements. Also, Sperry Sun has expressed an interest in providing a position monitor designed to interface with the WSB telemetry system.

4.5.1.2.2 Vibration Sensor

The relatively low sensitivity of the vibration sensor and the soft formation in which the hole was drilled combined to prevent a really meaningful test for the sensor. The instrument apparently performed as designed except for a 0.25 G bias which was eliminated by subtracting it from each value.

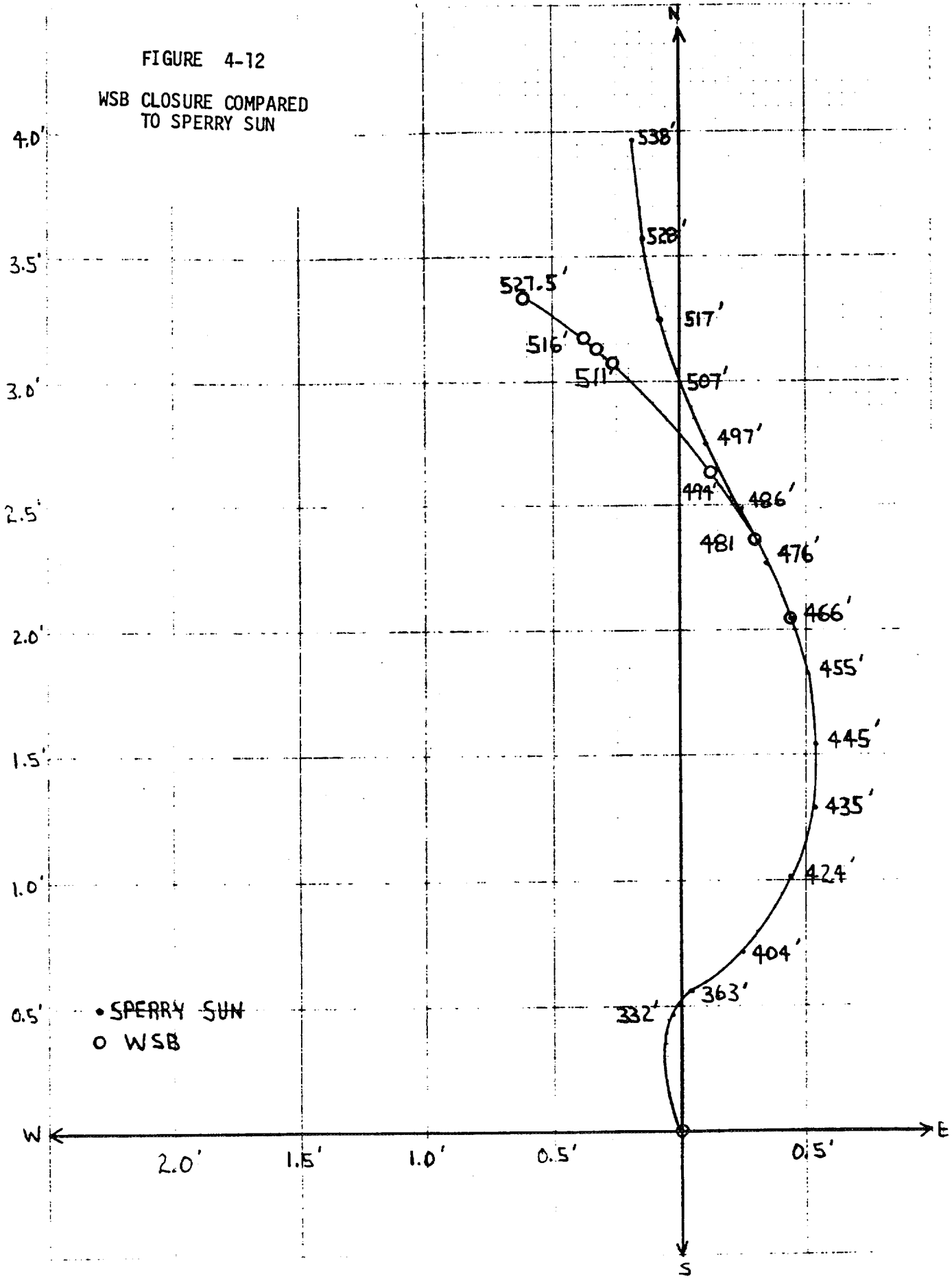
TABLE 4-3

POSITION MONITOR MEASURED ACCURACIES

	Requirement	Measured Accuracy
Drift		
- Absolute error @ N 45° W AZ	<8° (correctable)	5°
- Repeatability	± 0.2°	± 1.3°
Tool Face		
- Absolute error @ N 45° W AZ	<8° (correctable)	3.6°
- Repeatability	± 0.25°	±10°
Azimuth		
- Absolute accuracy	<8° (correctable)	36°
- Repeatability	± 0.2°	± 6.0°

FIGURE 4-12

WSB CLOSURE COMPARED TO SPERRY SUN



4.5.1.2.3 Voltage Sensor

The voltage sensor simply monitors the AC voltage level of the power transferred to the downhole instrument from the surface power source via the Electrodril cable center conductor. The sensed value is then transferred to the surface to be used to control the voltage sent downhole. This feedback loop keeps the voltage supplied to the downhole instrument at a constant level as the cable length changes. The entire control loop, including the voltage sensor, performed better than required. The downhole voltage was maintained within ± 3 volts whereas the requirement was for $\pm$ 11 volts.

4.5.1.2.4 Instrument Temperature

The temperature sensor in the instrument yielded an accurate, reliable temperature indication at all times during the test. Temperature was monitored with the instrument on the surface to allow a comparison between the temperature indicated by the sensor and that obtained with a standard thermometer. The sensor provided an accuracy of $\pm 2°$ over the temperature range of interest.

4.5.2 Surface Equipment

The WSB surface equipment was operated for a total of 313.4 hours.

4.5.2.1 Power Source

The power source is a fixed gain audio amplifier. Its function is to amplify the low level AC signal received from the control and display unit to the voltage and power levels required to operate the downhole instrument. It also contains a transformer to pick off the telemetry signal being sent uplink by the downhole instrument. This received signal is then sent to the control and display unit for demodulation and further processing.

The output stage of the power source failed prior to actual testing. The unit was repaired, tested and used to support the entire test with no additional problems.

The power source was physically located on the power skid. It was subjected to outside environmental conditions such as wind, sun, cold, rain, and dust without any adverse effects.

4.5.2.2 Control and Display Unit

The control and display unit performed as required throughout the field test. It consistently received the downhole telemetry signal, demodulated the signal, demultiplexed the received data, processed the data, displayed the processed data and transferred the data to the data analysis trailer for recording and additional processing. In addition, it accepted commands as entered by the operator, formatted them, and sent them downhole by frequency modulating the power signal.

The control and display unit was physically located outside on the drilling rig where it was visible to the driller. It withstood the environmental conditions with no adverse effects.

Figure 4-13 is a photograph of the control display unit (right) and the drillers' console used to control motor operation.

4.5.2.3 Data Analysis Trailer

The data analysis trailer was used to record WSB data during test. It also functioned as a preparation and maintenance area for all WSB equipment. Data received from the downhole instrument was recorded on an 8 track strip chart recorder. The recorder provided a continuously updated display of drilling parameters. Figure 4-14 is a photograph of the exterior of the data analysis trailer.

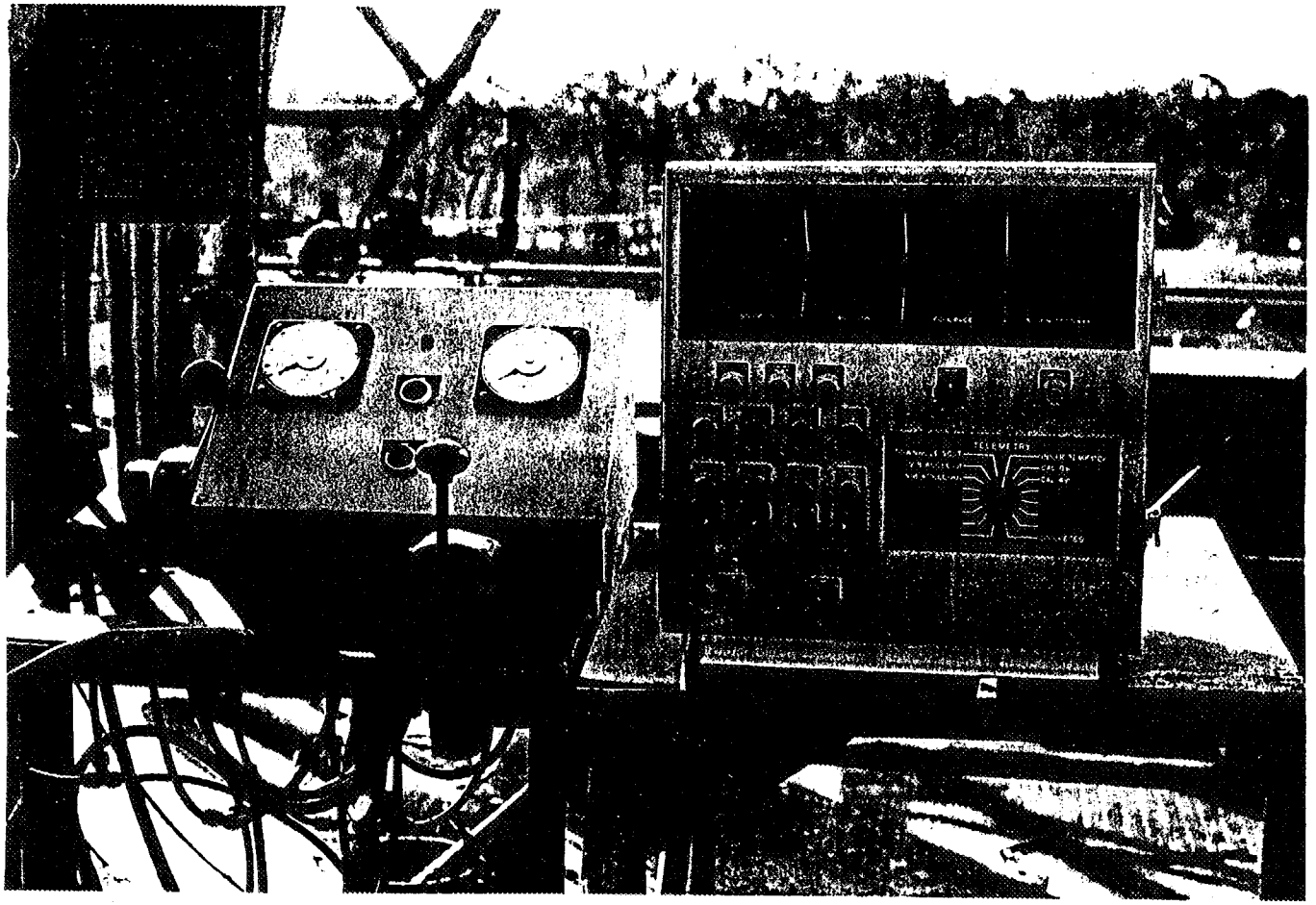


FIGURE 4-13

DRILLERS' CONSOLE AND CONTROL/DISPLAY UNIT

FIGURE 4-14

DATA ANALYSIS TRAILER

4.6 SURFACE CABLE HANDLING EQUIPMENT PERFORMANCE

The surface cable handling equipment consists of the hydraulically powered deployment and retrieval system, the rig sheave arrangement to guide the cable into the hole and a load cell to monitor cable weight (length) as it is deployed.

Each cable reel used during testing was powered by a hydraulic motor which turned the reel through a reduction gear. Hydraulic power was provided by a 50 hp electric motor, a hydraulic pump, and a control unit located on the power skid. Figure 4-15 is a photograph of the power skid, with both the hydraulic system (center of picture) and the motor electrical power system (left of picture), and of the cable reel (extreme right of picture). The hydraulic system was plagued with problems throughout the test but did function well enough to support the field test. Precise, positive control of the hydraulic system was not possible. The reels had a tendency to slip when under heavy load. The hydraulic system manufacturer was notified of the problem immediately. They came to the test site, observed, and are currently modifying the system to assure that the problems do not recur.

The rig cable handling equipment consists of a set of sheaves to guide the cable from the reels into the hole. Two were used during Task A testing. Three were used during Task B testing. The sheaves did perform their intended function but proved to be inconvenient in several respects. The lower sheave tended to fall over to one side while being used. This problem will be eliminated by mounting it on a fixed platform. During Task B testing, it was necessary to disassemble the lower sheaves to pass the cable connector as it was deployed or retrieved. These sheaves must be made to pass the connector without disassembly or be designed with a more convenient technique for assembling and disassembling.

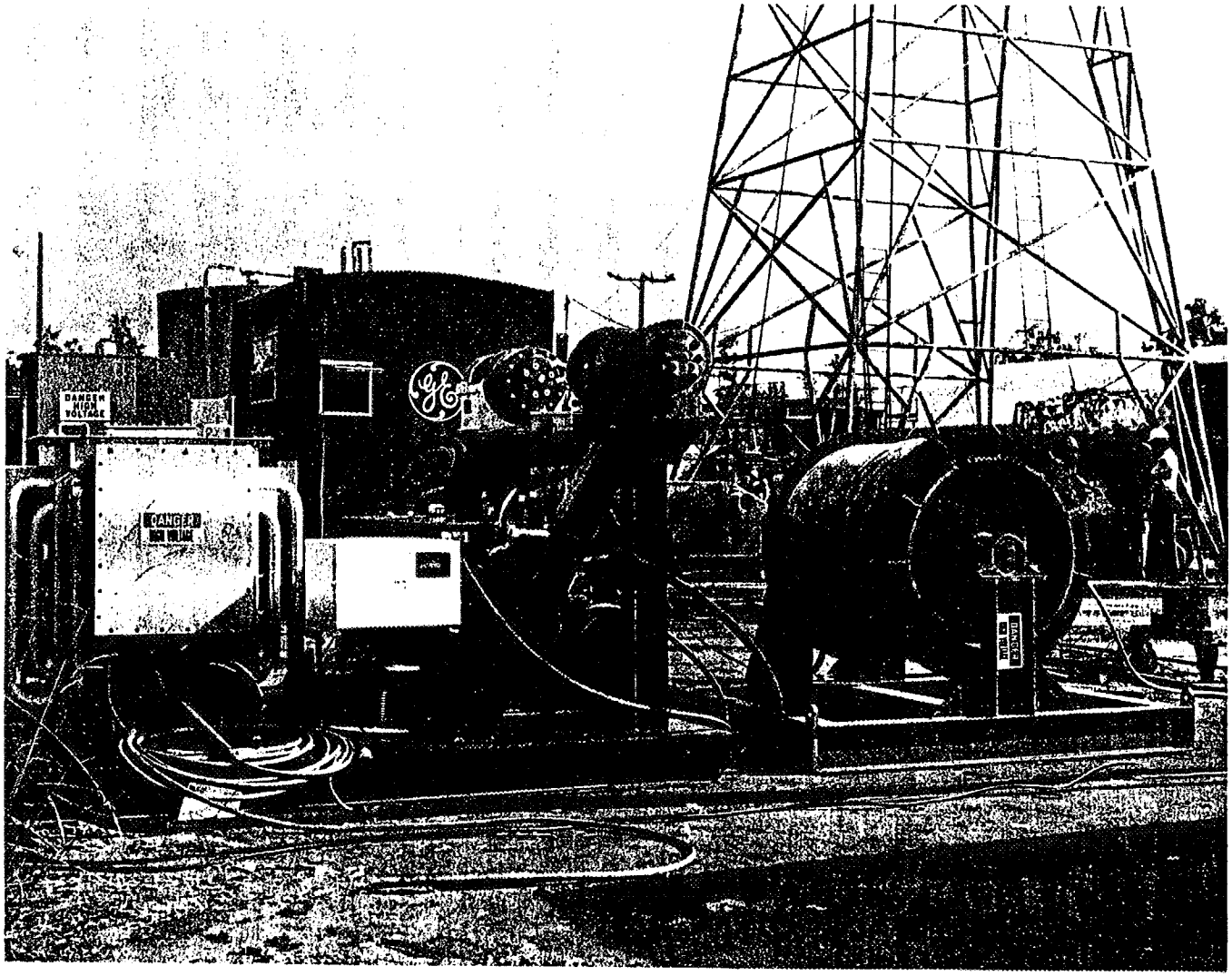


FIGURE 4-15

POWER SKID AND CABLE REEL

The load cell proved to be extremely useful when deploying the Electrodril cable and while making the downhole electrical connection with a known mating force. A rigidly fixed electrical cable was attached to the load cell. This cable was cut several times while installing and removing the rig cable handling sheaves. A connector will be provided on subsequent load cells so all equipment can be placed before making the electrical connection.

4.7 SURFACE ELECTRODRIL POWER EQUIPMENT

The surface Electrodril power equipment supplies 3 phase electrical power to the downhole motor. It is located on the rear part of the power skid and consists of switching contacts, protective circuitry, and a tapped transformer. 440 volt, 60 HZ, 3 phase power was supplied by the local utility company as an input. The 440 V passed through a switch, fuses, and overload trips prior to entering the transformer. The 3 phase transformer increased the voltage to the 1200 to 2000 volt range as a function of tap setting. During the field test, the taps were set to yield $\approx$1200 volts since little cable loss was evident over the short cable lengths employed.

The equipment also included drillers' console which provided a remote start/stop and output voltage/current display capability. It was located on the rig floor for the drillers use. Figure 4-13 is a photograph of the drillers' console (left) and the WSB control/display unit.

All functions of the power equipment functioned as intended. Problems in other parts of the Electrodril system caused an overload condition two times during the test. On both occasions, the fuses blew and prevented any real damage to the system.

4.8 ELECTRODRIL COMPATIBILITY WITH EXISTING RIG EQUIPMENT AND PROCEDURES

Overall, the Electrodril system proved to be extremely compatible with the existing BOT rig and the two portable rigs. Any equipment needed to interface Electrodril with the rigs (such as pipe joint crossover subs) were readily available from oil field supply companies. Three areas that did surface as incompatibilities are discussed below.

1. "Kopr Kote" pipe joint compound was being used at the site when Electrodril arrived. This compound is highly conductive. Since pipe joint compound can fall onto the downhole male plug prior to mating, a non-conductive compound must be used. A Teflon based compound termed "Bakerseal" was used during testing. Other non-conductive pipe joint compounds are currently being evaluated to determine the optimum one to specify for Electrodril.

2. Fine straight threads approximately 7 to 7-1/2 inches in diameter must be made up when assembling the motor in the mud tube and again when connecting the bit shaft to the mud tube. During the test period the mud tube to bit shaft joint galled completely two times. In each case, the joint had to be cut apart, resulting in loss of one of the mating pieces. The mud tube to motor joint started galling several times but was always able to be backed off so the threads could be "touched up" before trying again. These joints were suitable for motor assembly while in a factory environment but are not suitable for assembly by oil field personnel at the operation site. These threads will be replaced by acme or stub acme threads.

3. Mounting the rig Electrodril cable handling sheaves to allow precise guiding of the cable into the well while not interfering with other equipment normally located in the rig proved to be inconvenient. The test arrangement design was satisfactory but will be studied to see if additional flexibility can be provided.

4.9 SAFETY CONSIDERATIONS

An evaluation of the Electrodril system was made early in its developmental phase to identify all potential personnel safety problems and to eliminate the problems. As a result, all Electrodril components were designed with safety of utmost importance. All components were electrically grounded immediately upon placement at the field site. All electrical cables connecting Electrodril components were chosen to provide the ability to withstand being driven over and to function properly even under water. All high voltage equipments were located behind access panels. The panels were plainly marked "Danger High Voltage". "Hard Hat Area" signs were posted throughout the field test area.

It was recognized that the cable reels needed to be tied down while deploying and retrieving Electrodril cable so they were welded to the heavy power skid. During the actual testing, the power skid/cable reel combination was observed to slip slightly due to the suspended cable weight. Testing was stopped until anchors were obtained and installed to secure the power skid. No further slipping problems occurred.

No other safety problems or potential problems were encountered during testing.

5.0 REFERENCES

1. Technical Proposal - "Electrodril System Field Test Program, Phase I, Directional Drilling and Conductor System Tests" submitted to U.S. Energy Research and Development Administration by General Electric Company on March 25, 1976.

2. ES-R.7.1.0.2 Rev. A "Phase I Electrodril System Field Test Plan"

3. ES-R.7.1.0.3 "Phase I, Task B Electrodril Field Test Procedure"

4. ES-R.7.1.0.4 "Phase I, Task A Electrodril Field Test Procedure"

APPENDIX A

MOTOR LOGS

#1 60 HP MOTOR

SERIAL NUMBER 54-35337

Cased Well Area With BOT Permanent Rig

		Run Time
9/27	Motor delivered to BOT (not in mud tube, no bit shaft, but filled with oil)	
9/28	Motor put into mud tube	
9/29	Motor ran in horizontal position After removing bit shaft from 285 hp motor, attempted to install bit shaft onto #1 60 hp motor	1 Min
9/30	Bit shaft to mud tube thread joint galled Motor started on surface in horizontal position Motor down 310 feet (in mud but not circulated)	1 Min
10/4	Motor down to 200 feet (not sure in mud) Motor ran downhole 200 ft. Motor down to 2000 ft., left overnight for 24 hrs. total	1 Min
10/6	Motor down to 2000 ft., electrical connection made, no motor operation just pressure test, maximum surface mud pressure = 525 PSI. Motor left overnight in mud for 24 hr. total	
10/7	Tip of male connector on motor pulled off Motor removed from mud tube Connector section removed from motor	
10/8	Mud tube cut from bit shaft (results of galling of 9/30), bit shaft threads cleaned	
10/11	Rebuilt connector section attached to motor Filled motor assembly with motor oil Motor put into second mud tube. Threads tried to gall. Bit shaft put back on motor Motor started while lying horizontally on surface	1 Min
10/12	Motor down to 2000 feet, in mud 5 hours	
10/13	Motor down to 2000 feet, stayed down until 10/19	
10/19	Motor returned to surface after being in mud at 2000 ft. for 6 days	
10/20	Motor started on surface invertical position Motor down to 1600 feet, in mud 5 hours	1 Min

#1 60 HP MOTOR (CONTINUED)

		Run Time
10/21	Motor down to 1600 feet	
	Power applied to motor, excessive current drew (>50 amps) when sinker bar connector leaked.	
	Motor out of hole after 3 hours in mud	
	Motor started on surface in vertical position; V = 1200 volts, I = 13 amps	1 Min
10/27	Motor started twice on surface in horizontal position; V = 1200 volts, I = 18 amps	1 Min
10/28	Motor down to 1600 feet	
	Motor started while downhole in mud, no circulation; V = 1200 volts, I = 13.2 to 15 amps	1 Min
	Motor started second time while downhole in mud, no circulation; V = 1200 volts, I = 13.5 to 15 amps	1 Min
	Motor started third time while downhole in mud, V = 1200 volts, I = 12 to 13 amps; ran pressure test for 39 minutes with surface mud pressure up to 440 PSI, I down to 12.2 amps	39 Min
	Motor started fourth time while downhole in mud, no circulation; V = 1200 volts, I = 14 to 16 amps	1 Min
10/29	Pulled motor from 1600 feet after being in hole a total of 26 hours	
11/4	Motor started twice while 60 feet into hole, no mud; V = 1200 volts, I = 14 to 16 amps	1 Min
	Motor lowered to 1500 feet, circulation started, motor started three times then ran for 52 minutes to perform pressure test. Maximum surface mud pressure of 450 PSI; V = 1180 volts, I = 11.8 to 15 amps	52 Min
	Motor pulled from hole after being in mud for 4 hours	
11/10	Motor lowered 3400 feet into mud, no circulation	
11/14	Motor into hole to depth of 3500 feet, left downhole in mud	
11/17	Motor pulled out of hole after 70 hours in mud	
11/18	Moved to 500 Foot Un-cased Hole Area with First Portable Rig	
11/23	Motor started on surface while in vertical position; V = 1200 volts, I = 20 amps	1 Min
	Motor lowered into hole to 480 feet	
	Pulled motor after downhole in mud for 5 hours	
	Motor lowered into hole again to 480 feet	
	Pulled motor after downhole in mud for 3 hours	

#1 60 HP MOTOR (CONTINUED)

		Run Time
11/24	Motor lowered into hole to 480 feet	
	Motor turned on while downhole; V = 1220 volts, I = 15 to 17 amps	1 Min
	Motor started again while downhole; V = 1220 volts, I = 16.5 to 17 amps	1 Min
	Motor brought out of hole after 2 hours in mud	
11/29	Went Back to Cased Well to Drill with 285 hp Motor	
12/10	Moved Back to 500 Foot Un-Cased Hole with a Second Portable Rig	
12/11	Motor started horizontally; V = 1250 volts, I = 16.5 to 20 amps	1 Min
12/13	Motor down to 480 feet, left overnight	
12/14	Motor pulled to surface after 19 hrs. downhole	
12/15	Motor lowered to 480 feet	
	Motor started prior to drilling	57 Min
	Motor used to drill eight feet	8 Min
	Motor started prior to drilling	2 Min
	Motor used to drill 29 feet	22 Min
	Motor started prior to drilling	5 Min
	Motor used to drill 13 feet	55 Min
	Motor running while orienting tool face	22 Min
	Voltage for all running on 12/15 was 1230 volts	
	While running prior to drilling I = 11.5 amps	
	While drilling, I = 11.0 to 25 amps as the weight on bit varied from zero to 6000 pounds	
	Mud pressure supplied for drilling was always less than 100 PSI due to small mud pump used during this test	
	Motor drawing idle current even with weight on bit	
	Pulled motor after downhole for 8 hours	
12/16	Discovered that flexible shaft used in bent sub had come apart, nothing broke, retainer ring had just slipped out	
	While attempting to disassemble the motor from mud tube, the bent sub to mud tube joint galled, resulting in eventual cutting off of bent sub	
	While checking motor oil prior to deploying downhole again, discovered mud in oil in the motor protector section, cannot run with this condition so must use the second 60 hp motor.	

#2 60 HP MOTOR

SERIAL NUMBER 54-35336

500 Foot Un-cased Hole with Second Portable Rig

		Run Time
12/16	#2 60 hp motor assembly put together at Long Point Road. Connector section, reduction gear section and protector section removed from 285 hp motor and used to make up motor assembly.	
12/17	Motor assembly delivered to BOT	
	Motor made up with mud tube (same mud tube taken off #1 60 hp motor on 12/16 - bent sub was galled to mud tube so just welded together and used)	
	Bit shaft used previously on #1 60 hp motor attached	
	Motor turned on while horizontal	1 Min
	Motor downhole to 500 + feet	
	Motor ran downhole prior to drilling	8 Min
	Motor used to drill 10 feet	18 Min
	Motor ran downhole prior to drilling	4 Min
	Motor used to drill 7.5 feet	6 Min
	Motor ran downhole prior to drilling	5 Min
	Motor used to drill 12.5 feet	9 Min
	Motor ran downhole prior to drilling	11 Min
	Motor used to drill 18 feet	15 Min
	Motor ran downhole prior to drilling	1 Min
	Motor used to drill 30.5 feet	24 Min
	Motor ran downhole prior to drilling	3 Min
	Motor used to drill 14 feet	17 Min
	Voltage for all running on 12/17 was 1220 volts	
	While drilling, I = 11 to 25 amps as the weight on the bit varied from zero to 10,000 pounds	
	Mud pressure supplied for drilling was always less than 100 PSI due to small mud pump used during this test.	
	While drilling last 14 feet, motor current varied erratically with little drilling being accomplished, probably was mud balled around bit. Decided to come out, reconfigure with bent sub above motor and continue drilling	
12/18	Pulled motor from hole after 16 hours downhole	
	Motor assembly (less bit shaft) tied down horizontally, output shaft held and then motor turned on to determine if slip clutch was slipping. Clutch did not slip. When motor was turned on, mud/oil mixture seeped out around output shaft at lower end of protector section. Thus mud was discovered in the second protector section. Test was terminated.	

285 HP MOTOR

SERIAL NUMBER 54-14713

Cased Well Area with BOT Permanent Rig

		Run Tim
9/20	285 motor (in mud tube) delivered to test site	
9/22	285 hp motor started while in horizontal position	1 Min
9/28	285 hp motor down 2000 feet (no electrical connection attempted, only ran pressure test). Maximum circulating mud pressure = 500 PSI	
9/29	Male connector on top of motor discovered broken Removed bit shaft from 285 hp to install on #1 60 hp motor	
10/8	Connector section removed from motor	
10/12	Rebuilt connector section delivered to BOT	
10/13	Rebuilt connector section attached to motor Motor filled with oil	
10/14	Motor put into mud tube	
11/29	Motor started while in horizontal position; V = 1300 volts, I = 46.5 amps	1 Min
11/30	Motor started while hung vertically, V = 1150 volts, I = 32 to 33 amps	1 Min
	Motor down 3500 feet, left downhole overnight	
12/1	Motor started twice with bit off bottom; V = 1350 volts, I = 40 amps then V = 1250 volts, I = 30 amps	1 Min
	Motor started and used to drill eight feet of concrete; V = 1220 volts, I = 30 to 45 amps; maximum weight on bit = 8000 lbs; maximum mud pressure = 800 PSI	45 Min
	Motor started, current erratic, fuses blown due to moisture in connector on surface	2 Min
12/2	Motor pulled from 3500 feet after 48 hrs. downhole	
	Motor (with connector section, reduction gear section, protector section, and bit shaft attached) moved to Long Point Road.	

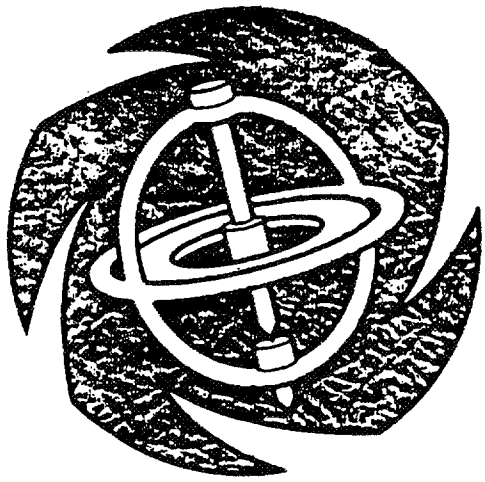
APPENDIX B

SPERRY SUN

DIRECTIONAL SURVEY REPORT

sperry-sun, inc.

General Electric Company
Test Well #1
Brown Oil Tool Field
Harris County
Average Angle Method



Precision Instruments/Professional Service

SPERRY-SUN

DIRECTIONAL SURVEY REPORT

FOR

GENERAL ELECTRIC COMPANY

TYPE OF SURVEY: Magnetic Multishot

SURVEY DEPTH: FROM 200 FT. TO 651 FT.

LEASE: Test WELL NO. 1

FIELD: Brown Oil Tool

COUNTY/PARISH Harris STATE Texas

DATE OF SURVEY December 18, 1976 JOB NO. MS-0001

OFFICE: Houston District Average Angle Method

GENERAL ELECTRIC COMPANY

TEST WELL NO, 1
BROWN OIL TOOL FIELD
HARRIS COUNTY, TEXAS
MAGNETIC MULTISHOT DIRECTIONAL SURVEY

DATE OF SURVEY DECEMBER 18, 1976
VERTICAL SECTION DIRECTION CLOSURE

JOB NUMBER MS-0001

SPERRY-SUN
RECORD OF SURVEY

MEASURED DEPTH	TRUE VERTICAL DEPTH	SUB SEA TVD	COURSE INCLINATION DEG MIN	COURSE DIRECTION DEG	DOG-LEG SEV DEG/100	TOTAL RECTANGULAR COORDINATES NORTH/SOUTH	EAST/WEST	VERTICAL SECTION
200	200,00	200,00	ASSUMED VERTICAL TO 200 FEET			0,00 N	0,00 E	0,00
209	209,00	209,00	0 24	N 54 W	4,44	,03 N	,01 W	,03
219	219,00	219,00	0 24	S 49 E	7,99	,03 S	,06 W	-,01
230	230,00	230,00	0 24	S 53 E	,25	,07 S	,00 E	-,07
240	240,00	240,00	0 26	S 15 W	4,67	,14 S	,03 E	-,15
250	250,00	250,00	0 21	N 14 E	7,83	,13 S	,04 W	-,11
260	260,00	260,00	0 22	N 19 E	,35	,07 S	,02 W	-,06
270	270,00	270,00	0 17	N 5 W	1,58	,01 S	,02 W	-,01
281	281,00	281,00	0 19	N 11 W	,42	,05 N	,02 W	,05
291	291,00	291,00	0 23	N 5 W	,76	,11 N	,03 W	,11
301	301,00	301,00	0 15	N 9 W	1,35	,16 N	,04 W	,17
312	312,00	312,00	0 9	N 33 W	1,17	,20 N	,05 W	,20
322	322,00	322,00	0 9	N 33 W	0,00	,22 N	,07 W	,23
332	332,00	332,00	0 8	N 12 W	,54	,24 N	,08 W	,25
343	343,00	343,00	0 15	N 39 E	1,78	,28 N	,07 W	,29
353	353,00	353,00	0 18	N 28 E	,72	,32 N	,04 W	,32
363	363,00	363,00	0 13	N 73 E	2,12	,35 N	,01 W	,33
373	373,00	373,00	0 16	N 69 E	,53	,36 N	,03 E	,34
383	383,00	383,00	0 18	N 50 E	,99	,39 N	,08 E	,35
393	393,00	393,00	0 23	N 55 E	,88	,42 N	,12 E	,37
404	404,00	404,00	0 46	N 35 E	3,88	,50 N	,20 E	,42
414	414,00	414,00	0 47	N 37 E	,32	,61 N	,28 E	,50
424	423,99	423,99	1 5	N 30 E	3,20	,75 N	,37 E	,61
435	434,99	434,99	1 18	N 8 E	4,56	,96 N	,45 E	,79
445	444,99	444,99	1 26	N 5 W	3,37	1,20 N	,45 E	1,02
455	454,99	454,99	1 22	N 10 W	1,39	1,44 N	,42 E	1,26
466	465,98	465,98	1 21	N 21 W	2,37	1,69 N	,35 E	1,52
476	475,98	475,98	1 20	N 25 W	,95	1,91 N	,26 E	1,75
486	485,98	485,98	1 26	N 25 W	1,00	2,13 N	,16 E	1,99
497	496,97	496,97	1 33	N 24 W	1,09	2,39 N	,04 E	2,28

GENERAL ELECTRIC COMPANY
TEST WELL NO. 1
BROWN OIL TOOL FIELD
HARRIS COUNTY, TEXAS
MAGNETIC MULTISHOT DIRECTIONAL SURVEY

DATE OF SURVEY DECEMBER 18, 1976
VERTICAL SECTION DIRECTION CLOSURE

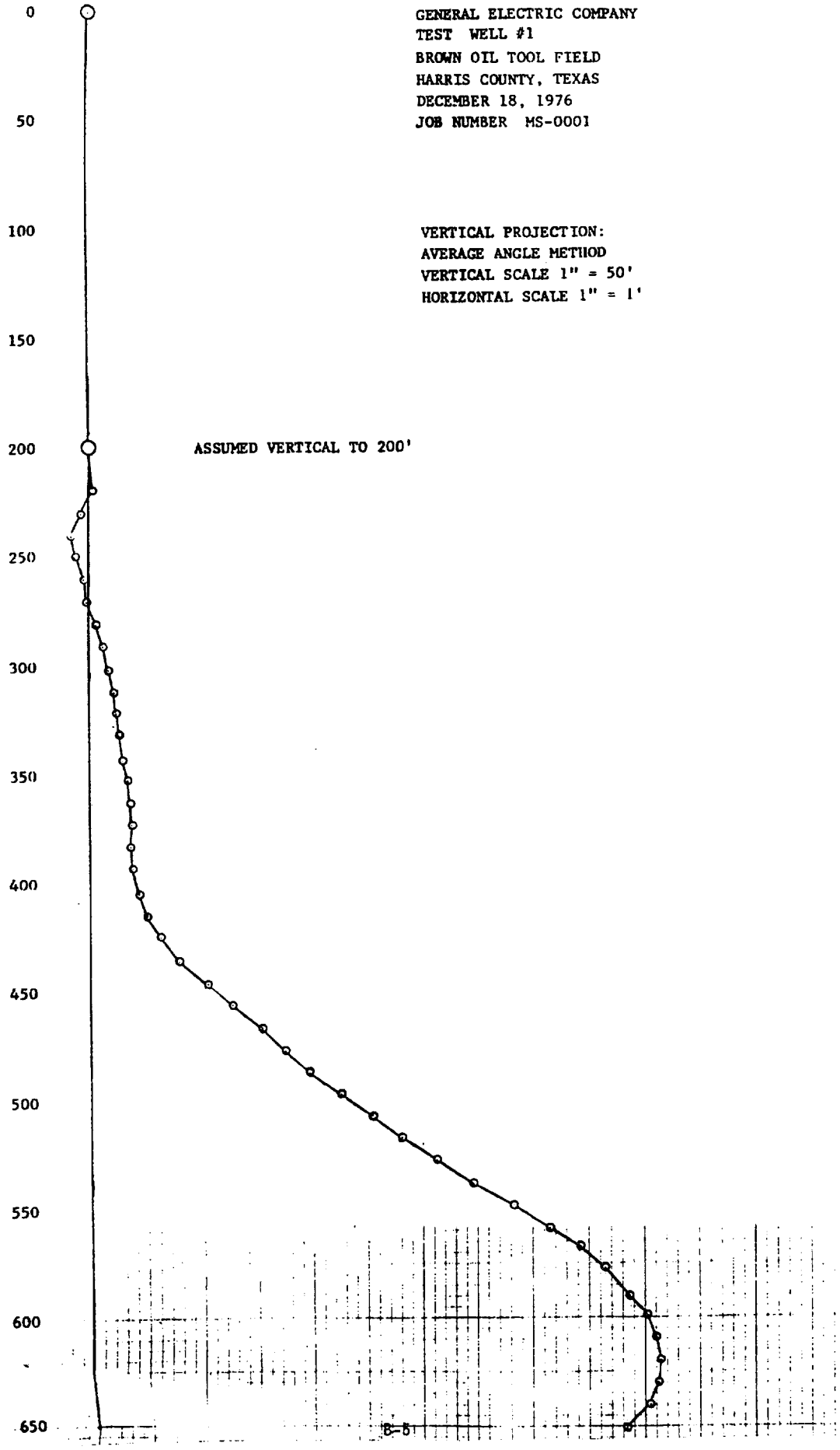
JOB NUMBER MS-0001

SPERRY-SUN
RECORD OF SURVEY

MEASURED DEPTH	TRUE VERTICAL DEPTH	SUB SEA TVD	COURSE INCLINATION DEG MIN	COURSE DIRECTION DEG	DOG-LEG SEV DEG/100	TOTAL RECTANGULAR COORDINATES NORTH/SOUTH	EAST/WEST	VERTICAL SECTION
507	506.97	506.97	1 30	N 25 W	.57	2.63 N	.07 W	2.54
517	516.97	516.97	1 31	N 12 W	3.42	2.88 N	.16 W	2.80
528	527.96	527.96	1 51	N 8 W	3.21	3.20 N	.21 W	3.12
538	537.96	537.96	2 5	N 7 W	2.36	3.54 N	.26 W	3.46
548	547.95	547.95	2 3	N 6 W	.49	3.90 N	.30 W	3.82
558	557.94	557.94	1 40	N 7 W	3.85	4.22 N	.33 W	4.14
568	567.94	567.94	1 25	N 16 W	3.47	4.48 N	.39 W	4.41
578	577.94	577.94	1 20	N 26 W	2.54	4.71 N	.47 W	4.64
589	588.94	588.94	1 4	N 42 W	3.87	4.90 N	.60 W	4.86
599	598.93	598.93	0 55	N 61 W	3.59	5.01 N	.74 W	5.01
609	608.93	608.93	0 54	N 81 W	3.16	5.06 N	.89 W	5.10
620	619.93	619.93	0 42	S 75 W	3.51	5.05 N	1.04 W	5.14
630	629.93	629.93	0 53	S 52 W	3.63	4.99 N	1.17 W	5.11
641	640.93	640.93	1 3	S 42 W	2.15	4.86 N	1.30 W	5.03
651	650.93	650.93	1 6	S 35 W	1.40	4.71 N	1.42 W	4.92

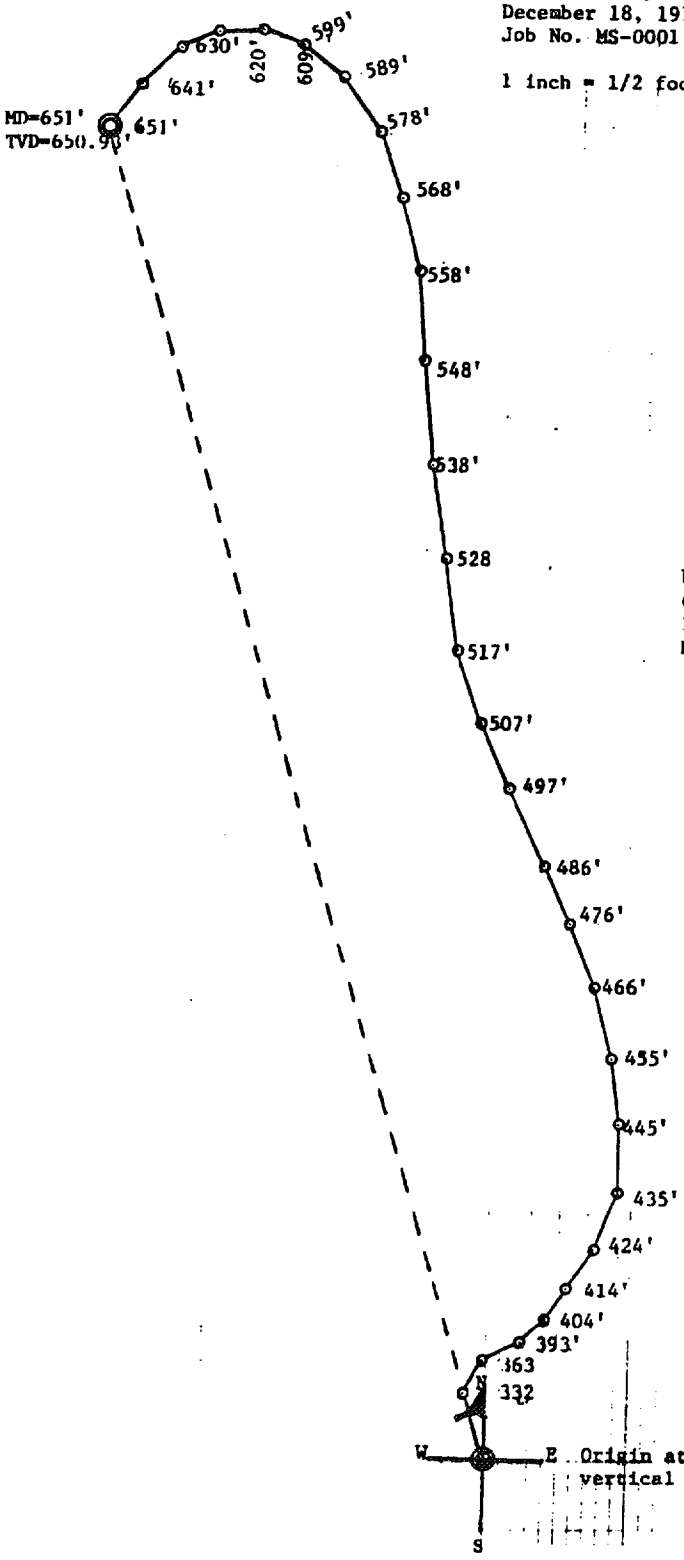
** THE CALCULATIONS ARE BASED ON THE AVERAGE ANGLE METHOD **

HORIZONTAL DISPLACEMENT = 4.92 FEET AT NORTH 16 DEG. 45 MIN. WEST (TRUE)


0
50
100
150
200
250
300
350
400
450
500
550
600
650
GENERAL ELECTRIC COMPANY
TEST WELL #1
BROWN OIL TOOL FIELD
HARRIS COUNTY, TEXAS
DECEMBER 18, 1976
JOB NUMBER MS-0001
VERTICAL PROJECTION:
AVERAGE ANGLE METHOD
VERTICAL SCALE 1" = 50'
HORIZONTAL SCALE 1" = 1'
ASSUMED VERTICAL TO 200'
B-5

SPERRY-SUN
FOR:
General Electric Company
Test Well No. 1
Brown Oil Tool Field
Harris County Texas
December 18, 1976
Job No. MS-0001

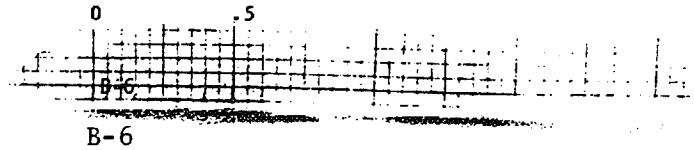
1 inch = 1/2 foot



HORIZONTAL DISPLACEMENT AT 651' IS 4.92' FEET AT NORTH 16° 45' MIN WEST CALCULATIONS BASED ON THE AVERAGE ANGLE METHOD.

5
4
3
2
1
0

1.5' 1'



APPENDIX C

WSS PROJECT FIELD TEST RESULTS

NUMBER ES-X.7.1.0.1

REVISION _____

ISSUED 26 January 1977

ELECTRODRILL

WSS PROJECT FIELD TEST RESULTS

PREPARED BY: [signature] DATE: Jan. 20, 1977

REVIEWED BY

ENGR. [signature] **DATE** Jan 26, 1977

ENG'G MGR. [signature] **DATE** Jan 26, 1977

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	ABSTRACT	1
1.0	OPERATIONS & TESTS PERFORMED	2
2.0	OPERATIONAL PROBLEMS AND SOLUTIONS	3
3.0	SYSTEM REQUIREMENTS	4
4.0	ACTIVITY REPORT	5

ABSTRACT

The overall objectives of the Real Time Data Acquisition Systems were realized in the demonstration program.

Operational time accumulated on the surface equipment was 313.4 hrs.

Operational time on the downhole instrumentation was 188 hours for S/N 001 and 177 hours for S/N 002.

Operational time on the Directional Packages were 44 hrs. 15 minutes for the first one and 28 hrs. 27 minutes for the second one.

This report details test and operations performed, the test results, the problems uncovered, and how the problems were solved, a review of the overall system and new requirements generated by the Demonstration Program, and a summarized Activity Report covering the period during the demonstration testing.

SYNOPSIS OF THE G.E. WELL SURVEY

DATE: 9-20-76 to 12/18/76

LOCATION: BROWN OIL & TOOL, HOUSTON, TEXAS

PURPOSE: TO EVALUATE THE G.E. DOWNHOLE TOOL AND THE HUMPHREY DIRECTIONAL PACKAGE IN OPERATION WITH ELECTRODRIL.

1.0 OPERATIONS & TESTS PERFORMED

1.1 Downhole Tool #001 was operated at a depth of 75 ft. in a shallow test well using a test console for power and data transference.

1.2 Surface equipment and the downhole tool were operated in the formal configuration.

1.3 The downhole tool, without the directional package, was operated at 1600 ft. in the deep well.

1.4 The power source was mounted on the power skid and operated.

1.5 The directional breadboard package and the first directional production package were calibrated and operated in the downhole system.

1.6 A pressure housing containing the downhole tool was installed in a Monel Drill Collar two times for directional drilling tests.

1.7 Directional drilling with the Electrodril and our downhole tool with the first production model directional tool was done two times in the Brown Oil & Tool Directional Test Well.

During the operations and tests at Brown Oil & Tool, faults and defects were detected in the Data Acquisition System. As pertaining to the operation of the system, the faults and defects fall into three categories: (1) Design, (2) Electrical, and (3) Mechanical.

2.0 OPERATIONAL PROBLEMS AND SOLUTIONS

2.1 The problems in the design area are noted as follows:

2.1.1 To lessen cross talk with downhole data - The power control board was modified to decrease the rise and fall time of the FM signals. Documentation was generated.

2.1.2 The surface receiver board in the test console and in the control and display unit was redesigned to improve data stability at "0" feet of line between the power source and the downhole tool.

2.1.3 The current source end of the 1 KHZ transformer was removed from the -15V line and tied to ground, removing 1 KHZ noise from the -15V line in the Control & Display Unit.

2.1.4 The directional data is being analyzed and results will be provided in a separate report.

2.2 The problems in the electrical area are noted as follows:

2.2.1 The output stage of the Power Source failed. The power amplifier was repaired and tested. The cause of failure has not been identified.

2.2.2 The downhole power supply fuses were blown because of overvoltage conditions. The control and display unit was reprogrammed to eliminate overvoltages.

2.2.3 The local 60 HZ power would sometimes decrease by 50% so a regulating transformer was put on the power skid to regulate the AC voltage to the power source. This was a temporary measure because the power source has a maximum rated input of 15 amps and the transformer is only rated to 7.5 amps.

2.2.4 A circuit guard (ground fault protector) problem occurred in the trailer. A new circuit guard has been received for evaluation.

2.2.5 The vibration "G" reading has a basis offset of .25G. This may possibly be removed by subtracting this basis by the processor.

2.2.6 Turn-off transients to the downhole power supply were measured and, although the downhole unit continued to function, the removal of these transients may improve reliability. The input signal to the power source could be switched on or off instead of the AC power, thereby removing the transients.

2.2.7 Various shorts have been located in the downhole instrument and corrected. They were between connector pins and case, flex circuit and case and flex circuit connector and case.

2.3 The problems in the mechanical area are noted as follows:

2.3.1 The problem of the IC's vibrating loose was solved by placing a compression material between them and the case cover in the downhole tool.

2.3.2 Alignment of tool face to the bent sub was improved by making the harness positioning ring adjustable.

Positioning of our tool in the pressure housing and positioning of the pressure housing in the harness is by sighting only. A tool or key for this positioning may improve alignment.

3.0 SYSTEM REQUIREMENTS

The functional requirements for the Data Acquisition System were evaluated during field test. The following observations were made:

3.1 A means to insert a correction factor in the control and display unit should be provided for a misalignment of tool face to the bent sub.

This could be provided by a set of thumb wheel switches or a dial on the control and display unit front panel.

3.2 A means for correcting for magnetic declination should be included in the control and display unit so that true north is always indicated.

3.3 It was obvious that tool face and drift are the only parameters in which the driller is interested. These might be combined with the motor current and voltage display since operationally he cannot spend time turning back and forth to look at two displays.

3.4 The processing of the data should be expanded to include the calculation of exact position and closure data. The display of data should also be expanded to include the plotting of true position. Real Time data should be processed and stored to allow a display of various position calculations. The calculations could be performed by various methods and be varied by selected initial positions.

4.0 ACTIVITY REPORT

DATE	ACTIVITY
9-20-76	1. Set up the trailer at Brown Oil & Tool.
9-21-76	1. D/H Tool and Pressure Housing S/N 001 tested at 75 ft. depth in a test well. Test OK, using the test console. 2. Vibration "G" level background noise is 0.25G.
9-22-76	1. P/S S/N 001 failure. Found pinched wire at the transformer.
9-23-76	1. Power skid voltage varies to too low a voltage to operate the power source. A constant voltage transformer was put on the power skid to power the power source for the D/H tool.
9-24-76	1. Control & Display Unit, Power Source & D/H Tool #001 operating with 5K ft of simulated line. Will not work with "0" feet line. 2. Control & display unit programming tapes completed.
9-27-76	1. Receiver board in the control & display unit marginal. Loses sync when commands are on.
9-28-76	1. Circuit guard trips shutting trailer power off. 2. D/H Tool #001 failed. Caused by a flex ckt conductor shorting to a stitchweld pin.
10-2-76	1. Operating D/H Tool #002 with the rig ground as tool power return.
10-4-76	1. In the control & display unit, the driven 1 KC signal transformer low side was removed from -15V and placed on ground to remove the 1 KC noise from the -15V source.
10-6-76	1. Teletype operating over phone with G.E. time share computer network. 2. Placed an AGC circuit in the surface receiver of the test console.
10-7-76	1. Pressure housing S/N 002 sent to Long Point to be mounted in the harness. 2. Completed the test console surface receiver modifications.

DATE	ACTIVITY
10-12-76	1. Varian interface completed and checked out.
10-13-76	1. Changed two timing resistors on the power control board.
10-18-76	1. Selsyn for measuring depth is not operating. 2. Armored cable with new connectors arrived from Long Point.
10-19-76	1. D/H Power Supply S/N 001 failed on an overvoltage condition. Replaced CR 1&2 and F1 & F3.
10-20-76	1. Replaced F3 in D/H Power Supply #002. 2. Mated the sinker bar and armored cable to the harness and tool #1 at 1600 ft downhole. Insulation test showed short.
10-21-76	1. Humphrey Directional Package arrived for test. 2. Directional Package output "Drift" failed when connected to D/H tool #002. 3. Directional Package returned to G.E. Bldg. 5 for test. Tested good.
10-22-76	1. Directional Package returned and tested at the trailer. Found internal shorts in the directional package. Returned it to G.E. Bldg. 5.
10-26-76	1. F1 opened in D/H Power Supply #002 on an overvoltage condition. Replaced F1 and tested the supply. 2. Directional Package returned to the trailer after repair.
10-27-76	1. F1 opened and CR2 shorted in D/H Power Supply #001 on an overvoltage condition. Repaired and tested OK. 2. Trailer steps broke when Al McNair stepped on them.
10-28-76	1. Crown Block Selsyn connected up and found defective. 2. Found IC's in the downhole tools loose. Reinserted them in their sockets.

DATE	ACTIVITY
11-1-76	1. Found the fiberglass outer coating of the trailer cracked.
11-4-76	1. Operated the G.E. D/H tool at 1600 ft with the motor running.
11-5-76	1. Found IC's in the downhole tools loose. Reinserted them in their sockets. Placed compression material over the IC's to hold them in place.
11-6-76	1. Found the 1 uf capacitor leads at the flex circuit connectors shorting to case. Formed the leads for clearance. 2. The D/H AC voltage would go to 550V peak at turn-off after the control & display logic shut the power down.
11-10-76	1. Demonstrated the trailer and working equipment to approximately 20 delegates. 2. The surface amplifiers failed after the demonstration.
11-11-76	1. Powered the D/H tool with a replacement amplifier. 2. Demonstrated the trailer equipment and D/H tool to Baroid representatives. 3. Mr. Low of Behlman Inc., stated over the telephone that we may repair the Behlman without voiding the factory warranty.
11-13-76	1. The first directional package was tested with our downhole tool #002. Tool face did not operate.
11-15-76	1. Received a new Ground Fault Interrupter for evaluation.
11-17-76	1. The programmed ROM board was placed in the Control & Display Unit. It tested OK. 2. Repaired the amplifier and placed it in the power source. 3. Turn-Off transients to our downhole instrument power input are from 200V P to 500V P.
11-18-76	1. Humphrey, Inc., and G.E. took calibration readings on the directional tool.
11-19-76	1. Tool face output of the directional package is bad. Humphrey, Inc., found the output open.

DATE	ACTIVITY
11-20-76	1. The -12V connection is intermittent at the lower connector on the directional package.
11-21-76	1. The downhole high pressure input connector twisted and caused the power input to short, S/N 001.
11-22-76	1. Found long pins on the back of Module I/O connectors touching the Module case, causing intermittent problems in our downhole tools. Problem was corrected.
11-24-76	1. Pressure housing was installed in the drill collar 180° off. The tool and D/H motor was operated just off well bottom, in the directional test well at Brown Oil & Tool. 2. Drill bit was put on bottom and the motor turned on. The connectors at the sinker bar and harness burned open. The input protection diodes in D/H Power Supply #001 shorted, thereby protecting the unit.
12-2-76	1. Installed the new receiver board in the Control & Display Unit, improved performance was noted.
12-7-76	1. Pressure Housing nuts were loc-tited on. The pressure housing #1 was damaged in removing the nuts. 2. An end connector was pulled off of the directional package.
12-9-76	1. Heat sub command on downhole tool #002 failed. The failure was caused by a short in the D/H transceiver.
12-11-76	1. The epoxy coating on the trailer is badly cracked and water gets in the trailer when it rains.
12-14-76	1. The sinker bar will not mate with the harness when downhole in the well. The silicon grease put in the female connector does not bleed out through the stabilizer sleeve and causes back pressure, keeping the connector from fully mating.

DATE	ACTIVITY
12-15-76	1. Drilled 57 ft in the directional test well at Brown Oil & Tool. 2. Data was recorded 3. An Eastman Whipstock multiple shot survey was made of the well hole. 4. Analog chart recordings were made of the 57 ft of hole drilled by "E" drill. Processed data was also recorded.
12-16-76	1. Received an Eastman Whipstock computer printout of the well survey. 2. D/H Tool #002, during operational check, malfunctioned. Channel 1 & 2 data is all "1's".
12/17/76	1. Drilled 92.5 ft in the directional test well at Brown Oil & Tool. 2. Analog chart recordings of the directional, thermal and vibrational data was made of the 92.5 ft. drilled on this date. Processed data was recorded by hand. 3. The Kelly bushing that anchors the well pipe on the rig floor slipped 90^{0} while we were drilling and had to be reset.
12/18/76	1. Eastman Whipstock ran a multiple shot survey of the directional well. 2. Sperry Sun ran a multiple shot survey of the directional well. 3. End of test.

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BETC–4033-3
Distribution Category UC-92a

164 PP

ELECTRODRIL SYSTEM FIELD TEST PROGRAM
PHASE II; TASK B–DEEP DRILLING SYSTEM DEMONSTRATION

Final Report for Phase II; Task B

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Prepared for the Department of Energy
Under Contract No. EY-76-C-02-4033

Date Submitted–December 1978
Date Published–April 1979

U.S. DEPARTMENT OF ENERGY

FOREWORD

The Electrodril System Field Test Program is a cooperative, cost-sharing venture between the U.S. Department of Energy (DOE) and the petroleum industry with the prime contractor being General Electric Company (GE). The work was performed under DOE Contract Number EY-76-C-02-4033. Other industry participants are as follows:

AMOCO Production Company
Brown Oil Tools Company
Chevron Oilfield Research Company
Dresser Industries
Gulf Oil Exploration and Development Company
Mobil Research and Development Company
Union Oil Company of California

The Electrodril concept is to provide a method to drill with a downhole electric motor that uses a retrievable power cable and employs a telemetry system which makes downhole measurements of various drilling and safety parameters and transmits them to the surface. The successful development of Electrodril should provide a significant addition to drilling technology.

This report covers the work performed during Phase II, Task B. The Electrodril System is now ready for testing at an active field site. All technical work for this project has been monitored by the Bartlesville Energy Technology Center.

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ABSTRACT

The Electrodril Field Test Demonstration is being conducted in two Phases. Phase I is complete. Work began on Phase II, Task A July 1977 and this initial Task was completed in September 1977. This report documents the results of Task B. Task B, initiated in October 1977, encompassed the design, procurement, fabrication assembly and test of the Electrodril Deep Drilling System. The Systems Verification Test program conducted at Brown Oil Tools, Houston, Texas during October and November, 1978 marked the conclusion of Task B.

The report documents key design tradeoffs and delineates the technical approach established for development and verification test. Details of both component and subsystem testing are presented together with the results of the Systems Verification Test program. Of particular interest are the results of a 100 hour bit shaft test and the extensive test of a static inverter-motor combination.

The report presents the conclusion that the Systems Verification Test of the Electrodril Deep Drilling System was successful and the recommendation that the Task C Operational Drilling Demonstration be initiated.

FINAL REPORT

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1.0 SUMMARY

This report documents the results of the Phase II, Task B effort of the Electrodril Deep Drilling System. This effort included the design, fabrication and Systems Verification Testing of the Deep Drilling System. The Systems Verification Test was conducted, during October 1978, in a test well located on the premises of Brown Oil Tools Inc., Houston, Texas.

The Systems Verification Test was the culmination of a joint U.S. Department of Energy, Industry and General Electric effort to procure, assemble and demonstrate the key elements of the Electrodril Deep Drilling System preparatory to further demonstrations in a series of operational wells.

In general, the Systems Verification test program was an unqualified success. All of the system elements of the Deep Drilling System were exercised and evaluated and in every instance the system can be declared ready for operational well demonstration.

The motor/bit shaft combination operated very well and post test inspection indicates that seal performance exceeds the design goals. The redesigned oil compensation system demonstrated a usable life in excess of 100 hours between refills.

The rig floor system performed better than expected. The power cable flexural characteristics are much better than anticipated and longitudinal stability is excellent. The area of prime concern relating to cable/connector deployment

over the floor and traveling sheave appears to be groundless. The cable/connector combination, together with the cable slips, worked flawlessly. Industry observers have remarked on how easily the cable can be deployed and retrieved.

The prototype production connectors have functioned without failure. The reliability of these devices has been increased tremendously since the initial Phase I tests. During the first test day, six consecutive successful remote matings were recorded and no connector failures were recorded during the entire test program.

The cable reels and drive skid have also worked very well during the test program. The key to this success is careful deployment at the test site and the attention given to correct alignment of the skid axis to the rig vee door.

The power generation subsystem had been extensively tested some months before the onset of the Systems Verification Test program. No major power related problems were therefore expected and none were experienced.

The redesigned and expanded instrumentation subsystem also functioned very well. The downhole unit had been expanded to include an all new formation sensor sub which doubled as the control center for the Electrodril heat sub (deviation sub). Both the formation sensor and the heat sub were developed

independently for application to the Field Test Program. Since functional test was not possible in the cased test well, both of these subs were exercised extensively in the laboratory. Some electronic component malfunctions were experienced during the early test stages. These problems were isolated quickly and repaired. Subsequent downhole instrumentation deployments were successfully executed and downhole data was displayed both in the Electrodril instrumentation trailer and on the remote control and display unit.

In general, the test program proceeded very smoothly. During the last week of the Task B Program the test well deployment of the Deep Drilling System was demonstrated to the Department of Energy and Industry personnel. These observers agreed, unequivocally, that the Electrodril Deep Drilling System was ready for field deployment and operational drilling demonstrations.

2.0 INTRODUCTION

The Electrodril Field Test Demonstration was begun in May of 1976. Phase I, which was concluded successfully in August 1977, was directed toward the demonstration of the 60 HP Directional Drilling System. Phase I work is documented in BERC/TPR 77/4 and in BERC/TPR 77/11.

The Phase II Deep Drilling System Field Test Demonstration was initiated in July of 1977. The Phase II Program was divided into three major tasks to provide a means of measuring technological progress and a basis for making program control decisions.

The first major task (Task A) encompassed the completion of the design engineering and preprocurement documentation effort in preparation for the release of the system design for fabrication.

The second major task (Task B), which began in October, 1977, covered the manufacture, assembly and system verification testing of the Deep Drilling System. The results and the conclusions drawn from the Systems Verification test are presented in this document.

Task C, will encompass the operational demonstration of the Deep Drilling System at a series of active drilling sites. Task C will be completed during the first half of calendar year 1979.

In executing the Task B effort, maximum advantage has been taken of the lessons learned in conducting the Phase I Directional Drilling System Field Test Program. The cable connectors, for example, have been redesigned to make them more rugged and to improve their water blocking capability. In addition, the mating connector design was modified to make it possible to field assemble and replace connectors on the cable. Product improvement has been continued on the downhole motor lower seals and oil compensation system to extend the operational life of the motor to at least 100 hours between refurbishment.

The bit shaft has been redesigned with a new lower seal assembly to assure an operational life between refurbishment of at least 100 hours. Power cable surface handling equipment designs and their operating procedures have also been modified to minimize handling time. Numerous component and subsystems tests have been conducted to assure that these design modifications are technically valid and correctly implemented. A technical description of the system configuration selected is presented in Appendix A.

The intent of the Systems Verification Test was to demonstrate the functional capability of all the Deep Drilling System elements and the total, integrated system and to exercise and evaluate the planned Electrodril operating procedures to assure their compatibility with existing drill rig procedures. Prior to integration of the Electrodril system elements at the Brown Oil Tools test facility, all subsystems had been individually tested to assure their readiness for the Systems Verification Test.

3.0 DESIGN CONSIDERATIONS

As a part of Phase I, the basic elements for the Deep Drilling System were demonstrated in a test well during December 1976. The Phase II design effort was directed towards refining system design and incorporating the lessons learned from the Phase I Field Test Program. Specific areas of design work conducted during the Task B effort are described below:

POWER GENERATION SUBSYSTEM

The Electrodril Deep Drilling System power requirements are essentially as follows:

Primary Power:	240 V to 3300V, 3 phase, with variable AC frequency ranging from 12 to 120 Hz. Continuous current rating from 22 to 75 amps.
Secondary Power:	280V, 3 phase, 60 Hz AC 110V, single phase, 60 Hz AC

The satisfaction of these power requirements can be accomplished by two methods:

1. The use of a diesel prime mover coupled to a DC generator to develop basic DC power. The DC power is then applied to DC motor which in turn drives an AC alternator. By varying the speed of the DC motor through changes in excitation voltage, variable frequency AC is generated at specific voltages. Control for the DC motor excitation is developed from

inputs from the downhole current and voltage sensors. A schematic of this power generation approach is shown in Figure 1.

2. The use of a diesel prime mover driving an AC alternator to produce 440V, 60Hz. The 440V AC output is then applied to a static inverter which converts the AC to DC and subsequently "chops" the DC output at varying rates, upon demand, to create variable frequency "pseudo" AC. Control for the DC "chopping" is developed from inputs from the downhole current and voltage sensors. A schematic of this power generation approach is presented in Figure 2.

Both power generation schemes are "demand response" systems and as such their relative ability to respond quickly to the power requirements of the Electrodril motor is key to the selection decision. Given power demand situations in which the power spectra fluctuate rapidly, as is the case with the Deep Drilling System, the inherent magnetic inertia of the "rotary" system depicted in Figure 1 makes it unsuitable for Electrodril application. The static inverter system is capable of responding to these power fluctuations. The supporting downhole sensory system and surface controllers must however, be capable of sensing demand and switching power levels at high rates.

A series of studies was made to establish the design characteristics of the static inverter power controller and to determine its transient response capability. Two basic technical approaches were identified as having applicability to the power controller problem: current limiting and voltage limiting.

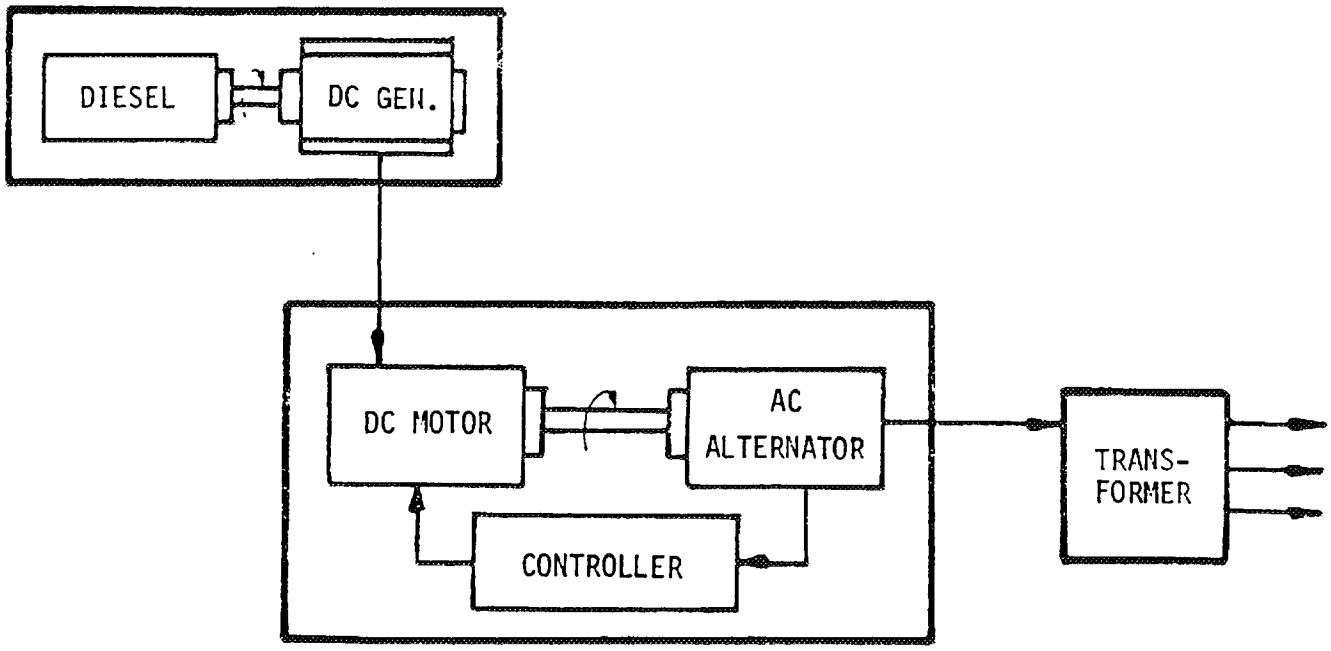


FIGURE 1
ROTARY POWER GENERATION

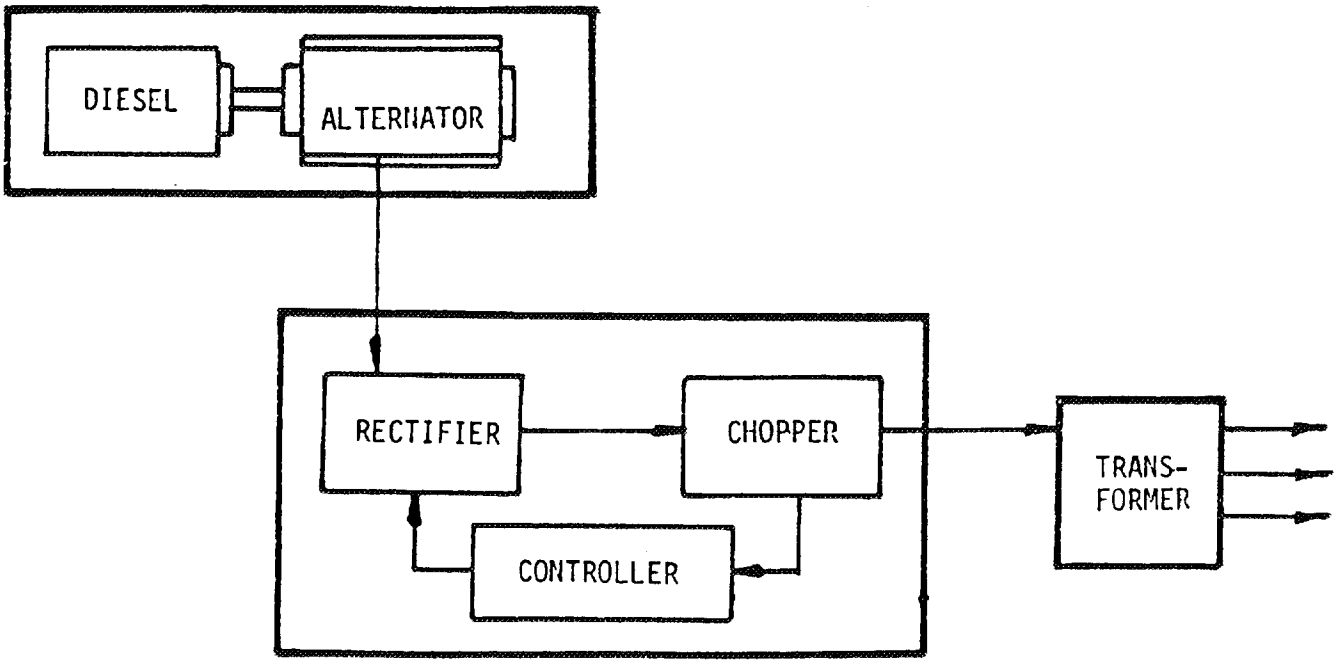


FIGURE 2
STATIC INVERTER POWER GENERATION

Neither approach can cover the full power demand spectra of the downhole motor. The best technical compromise is a combination of the two approaches.

As a result of these studies, the decision was made to measure downhole motor voltage and send it to the surface. Current will be measured at the surface downstream of the power converter and output transformer and the rate of change of these two parameters, together with their phase relationship will provide the basis for modulating the static inverter power controller.

The power controller was not planned to be part of the power generation subsystem during the Systems Verification Test at Brown Oil Tools. The plan was to run the system "open loop" so that voltage and current demand characteristics could be verified before the Field Test demonstrations were begun.

CABLE AND CABLE HANDLING SUBSYSTEM

A general layout of this subsystem at a typical rig site is shown in Figure 3. It consists of a powered cable spool for deploying the electrical cable downhole and the rig floor system which facilitates cable deployment in and out of the well and accommodates the rotating/non-rotating environment surrounding the drill string.

Rig Floor Assembly. The technique for deploying the cable at the rig floor differs from that used in the Phase I Directional System in that the Deep Drilling System must provide means for drill pipe rotation to obviate the potential for differential sticking. Pipe rotation will be achieved using

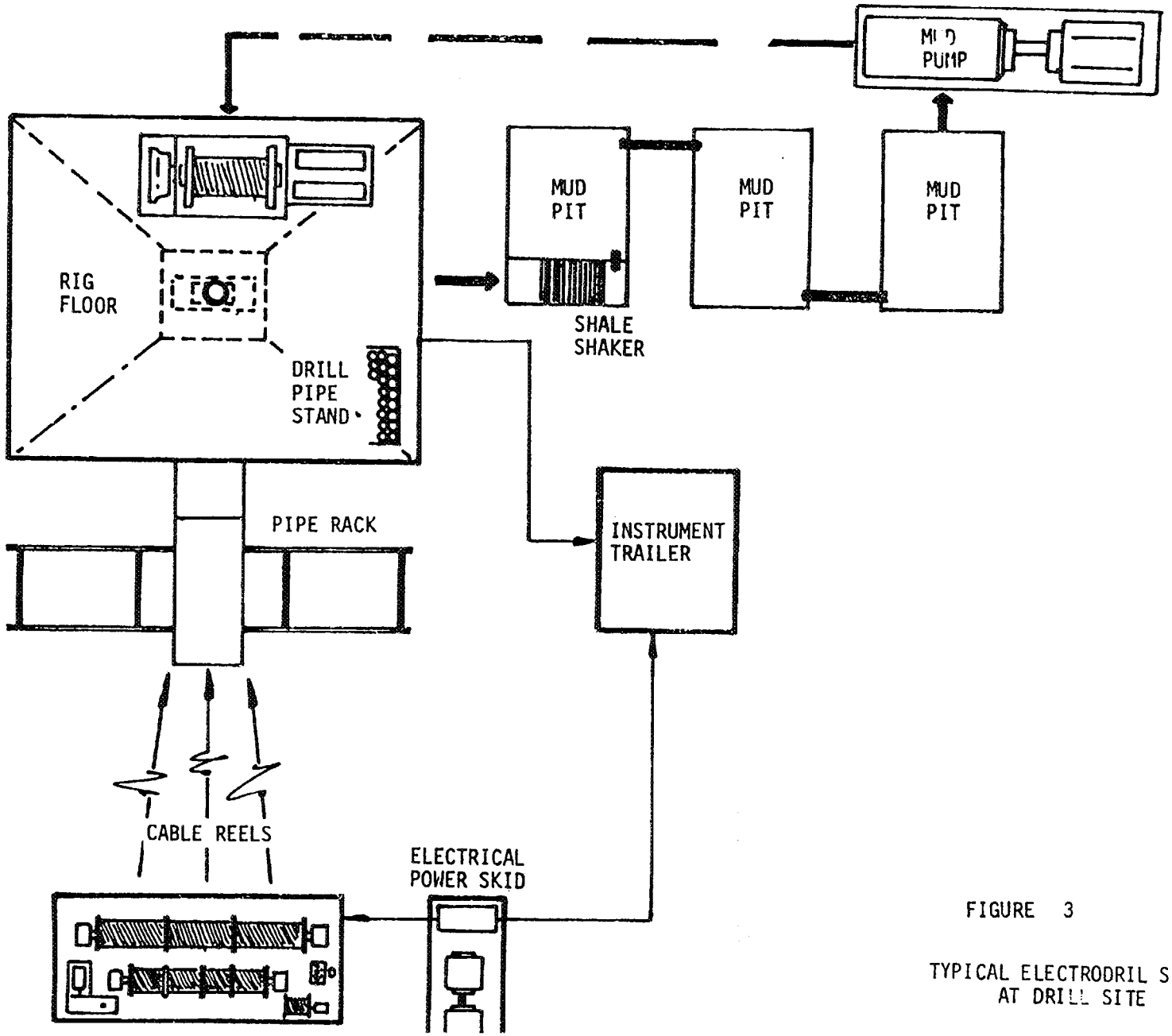


FIGURE 3

TYPICAL ELECTRODRIL SET UP AT DRILL SITE

the conventional rotary table/kelly combination. Electrical connection to the downhole cable (rotating) and the surface cable (non-rotating) is made through a slip ring assembly located below the rig power swivel (Figure 4). Mud circulation will be made in the conventional manner through a circulating head above the power swivel. A kelly cock will be inserted between the circulating head and slip ring assembly to provide hydraulic safety. The relative desirability of using a power sub (or swivel) to make up the drill string and to rotate the string during the drilling operation was investigated. The consensus of an industry survey made during this time period indicated the preference for the use of the rotary table/kelly combination. Subsequent design reviews have corroborated these findings. Thus, the method of rig floor deployment to be used for the Phase II drilling program will be essentially identical to that successfully demonstrated during the Phase I Deep Drilling Program.

The hole will be drilled ahead 90 feet utilizing two prewired dedicated joints of drill pipe and the prewired kelly. These will then be removed and replaced with a 90 foot stand of prewired pipe. This sequence will be repeated 10 times (a total depth of 1000 feet) at which time the prewired pipe is withdrawn and substituted with standard drill pipe and 1000 feet of cable. This prewired pipe is utilized in place of standard drill pipe for the first 1000 feet to maintain electrical continuity with the deployed downhole lengths of Electrodril cable during drilling operations. Each succeeding 1000 feet of hole is drilled in a similar manner to a depth of 5000 feet, at which time the prewired pipe is replaced with standard drill

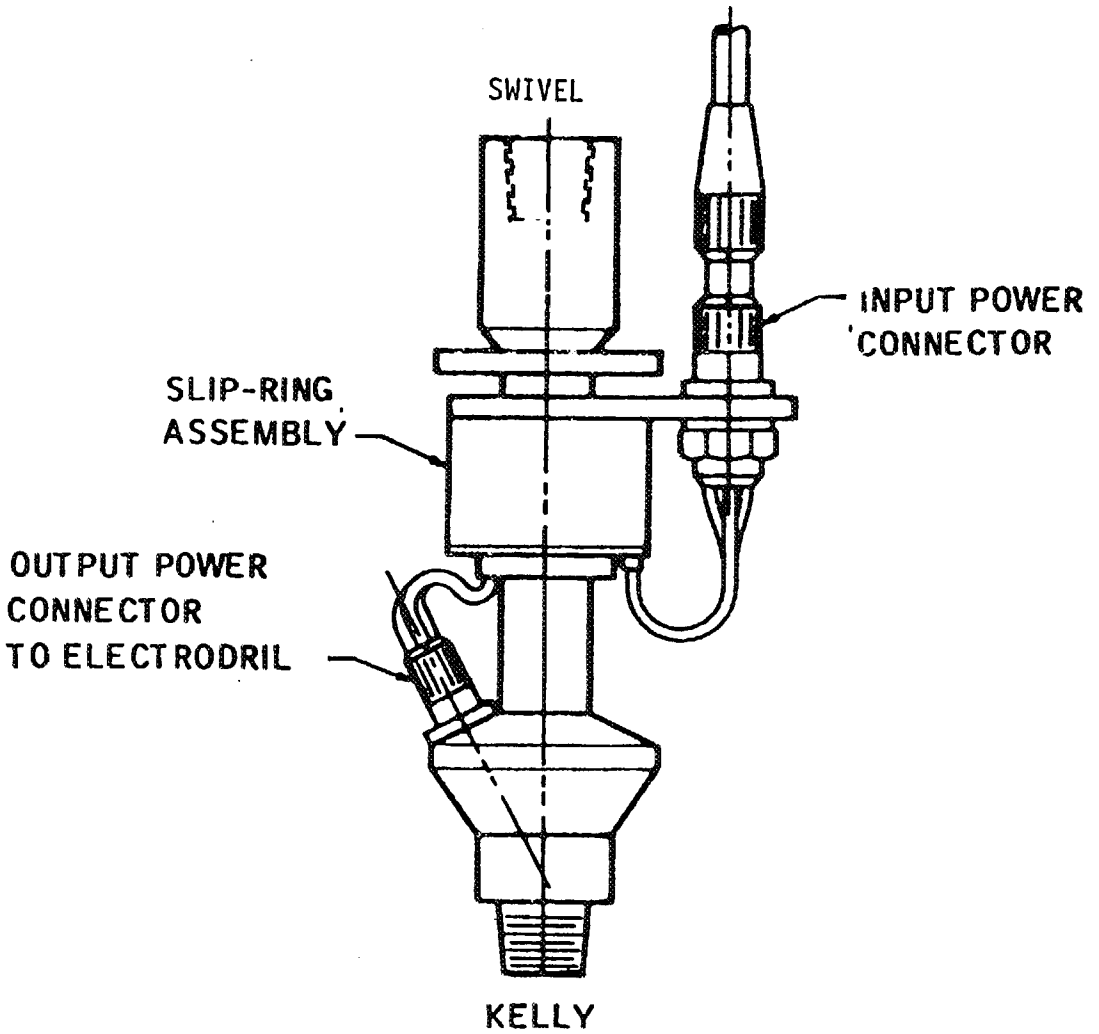


Figure 4
ELECTRODRIL SLIP RING ASSEMBLY

pipe and a 5000 foot length of Electrodril cable is mated downhole with the previously deployed cable. An electrical crossover sub located below the slip ring assembly allows the transition of the electrical cable from inside the drill pipe bore to the outside of the slip ring assembly.

Cable and Connectors. The Electrodril cable requires a total of four conductors as shown in Figure 5. To supply downhole electrical power to the motor, three conductors of No. 6 AWG will be used. A smaller center conductor of No. 18 AWG will be used for instrument power and data transmission. The cable will be composed of multistranded conductors to assure cable flexibility and will be housed in a double layer of torque balanced steel armoring to carry the weight of the cable and provide a return for the instrument power. The cables are connected through specially designed field replaceable connectors (Figure 6) which allows easy assembly of the cable sections while providing high electrical reliability. The cable is supported in the drill pipe by cable hangers which provide cable stability during drilling operations. The hanging weight of the suspended cable is less than 20% of the cable breaking strength.

The importance of keeping both cable and connectors free from water intrusion was shown in Phase I. The cable and connectors used in the Deep Drilling System will be 100% tested to provide assurance that water will not present a problem at the pressures which will be encountered.

Preliminary design trade-offs centered around the selection of a cable design cross-section with basic materials capable of withstanding bottom hole temperatures

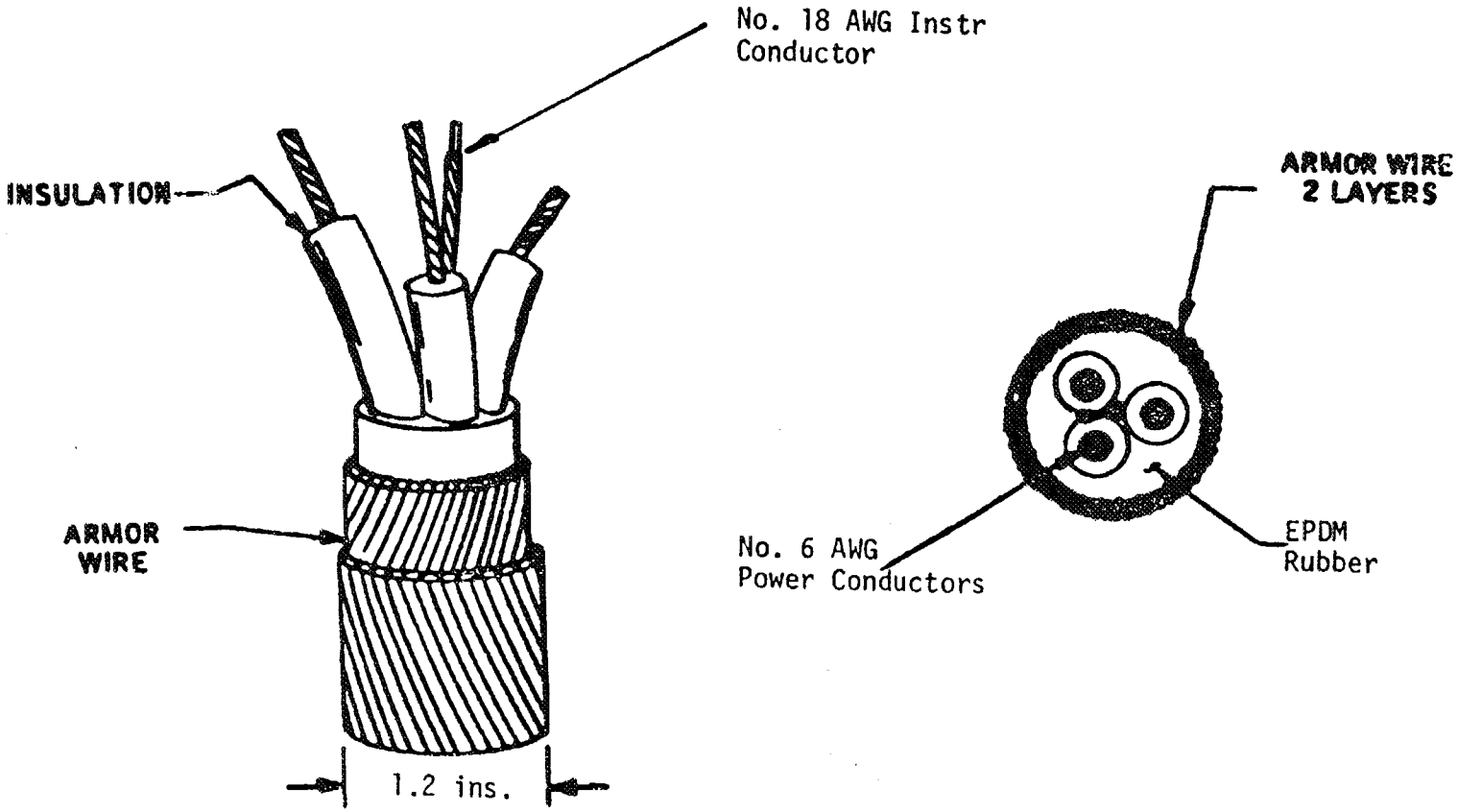
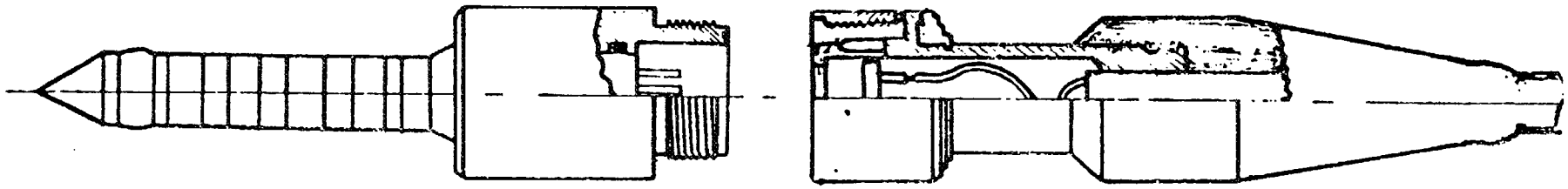


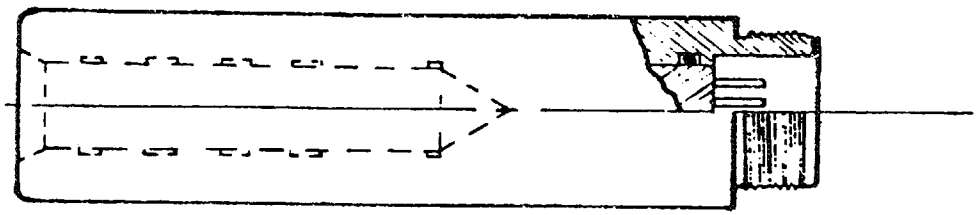
Figure 5

Deep Drilling System
Power Cable



MALE

ADAPTER ON CABLE



FEMALE

Figure 6

FIELD REPLACEABLE CONNECTOR

of 350°F while maintaining high dielectric strength. The requirement for the particular conductor geometry was to obviate inductive coupling between the high voltage motor conductors and the centrally located instrument lead. Material choices for the conductor insulation are currently quite limited due to the downhole environment. EPDM, or EPC polymers were recommended, but after further performance investigation of each it was found that EPC had a very limited downhole life at 300°F or higher. The final insulation selection was therefore EPDM.

Cable Reels. The hydraulic drive cable reels to be used for the Deep Drilling System will accommodate a total of 19,000 feet of cable. The selected cable reel skid arrangement is shown in Figure 7. A total of five reels will be required; three 5,000 foot cable reels, and two duplex 1,000 foot reels. In an effort to minimize "open hole" time, Phase I cable reel up speed has been increased to a maximum of 400 ft/min. This speed is over twice that used for the directional drilling system and is considered adequate for the field test demonstrations. The need for positive cable laydown (spooling) control was also investigated. It was concluded that so long as the cable fleet angle was held to less than 1° there was no need for spooling control. The decision was made to provide cable bedways on the reel drums to minimize the lower tier cable crush loads.

The selection of hydraulic power for the reels was made after trade studies indicated that from a skid weight, safety and economic viewpoint an AC or DC electric system would not be as efficient. The hydraulic system chosen operates

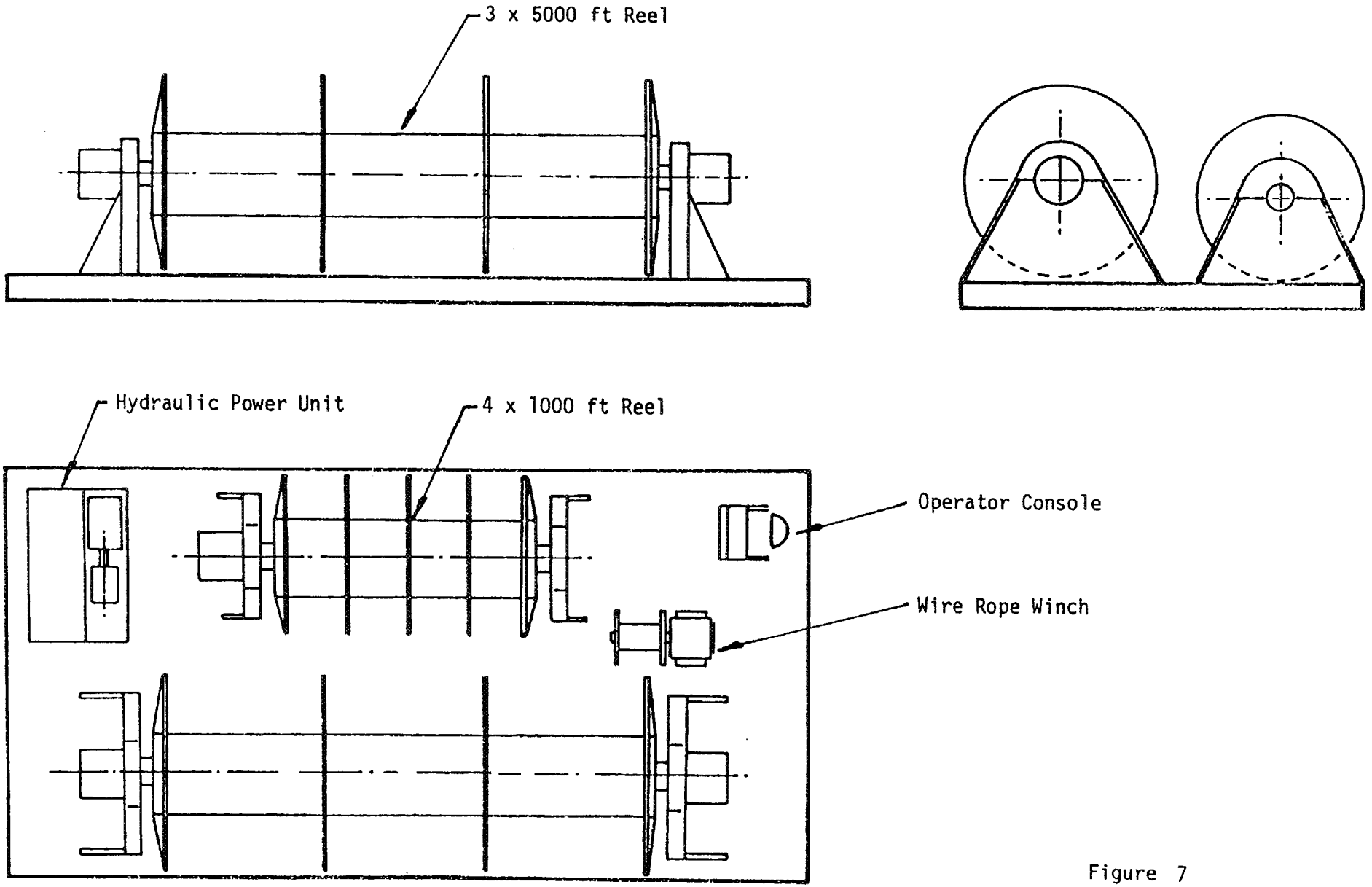


Figure 7
ELECTRODRIL CABLE REEL SYSTEM

nominally at 1500 psi and has automatic fail safe (lockup) features incorporated.

MOTOR SUBSYSTEM

The Phase II Electrodril motor subsystem, excluding the deviation sub and monel collar for the instrumentation, is a total of 51 feet in length, and 7 3/4" in diameter. A cutaway of this assembly, together with pertinent dimensions, is shown in Figure 8. The motor subsystem is electrically protected at the surface. In the event of an overload situation, current sensors will trip the power generation circuit breakers to prevent motor damage. Motor temperature will be sensed downhole and displayed at the surface.

Motor. The Phase II Electrodril motor is centered around a standard industrial REDA type 540 submersible pump motor rated at 150 HP at 1150 V 60 Hz. At this rating the motor has a speed of 3200 rpm. The output of the motor is put through a 16 to 1 gear reduction so that when the motor is operated through its planned range, the effective bit speed range will be from 40 to 400 rpm. Motor speed is varied by changing excitation frequency, which for this system will range from 12 Hz (35 HP) to 120 Hz (285 HP).

A normal start for the Electrodril motor will begin at 12 to 30 Hz depending upon length of cable deployment. This low frequency start is made to minimize the motor inrush current. The motor is then brought up to speed as dictated by the bit type and formation to be drilled.

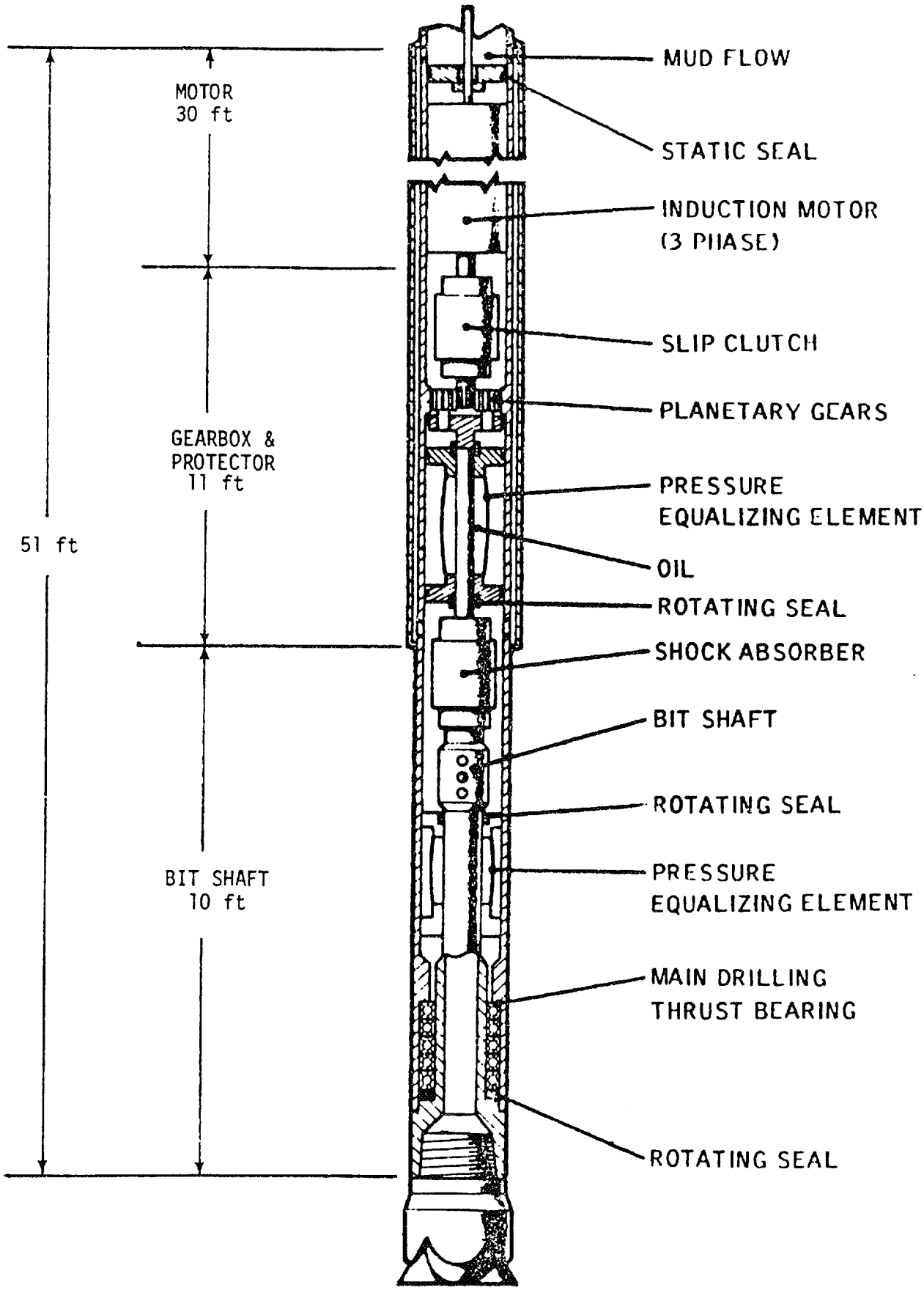


Figure 8

285 HP ELECTRODRIL MOTOR ASSEMBLY

Gearbox and Protector. The motor gearbox is a double train planetary reduction unit designed and tested to withstand weights on bit of up to 70,000 lbs. and torques in excess of 3,500 lb.-ft. A shock absorber unit is provided to isolate the motor from the shock loads produced by the drilling operation. A slip clutch unit, designed to safeguard the motor in the event the bit is suddenly stopped is also included. Internal oil pressure compensation bags are also provided in this assembly to assure that the internal oil pressure is the same as the mud pressure in the mud tube thus maintaining an almost zero pressure drop across the lower motor seals. The oil leakage over the lower motor seal is thus held to a minimum and the seal surface wear characteristics are idealized. Seal leak tests have been conducted. Data from these tests indicates that the Electrodril design will exhibit less leakage than the manufacturers estimate of 6cc/hr. Pressure compensation bags have been designed with a capacity to accommodate more than a 200 hour downhole deployment.

Bit Shaft. The bit shafts used in the Phase I Program will not be used in the Deep Drilling test program as their bearings and seals are inadequate to withstand the higher downhole temperatures and pressures. A new bit shaft has been designed to incorporate metal-to-metal seals capable of withstanding pressure differentials in excess of 2,000 psi and bearings rated to accommodate weights on bit of up to 70,000 lbs. and the more severe downhole environment. In addition, the pressure compensation bag in the new assembly has been designed with sufficient oil capacity to assure lubrication is maintained at least for the life of a diamond bit (i.e, 200 hours). The oil is then replenished each time the drill bits are replaced or at intermediate times when the drill string is removed for other reasons.

The seal and bearing design chosen has been utilized extensively in downhole water pump applications. A special internal flush feature assures positive oil-to-mud leakage to minimize the potential for mud intrusion. In addition, a grease packed labyrinth seal is incorporated into the seal housing to act as a primary mud barrier.

Test data to date on this Electrodril seal/bearing configuration indicate that actual seal leak rates are much lower than estimated which indicates that the 200 hour oil compensation bag designed into the system has reserve capacity.

Much effort was spent conducting design reviews with industrial peer groups to establish the manufacturability and maintainability of the device. Design reviews were also conducted with bearing and seal manufacturers to assure that the bearing/seal combination chosen was the best available for the application.

Prior to system verification testing, the redesigned bit shaft will be operated in a mud environment with pressure drops commensurate with those expected during deep drilling. Successful completion of this test will provide confidence that the bearings, seals, and oil pressure compensation system are adequate for the Deep Drilling System.

INSTRUMENTATION SUBSYSTEM

The instrumentation subsystem (Figure 9) remains functionally the same as that demonstrated during the Phase I Program. A basic design ground rule was to

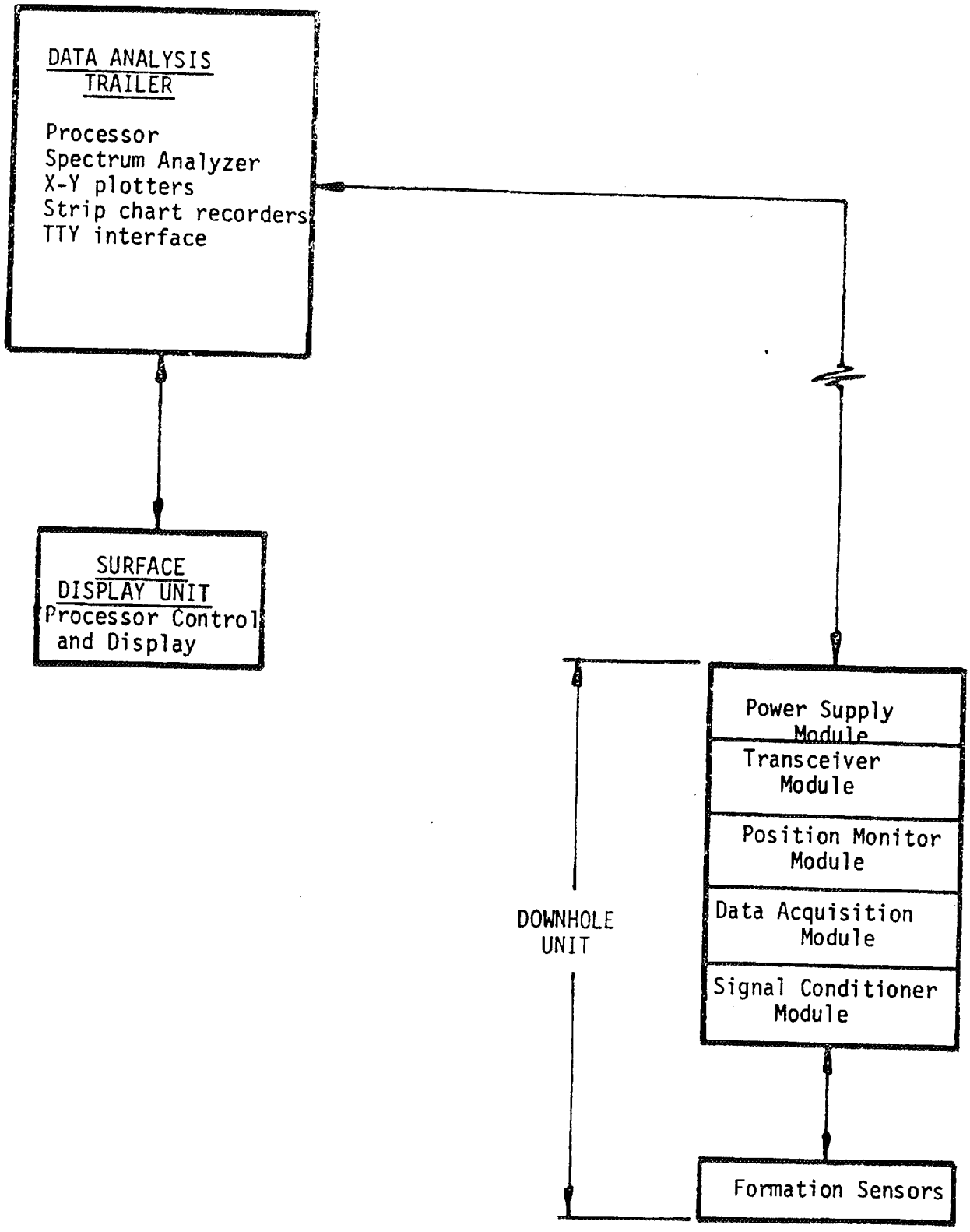


Figure 9

Electrodril Phase II
Instrumentation Subsystem

utilize as much of the Phase I instrumentation hardware as possible. Modifications to the downhole instrumentation system include:

1. Replacement of the original position monitor with a new three axis solid state device designed by General Electric. The new design is much more sensitive, has much lower hysteresis and higher repeatability than the original electromechanical unit.

2. Replacement of the original instrument pressure housing with a 20,000 psi design.

3. Addition of a formation sensor sub between the Monel collar and the motor. The sensor sub houses a gamma log, outside mud temperature sensor and differential pressure sensor. These three sensors are considered sufficient to demonstrate the capability of formation sensing while drilling.

4. Addition of a temperature and voltage sensor in the motor so that the well-being of the motor can be monitored at the surface while drilling is in progress.

Modifications to the surface equipment include addition of a processor/display/recorder system to the data analysis trailer and modifying the driller's console to handle the high motor current.

Downhole Instrument Package. The downhole instrument package has been designed to perform the following functions:

1. Receive from the surface 115V AC 60 Hz electric power and convert and distribute same to support the downhole instrumentation.

2. Monitor up to 15 analog plus 11 digital downhole parameters and process (multiplex) this data.

3. Send to the surface processed data in pre-established digital formats.

4. Receive two to four commands from surface equipment for execution by downhole auxiliary units.

Surface Support Equipment. The surface equipment receives the downhole data, establishes bit and frame synchronization, checks parity, decides on the data acceptability, performs data transformation, routes and displays data.

The surface equipment transmits commands to the downhole equipment utilizing frequency shift keying of the power source to transmit the data. The correct voltage level downhole is also commanded by the surface equipment and maintained by varying the surface voltage level in proportion to the surface power signal level.

The power supply for the surface equipment utilizes 115 VAC - 60 Hz developed from the Electrodril power subsystem. The surface equipment converts this system power to supply the logic and analog power for the surface equipments. The surface equipment power supply also provides the 1000 Hz power for the downhole instruments. Sufficient power is supplied at the surface to assure that 120 volts $\pm$ 12% is received by the downhole unit. The surface support equipment includes two data display stations:

1. The display control unit displays the three axis hole direction data and has one other display window for other selectable data.

2. A second microprocessor has been added in the trailer so that raw downhole data can be decoded, converted, and displayed independently from the rig floor display and control unit. This feature, which was not available during Phase I, will permit system diagnostics to be performed and enhance the analysis capabilities to support the evaluation of Electrodril system performance.

4.0 FABRICATION

The functional compatibility of the major elements of the Deep Drilling System was successfully demonstrated during the 1976 Phase I field test demonstration. The equipment inventory, as a result of the Phase I program, was essentially related to the 60 HP Directional Drilling System although there did exist one 285 HP motor and two gear boxes that were available for use in the Phase II program. The remainder of the equipment inventory required to support the Phase II program had to be procured as part of the Task B effort.

The procurement plan for the remainder of the Phase II equipment was concentrated on a "buy" rather than "make" concept. The major exception to this strategy was the decision to make the instrumentation subsystem. The decision to continue the in-house fabrication of instrumentation subsystem elements was based on the assessment that General Electric's forte was in this area; it had the manufacturing continuity and the subsystem was relatively free of problems.

In general, procurements for the Phase II system were made from sources established during the Phase I equipment procurement cycle. One significant exception to the plan was the procurement of the electrical cable. After having established the preferred cable jacketing material (Ethylene, Propylene, Diene monomer-EPDM), the original cable manufacturer "no bid" the procurement specification due to his inability to manufacture an EPDM cable of the size required. Subsequent searches for an alternate manufacturer uncovered an established supplier who had many years of cable manufacturing experience with this material.

Another significant procurement decision for the Phase II program was the selection of a subcontractor to manufacture the field replaceable connectors. During the Phase I program the connectors were manufactured in-house. This was done to establish the preferred manufacturing method and to develop quality control criteria so that subsequent production procurements could be intelligently specified. The successful testing of the field replaceable connector concept during the Phase I program facilitated the decision to develop a subcontractor source for these connectors. Full technical and procedural disclosure was made to the selected subcontractor to assure maximum connector technology transfer. In most instances acceptance testing of subcontractor deliverables was accomplished at the subcontractor's facility. GE project engineers were witness to the key elements of each test program. Substandard deliverables were repaired or remade before acceptance was approved.

5.0 TECHNICAL APPROACH TO TEST

The major objective of the Systems Verification Test was to demonstrate the functional compatibility of all the Electrodril system elements and the readiness of the total system to be deployed in operational wells for further evaluation. It was important, therefore, to develop a test plan so that the System Verification Test could be conducted in an orderly and controlled manner and thus assure that the test data derived was valid and meaningful. Such a test plan was devised (Appendix B) and adhered to throughout the test period. A summary of the test plan, in schedule form is shown in Table 1.

The fundamental Systems Verification Test concept was to enter the test well initially, with a minimum Electrodril string, to test this baseline system and then to add other system elements in a logical sequence so that anomalies and failures, when they occurred could be isolated quickly and corrected.

One overriding requirement during the Systems Verification Test was to perform a 100 hour bit shaft test to demonstrate the integrity of the newly designed bit shaft. Clearly it was important to execute this test as early as possible to provide a maximum of time for the correction of any problems isolated during the bit shaft test.

	MILESTONES
1	CONVENE & DEPLOY EQUIPMENT
2	ASSEMBLE MOTOR & BIT SHAFT
3	RUN 100 HOUR BIT SHAFT TEST
4	REMOVE BIT SHAFT & REDEPLOY MOTOR
5	CONDUCT YO YO CABLE TESTS
6	CONDUCT 1000' CABLE TESTS
7	CONDUCT CABLE FISHING TESTS
8	CONDUCT CABLE & KELLY TESTS
9	CONDUCT CABLE/KELLY & DED PIPE TESTS
10	CONDUCT TEST WITH 2 x 1000' CABLES
11	REMOVE STRING & INSTALL INSTR SUB
12	CONDUCT INSTR TESTS ON 1000' CABLE
13	REMOVE STRING & INSTALL FORM SENSOR SUB
14	CONDUCT TOTAL INSTR TESTS ON 1000' CABLE
15	CONDUCT DEMONSTRATIONS TO INDUSTRY
16	
17	
18	
19	
20	

NOTES

Table 1

SYSTEMS VERIFICATION TEST SCHEDULE

The initial test priority then was placed on conducting the 100 hour bit shaft test. This test required the Electrodril motor, the bit shaft, appropriately plugged at its lower end to simulate drill bit hydraulics, a minimum of drill pipe, electric cable and pack offs and the power generator and control system. It was not considered important to simulate the rig floor environment in this test as primary concern was focused on the motor/bit shaft compatibility and the capability of the bit shaft to function over the complete speed range of the motor while subjected to a simulated downhole environment.

Upon completion of the 100 hour bit shaft test, the drill string was to be removed from the well and the bit shaft removed from the motor and returned to the assembly facility. The bit shaft was then to be subjected to tear-down inspection to evaluate seal and bearing wear characteristics. During this inspection period the motor assembly could be reinserted into the well (without bit shaft) so that cable deployment procedures and connector reliability could be evaluated.

Initially, cable deployment was planned at shallow depths (i.e., less than 1000 ft.) and the cable was deployed onto the motor. This approach was taken so that repetitive connector matings could be made swiftly to build up confidence in the new connectors. Upon the completion of each connector mating downhole, electrical measurements would be made to verify that good connector mating had occurred and then the motor would be "bumped" to assure the electrical characteristics of both motor and cable were satisfactory. These initial cable/connector matings were to be accomplished in a mud environment, but mud would not be circulated.

The next logical step was to "land" a 1000 ft. cable length in a typical drill string and to connect the prewired kelly to the string so that mud could be circulated at various pressures while the motor was exercised through its power regime. Upon successful completion of this test series, multiple cable lengths and dedicated (prewired) drill pipe were to be deployed in single steps so that all cable and drill pipe combinations could be exercised and evaluated.

After establishing the functional reliability of the cable and connectors, together with the prewired drill pipe and kelly, the Electrodril instrument sub is to be deployed. This approach affords the best possible electrical environment for the instrument sub and minimizes the potential for catastrophic failure of the sub due to cable shorts or power excursions.

Testing of the Electrodril instrumentation was to be executed in two steps as the subsystem is divided into two downhole elements: (1) the directional sub, which houses the three axis directional sensors and the downhole signal processing and telemetry, and (2) the formation sensor sub, which houses the sensors for evaluating the downhole (drill pipe core and annulus) environment. The directional sub can be deployed downhole without the formation sensor sub as it houses all the downhole data processing and telemetry capability. The formation sensor sub cannot be deployed without the directional sub as it lacks a "stand alone" telemetry capability. The logical sequence for evaluating the Electrodril downhole telemetry and sensors was established as follows: First the directional sub was to be evaluated in the drill string and after successful evaluation, the formation sensor sub was to be added to evaluate

the full complement of Electrodril Deep Drilling System instrumentation. In both test operations the surface trailer was to be used to collect, process and display the data from the downhole instrumentation.

Upon successful completion of this test program, the drill string was then to be stood back in the derrick and a series of deployment, retrieval and fishing exercises were to be conducted by the drill rig crew so that deployment, retrieval and fishing methods could be evaluated. The final series of exercises was to be conducted before members of the Electrodril Technical Advisory Board so they, too, could evaluate the system.

6.0 TEST ACCOMPLISHMENTS

6.1 GENERAL

All major system elements were functionally tested prior to shipment to the Brown Oil Tools test site. These functional tests were conducted either at a subcontractor's plant and witnessed by General Electric engineers, or at the General Electric assembly facility in Houston, Texas. The Systems Verification Test was, therefore, to determine the functional compatibility of the total Deep Drilling System and to assure the system was ready for field demonstration.

The Electrodril Systems Verification Test was conducted in a test well at Brown Oil Tools Inc., Houston, Texas. The system was deployed as a 3400 foot section of a 6000 foot well in 9 5/8" casing. A packer was set at the 3400 foot depth by Brown Oil Tools. General Electric was requested not to remove che packer and the depths for the Systems Verification Test were limited to 3400 feet.

6.2 COMPONENT/SUBSYSTEM TESTS

BIT SHAFT

Prior to the initiation of the 100 hour bit shaft test, the bit shaft was assembled and tested to assure the oil compensation system was operating correctly. The fill procedures for the oil compensation system included evacuation by vacuum pump to approximately 100 torr. This partial vacuum technique verifies that the upper and lower shaft seals are correctly assembled and facilitates quick back-filling of the lubrication cavity with oil.

Upon the successful completion of the evacuation and fill procedure the bit shaft was "run in" on a spin test facility (Figures 10 and 11) to assure tne seals are dynamically functioning and that the leak rate is within tolerance. The run-in period is typically for 24 hours at the completion of which the bit shaft is set aside and is considered ready for deployment.

MOTOR

The motor is a standard Reda series 540 submersible pump motor upon which is installed a special motor riser to mate with the Electrodril connector system. Integral with the motor riser is the thermistor bead for motor core temperature monitoring. The motor riser is installed to the motor by General Electric and subsequent post assembly test consists primarily of electrical high potential testing and resistance checks to ground. The installation of the gear box and oil compensation section is accomplished in a similar manner to that for the bit shaft. The evacuation and fill procedure for the lubrication cavity is also accomplished similar to the bit shaft.

CONNECTORS

Development was started on the field replaceable connectors as a result of the Phase I test program. Materials and processes were evaluated in light of their electrical and mechanical properties, bondability and compatibility.

Prototype designs were made and subjected to tests to determine their reliability under simulated downhole pressures and temperatures. The South Houston field

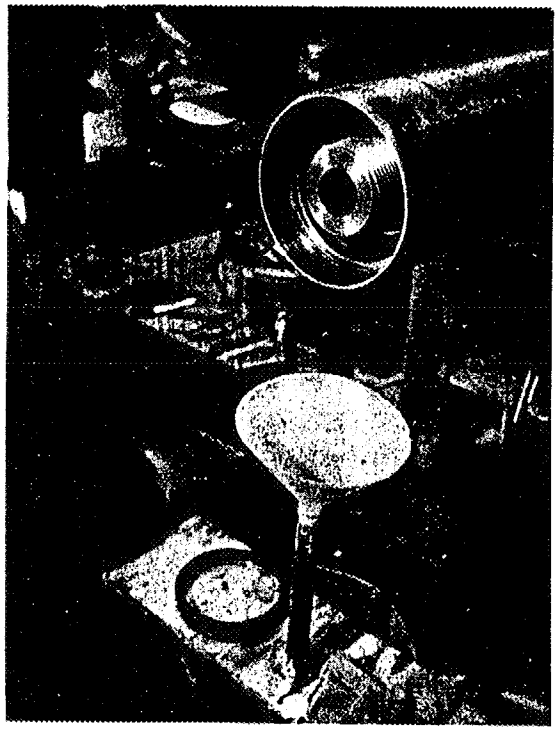


Figure 10

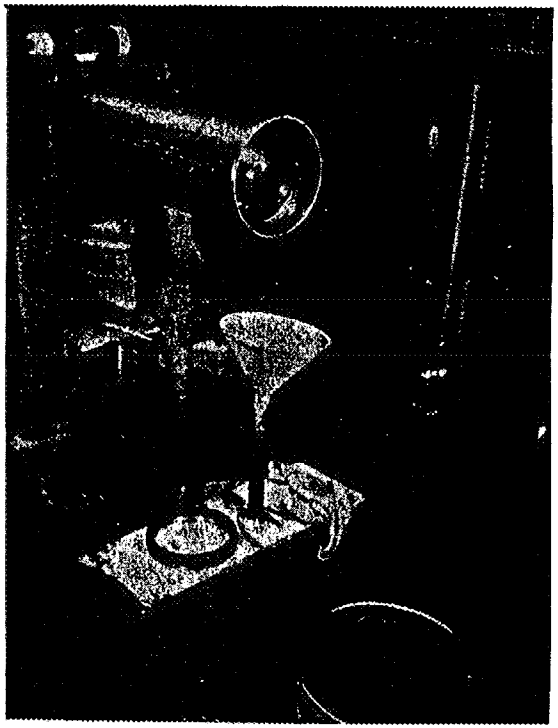


Figure 11

BIT SHAFT SPIN TEST FACILITY
SHOWING BIT SHAFT BEING RUN-IN

test demonstrated the viability of the design but did not show that the connector would still mate reliably after repeated matings and unmatings. The test fixture shown in Figure 12 was made to investigate the life characteristics of male/female connector combinations in a simulated tool joint bore. The effects of various dielectric greases as well as the scouring caused by mud were investigated. Rhodium plated conductor rings to minimize the scouring were tested but, because of their additional contact resistance, were not used in the final design. As many as 7000 matings were made without appreciable electrical performance decline.

Connectors purchased for the Systems Verification Test had been 100% pressure tested and electrically checked for continuity and leakage to ground prior to shipment. One set of connectors was put on the life test fixture and, after 2500 matings, demonstrated no degradation in electrical contact resistance.

CABLE

Because the final cable diameter greatly affects the proficiency of the cable drum rewind pattern, it was closely monitored and checked during its fabrication. General Electric personnel were witness to the final testing (both electrical and mechanical) at the vendor location. The final product was prestressed prior to shipment to minimize cable stretch during deployment. A sample was also placed in a tensile tester and pulled to destruction to demonstrate that the breaking strength specification was met. The cable vendor subjected samples of the cable to environments which verified their thermal and chemical resistance characteristics.

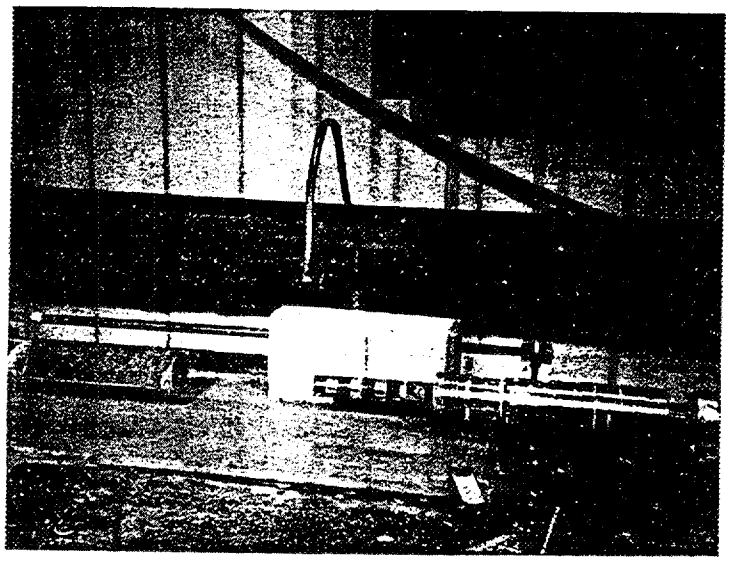


FIGURE 12

CONNECTOR LIFE TEST FIXTURE

It is planned to investigate the use of time domain reflectometry testing techniques to assist in the identification and location of cable/connector faults in the Electrodril string faster and more accurately.

Flexibility tests were not run by the vendor but, during Systems Verification testing, it was established that about 1004 feet of cable could be installed in a 1000 foot section of 4 1/2" X-hole drill pipe.

CABLE REELS AND DRIVE

Prior to accepting delivery of the cable reels and drive skid from the vendor, testing was conducted to insure that specifications were met. The hydraulic system was operated and reels rotated in both forward and reverse directions over its entire speed range. It was decided that the braking system could best be tested during cable deployment at Brown Oil Tools.

INSTRUMENTATION

For the Phase II program three major changes were incorporated into the basic instrumentation package. A new solid state position monitor was developed to increase reliability and enhance performance accuracy. Since the tests were to be run in a cased straight hole at Brown Oil Tools, no accuracy testing of the new solid state position monitor was possible. The new position monitor was thoroughly tested in a laboratory prior to the Brown Oil Tools testing. Its accuracy and repeatability were demonstrated to be better than 1.0 degrees in drift and 3 degrees in azimuth and tool face. A new sensor package was

developed to function with the downhole directional sub to allow for heat sub control via commands from the surface and for downhole measurement of motor temperature, motor voltage, annulus mud temperature, drill pipe/annulus differential mud pressure, and formation gamma radiation. The third change was the addition of a processor in the data analysis trailer to "back up" the display control unit and to process downhole and surface measurements for recording on magnetic tape and display on strip chart recorders and on a hard copy printout.

POWER GENERATION

A series of tests, reported in Appendix D, was conducted to evaluate the transient response characteristics of the motor/inverter combination so that an adequate control system could be designed. The specific objectives of the test program were to determine:

a. The compatibility of static inverter drive systems to Electrodril applications.

b. The drill motor losses attributable to oil sheer, (windage), at various motor speeds and with different lubricants.

c. Drill motor starting current requirements at low frequency

d. Drill motor HP and temperature rise with respect to various power frequencies, loads and cooling flow rates.

e. Effects of the "Static Inverter Wave forms" upon the downhole telemetry system operation.

f. The effects of cable IR losses to motor terminal voltage regulation requirements.

6.3 SYSTEMS VERIFICATION TESTS

100 HOUR BIT SHAFT TEST

Prior to the initiation of the 100 hour bit shaft test, the bit shaft was "run in" on the spin test facility as previously described to assure the seals and bearings were in good operating order. Subsequent to this test the bit shaft and motor were assembled together in the rig (Figures 13 and 14). This "in the well" assembly was necessitated because the rig Vee door could not accept an assembly with a length approximately 60 ft. Some concern existed about the ease by which the motor and bit shaft could be assembled in the rig due to the precise makeup requirements of the shock sub and drive splines. The concern, however, was groundless as the bit shaft was mated to the motor quite easily. Subsequent matings and breakings were made during the course of the system verification test which indicates that bit shaft replacement in the rig, should that become necessary, would be a relatively easy procedure.

The formal 100 hour bit shaft test was begun October 19 and successfully concluded October 25. Subsequent post test inspection indicates that the overboard leak rate of the shaft seals are well below design limits and thus the oil compensation system appears to be more than adequate to support a 100 hour bit life.

Motor performance during this period was normal. No unusual power surges or voltage fluctuations were noticed and the core temperature of the motor, after initial warmup, stayed within design limits.

A test report documenting the specifics of the 100 hour test is presented in Appendix B.

Figure 13

BIT SHAFT IN SLIPS BEING
PREPARED TO RECEIVE MOTOR

Figure 14

MOTOR BEING MATED TO
BIT SHAFT ASSEMBLY

CABLE AND CONNECTORS

After removal of the bit shaft for post test evaluation, the motor was run in the test well to a depth of approximately 200 ft. The cable skid (Figure 15) and rig sheaves, (Figures 16 and 17) were already in place by virtue of their use in support of the 100 hour bit shaft test.

A sinker bar, weighing approximately 375 pounds, was subsequently prepared for deployment (Figures 18 and 19) and lowered onto the motor using a portion of t 1000 ft. power cable. The cable was then checked for electrical continuity throug the downhole connector and motor by measuring these values at the cable connector on the cable skid. Electrical continuity on all four conductors and the electrical resistance to ground for each conductor was also measured. Each of the electrical checks indicated that the sinker bar/connector combination had mated with the motor. The motor was therefore powered up and brought to approximately 200 RPM while in-rush current and applied voltage levels to the output transformer levels were noted. A typical in-rush current maximum would be in the order of 190 amps while applied voltage at 60 Hz would be 1200 volts.

During the first day of connector/sinker bar/cable and motor tests a total of six remote downhole matings were attempted and in all six proper electrical connections were achieved and electrically verified.

CABLE LANDING/PREWIRED KELLY/DEDICATED PIPE

A total of 1024 feet of drill pipe was then added to the top of the motor. An

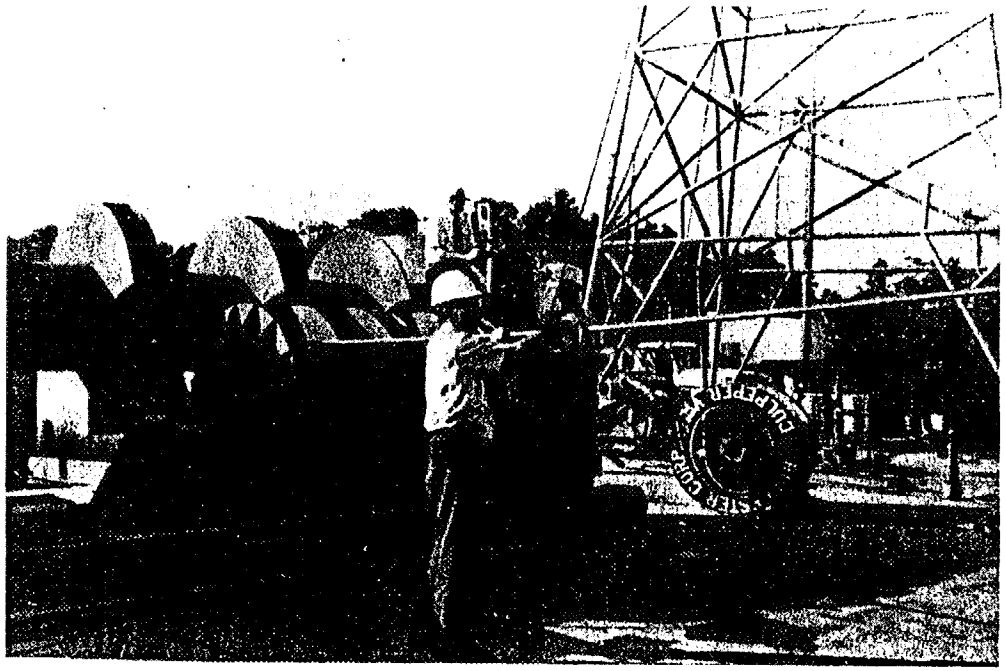


Figure 15

ELECTRODRIL POWER CABLE SKID

CAPACITY 19000 Ft.

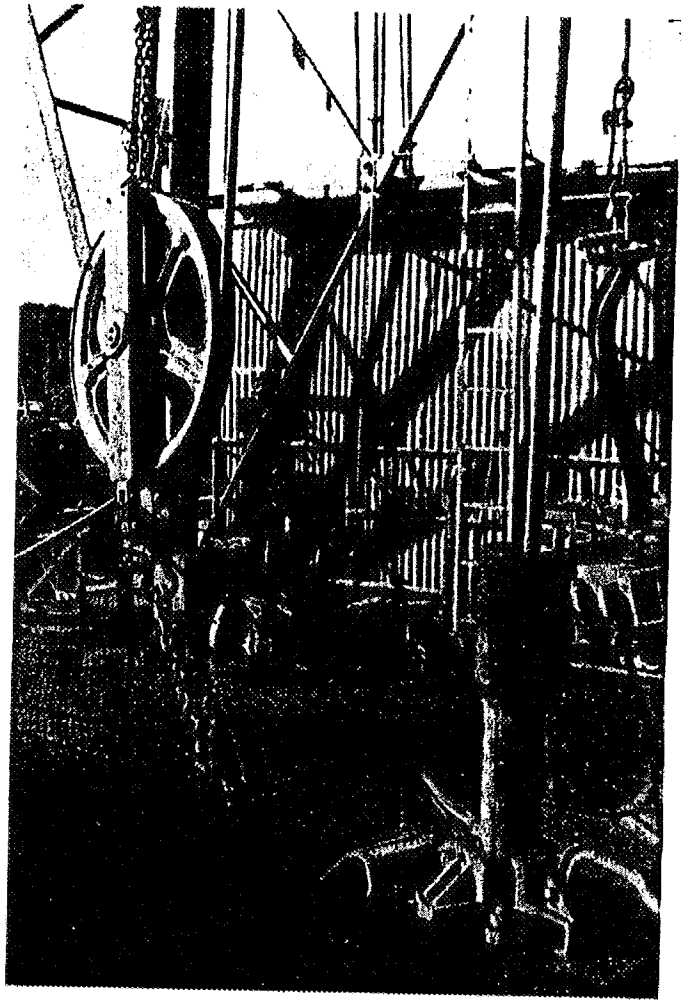


Figure 16

ELECTRODRIL RIG FLOOR SHEAVE

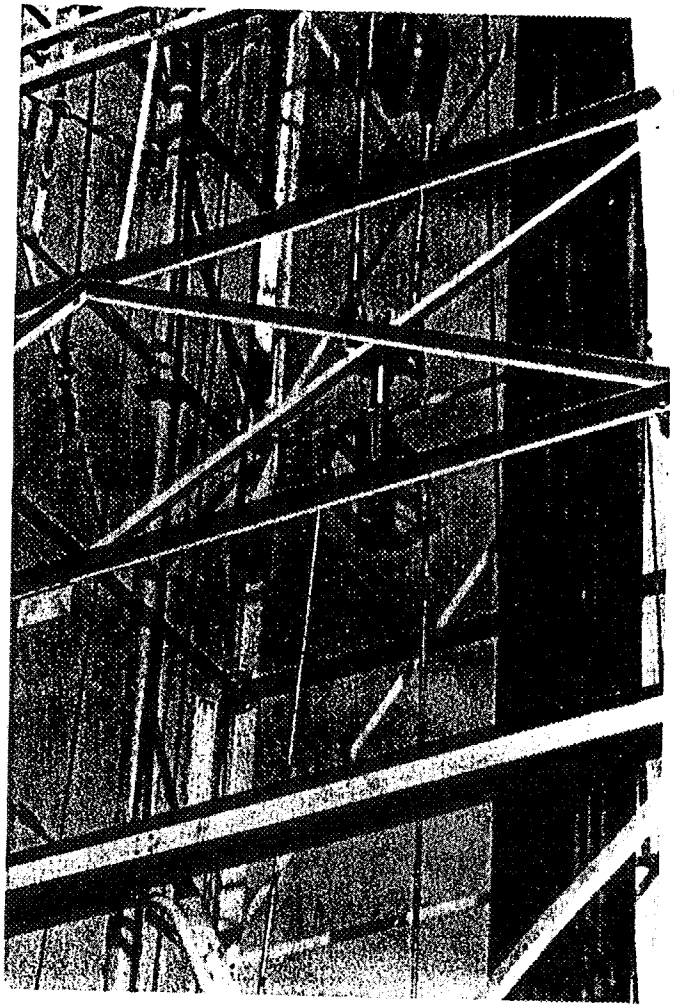


Figure 17

ELECTRODRIL TRAVELING SHEAVE

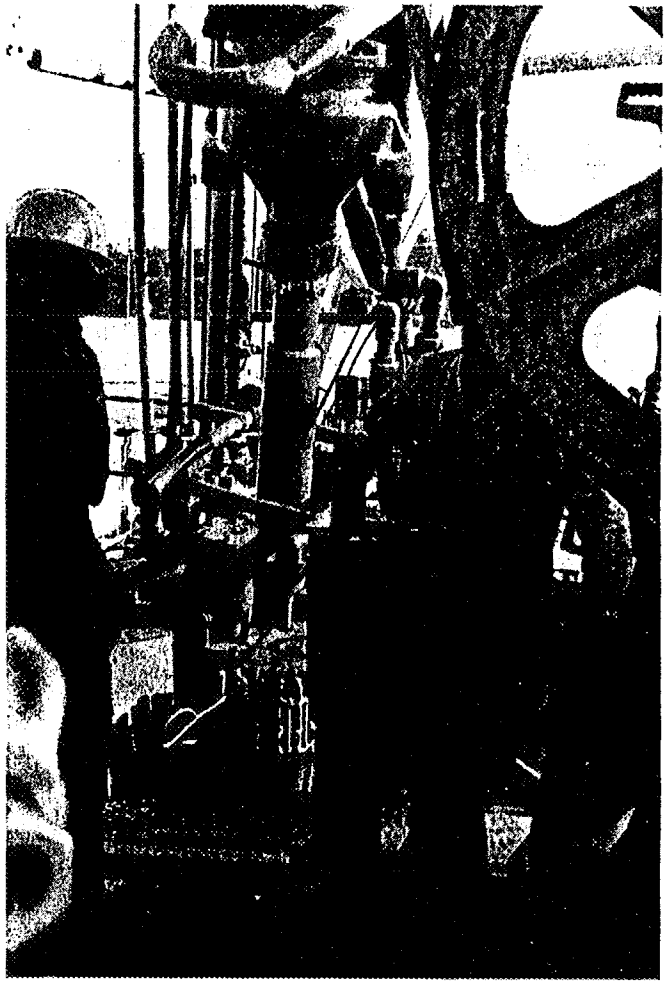


Figure 18

SINKER BAR IN SPECIAL SLIPS

SUSPENDED IN DRILL PIPE

Figure 19

CABLE ADAPTER BEING

PREPARED FOR SINKER BAR

Electrodril landing sub was made up to the last joint of drill pipe and the sinker bar/connector/cable was lowered into the hole. When most of the cable was removed from the drum, the cable slips, (Figure 20) were set and the cable was freed from the reel. The wire rope was then attached to the cable end with the landing shoe attached to the male connector and the slips were removed after slack was taken out of the cable/wire rope. The remainder of the cable was lowered into the hole with the cable and wire rope passing over and under the sheaves with no damage. When the landing shoe was secure in the landing sub (Figure 21) the wire rope was removed and the down-hole cable checked electrically. Each of the checks indicated that a successful mate had been achieved. This was verified by "bumping" the motor and monitoring voltage and current. The cable was then retrieved by reversing the deployment procedures previously described. A total of four redeployments into the same drill string were made with equally successful results. This success gave confidence that cable stretch was essentially negligible and that, once a length was known, the drill string required for landing remained constant. The cable slips worked extremely well in both dry and wet (oily) conditions. No abnormal squeeze appears to have been placed on the cable cross section during the landing or retrival process.

During this test series a test was conducted to determine the amount of cable that could be "stuffed" into drill pipe. This parameter is important as it affects how accurately the drill pipe tally should be taken and establishes the tolerance allowed on the cable lengths of prewired pipe. The test indicated that approximately four extra feet of cable could be stuffed into 1000 ft. of drill pipe while monitoring good connector mating and correct cable landing.

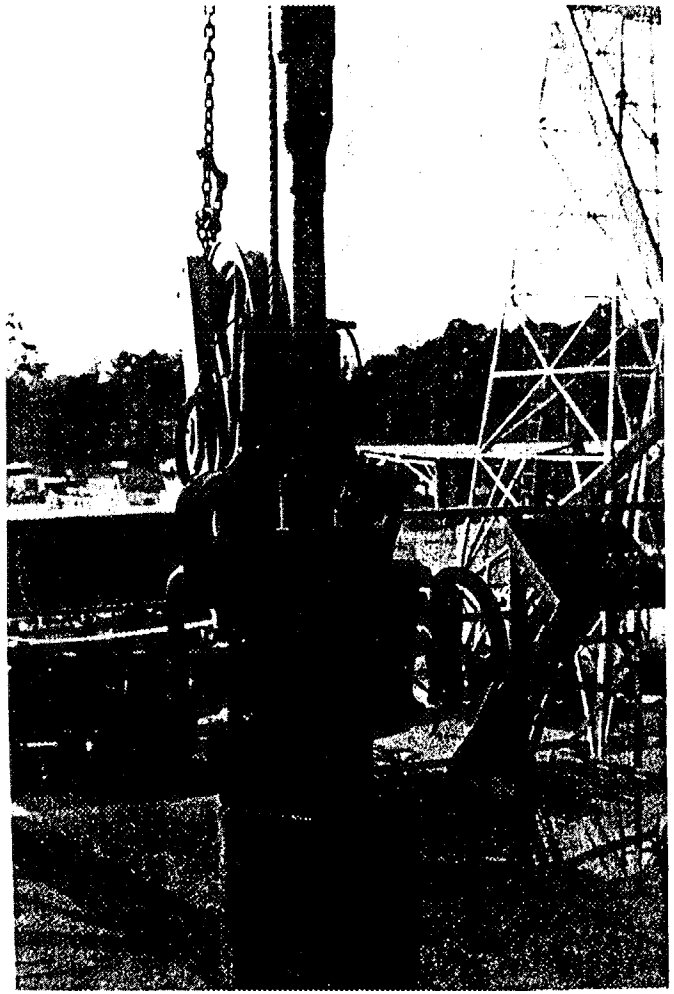


Figure 20

ELECTRODRIL CABLE SLIPS

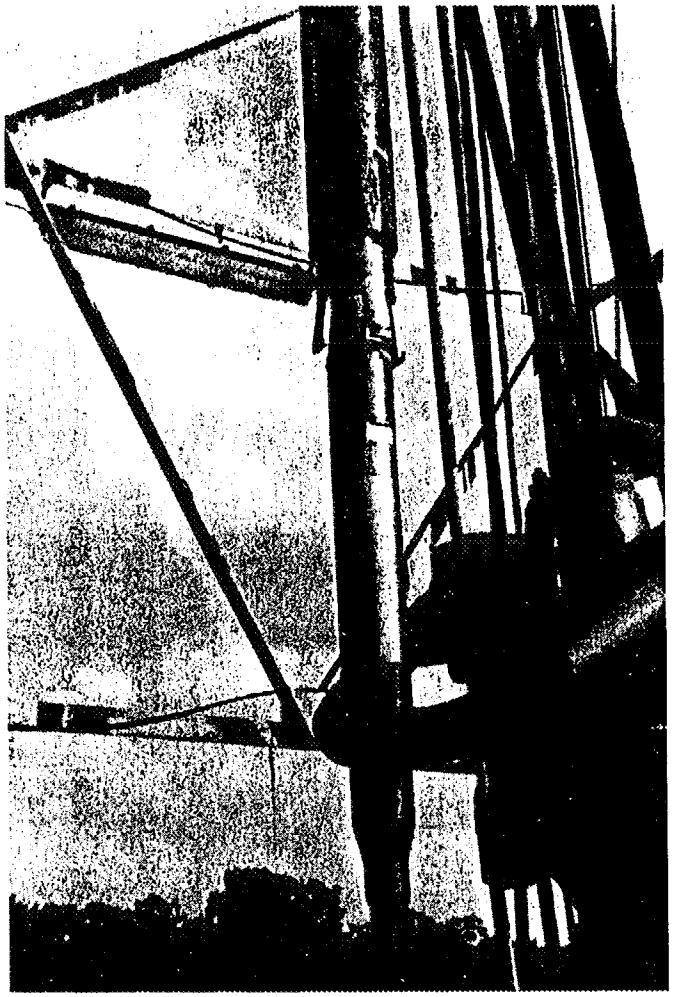


Figure 21

UPPER END OF POWER CABLE
SHOWING LANDING SHOE

The prewired kelly was then made up to the drill pipe landing sub and the string was lowered into the hole until the kelly crossover sub was just above the slips (Figure 22). Electrical measurements at the slip ring electrical crossover indicated that correct connector mating had occurred. The surface cable was then connected to the power skid and the motor was turned on. Mud was circulated through the string at pressures up to 850 psi while the motor was slewed from 55 to 257 RPM.

Upon successful completion of the previous test phase, an additional 1000 ft. of cable and two 30 ft. dedicated (prewired) drill pipes were deployed in single steps so that all the cable and drill pipe combinations were exercised and evaluated. The feasibility of making electrical kelly to dedicated pipe connections using the mousehole was also proven. A slip ring assembly was then added to the top of the kelly (Figure 23). Powering the motor through the slip ring was uneventful and demonstrated that string rotation while drilling with the Electrodril system could be readily achieved.

It should be noted that the 90 ft. dedicated stands which are planned for use in the drilling demonstrations were not exercised at the Brown Oil Tools test facility as the derrick was not capable of manipulating them. There is no difference in the electrical or mechanical makeup between the 30 ft. and 90 ft. dedicated stands and, as such, this technical omission is not considered a violation of the validity of the test series.

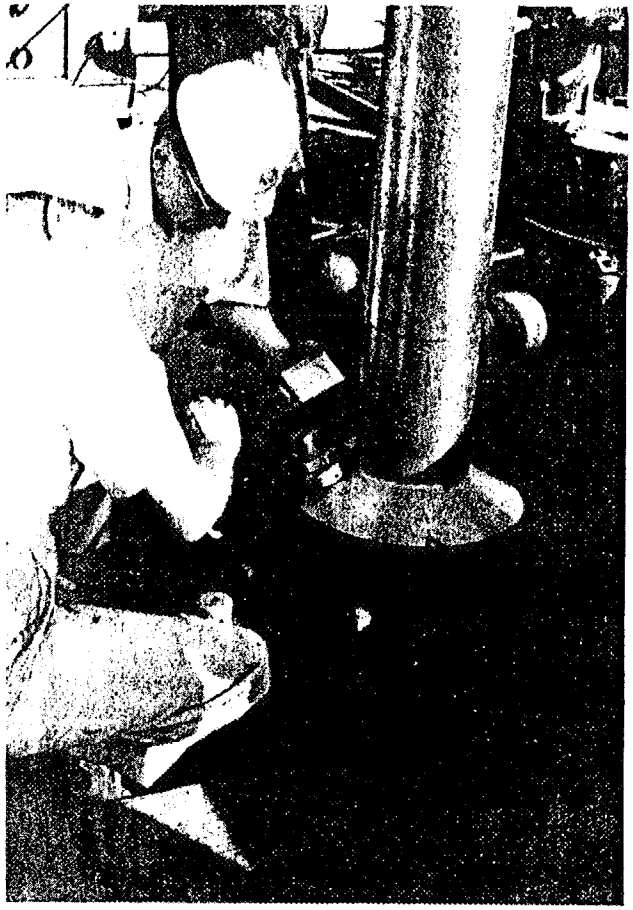


Figure 22

ELECTRICAL TESTING BEING DONE
AT CABLE CROSSOVER

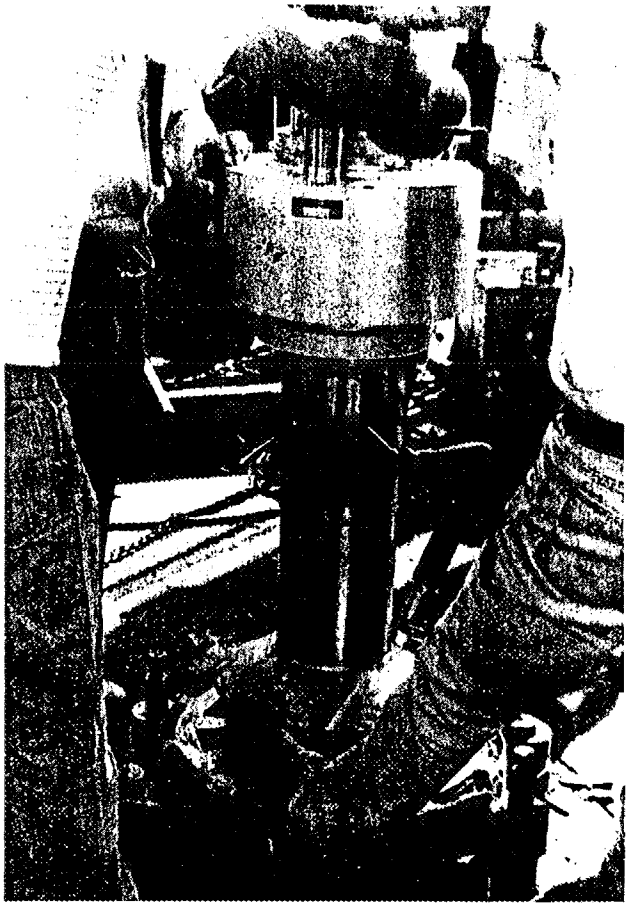


Figure 23

SLIP RING ASSEMBLY INSTALLED
ABOVE CABLE CROSSOVER

To demonstrate that the landed Electrodril cable could be retrieved in the event that the string was stuck, a specially designed fishing tool was deployed in open drill pipe in which a 1000 ft. cable had been landed. The landing sub for the cable was approximately 200 ft. below the pipe slips. The fishing tool latched on to a fishing neck below the replaceable male connector. A force of 300 pounds greater than the cable hanging weight (i.e., approximately 2300 pounds total) was exerted causing the landing shoe to deform and pass through the tool joints and pipe bores. The landing shoes can be resized and reused without structural deterioration after having been fished.

INSTRUMENTATION SYSTEM

The basic Electrodril instrumentation consists of a downhole directional sub and surface display and control unit. This equipment, together with a data analysis trailer, was tested extensively in both test and operational wells during the Phase I program and was shown to be operationally ready.

For the Phase II Program, however, three major changes were incorporated into this basic instrumentation package. A new solid state position monitor was developed to increase reliability and enhance performance accuracy. A new sensor package was developed to function with the downhole directional sub to allow for heat sub control via commands from the surface and for downhole measurement of motor temperature, motor voltage, annulus mud temperature, drill pipe/annulus differential mud pressure, and formation gamma radiation. The third change was the addition of a processor in the data analysis trailer to "back up" the display control unit and to process downhole and surface measurements for recording on magnetic tape and display on strip chart recorders and on a hard copy printout.

The Phase II testing of the instrumentation subsystem at Brown Oil Tools was to demonstrate the total instrumentation subsystem with the new instrumentation elements in a simulated drilling environment. Testing was performed in two steps. First, the directional sub was run downhole with the motor to a depth of approximately 1000 feet, mud circulation was established and the instrument successfully operated. This test demonstrated the compatibility of the directional sub with the drill string, motor, and cabling subsystems. Next, the formation sensor sub* and heat sub* were added to the downhole configuration.

The test was performed by lowering the motor, formation sensor package, heat sub and directional sub into the test well, making up electrically and then exercising all portions of the instrumentation system while starting, running (at different frequencies), and stopping the downhole motor. Downhole telemetry was received by the data analysis trailer (Figures 24 and 25) and by the Control and Display Unit (Figure 26) from the directional sub with no loss of data during the entire test. The following measurements were made, processed and displayed during the test:

* The solid state position monitor, the formation sensor and the heat sub were developed independently for application to the Field Test Program.

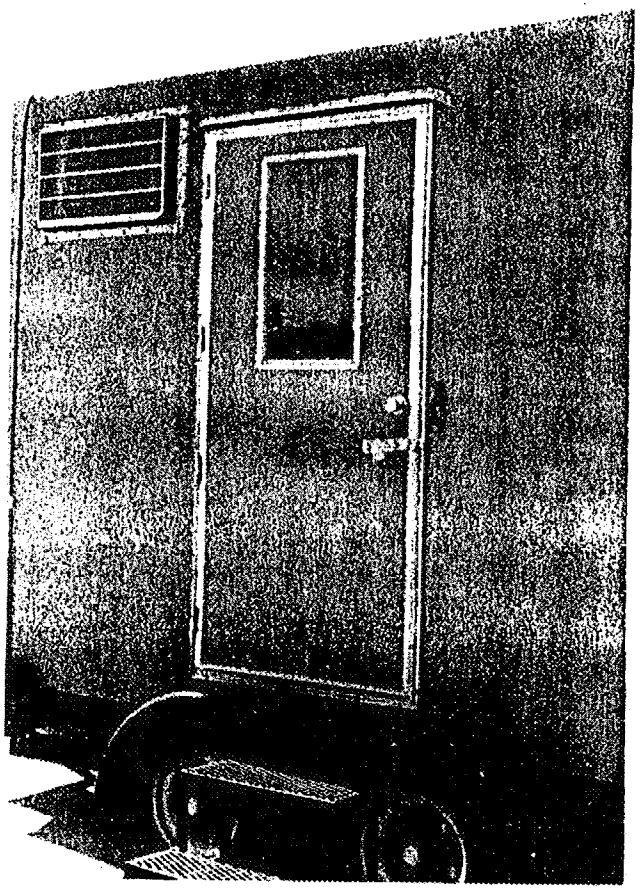


Figure 24

ELECTRODRIL DATA ANALYSIS
TRAILER

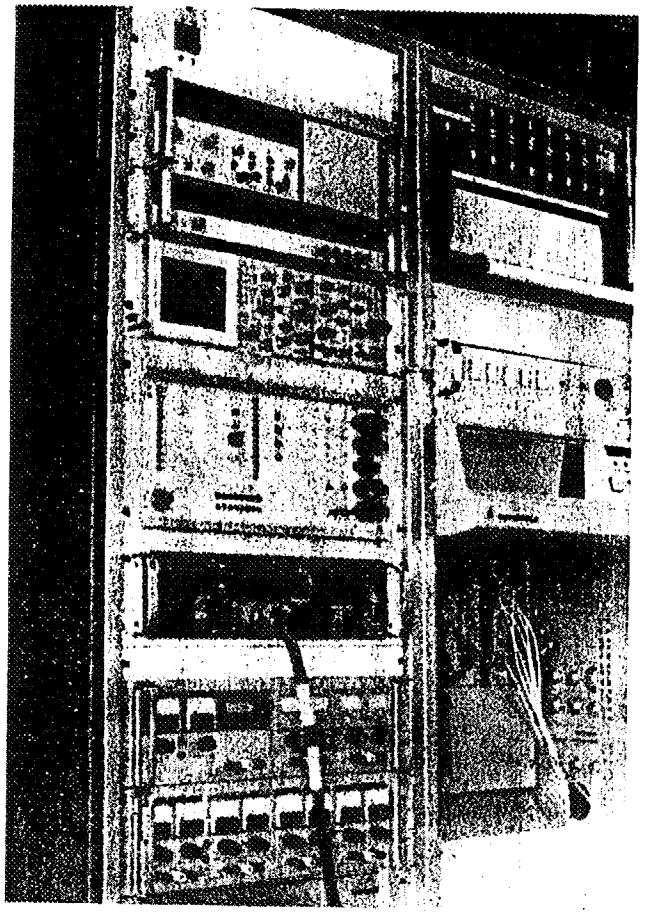


Figure 25

INTERIOR OF TRAILER SHOWING
DIAGNOSTIC EQUIPMENT

From the directional sub:

Instrument voltage

Instrument temperature

Vibration

Hole position (drift, azimuth, and tool face)

Commands received response

From the downhole sensor package:

Motor voltage

Differential mud pressure

Annulus mud temperature

From surface sensors:

Depth of hole and penetration rate

Mud pressure

Mud flow rate

Motor current

The motor temperature and gamma count measurement channels failed to function during the downhole test due to electronic component malfunctions in the downhole telemetry module. Both channels performed perfectly after the failed electronic components were replaced after the test.

The following drilling parameters were printed out at a preselected rate in the data analysis trailer (Figure 27).

Well data (lease and drilling company in formation)

Date

Time of day

Well depth

Penetration rate

Well position (drift, azimuth, tool face)

Motor temperature

Instrument temperature

Annulus mud temperature

Motor current

Annulus/drill pipe pressure differential

Surface mud pressure

Surface mud flow rate

Gamma count

Drill string hang weight

Motor RPM

Display formats for this data are shown in Table 2 and 3 and an explanation of the display abbreviations is presented in Table 4.

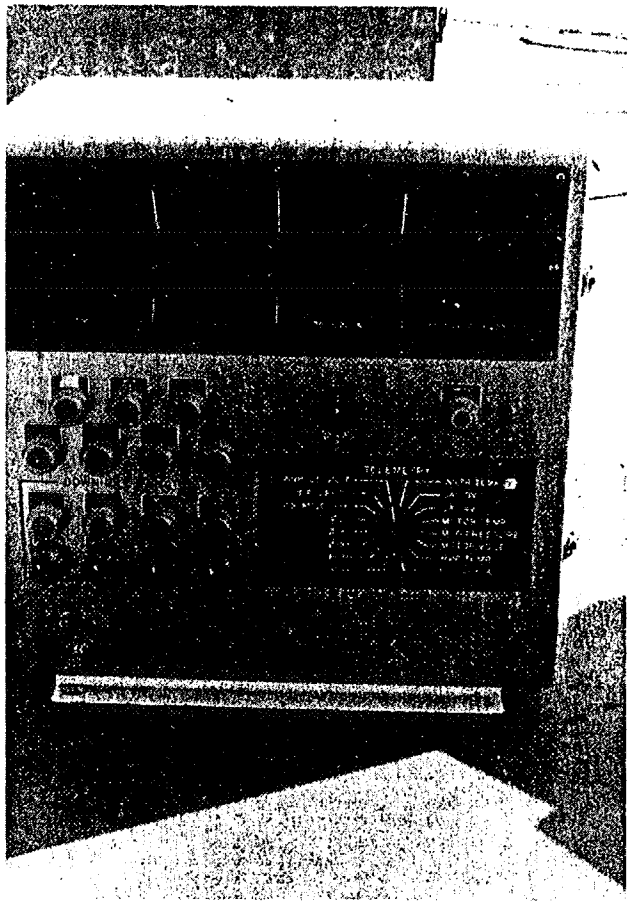


Figure 26

ELECTRODRIL CONTROL & DISPLAY UNIT

Figure 27

INTERIOR OF DATA ANALYSIS TRAILER SHOWING PRINTOUT DEVICES

DATA LOGGER PRINTOUT OF DOWNHOLE INFORMATION

```
DATE?  -  MM/DD/YY,HH:MM  -  11/07/78,18:53
COMPANY?  -  GENERAL ELECTRIC
FIELD?  -  BROWN OIL TOOL
LEASE?  -  BOT
WELL NO.?  -  TEST
COUNTY?  -  HARRIS
STATE?  -  TEXAS
MAGNETIC DIP ANGLE?  -  56.7
TRUE NORTH CORRECTION?  -  1
CURRENT DEPTH?  -  1015.9
GAMMA MULTIPLIER?  -  1
GAMMA CORRECTION RATIO?  -  1
MUD PUMP DIAMETER?  -  7
MUD PUMP STROKE LENGTH?  -  6
NO. MUD PUMP CYLS?  -  2


 COMPANY: GENERAL ELECTRIC FIELD: BROWN OIL TOOL   LEASE: BOT
 WELL NO: TEST COUNTY: HARRIS          STATE: TEXAS          DATE: 11/07/78

TIME   DEPTH  PEN DRFT AZMTH TFACE MTR INS ANN MTR DPRS SURF VOL GMMA HANGWT SPD
HR:MN  FEET   F/H DEG   DEG   DEG  DGF DGF DGF AMP PSI  PSI  GPM CNT  POUNDS RPM

P,15
13:55 01015.9 000 00.2 180.5 000.0-401 059 084 000 0032 0508 *43 0000 000000 000
13:55 01015.9 000 00.2 180.5 000.0-401 059 084 000 0032 0520 472 0000 000000 000
13:55 01015.9 000 00.1 180.5 000.0-400 059 084 000 0035 0571 520 0000 000000 000
13:55 01015.9 000 00.1 180.5 000.0-400 059 084 000 0035 0537 504 0000 000000 000

13:56 01015.9 000 00.0 180.5 000.0-401 059 084 000 0032 0513 328 0000 000000 000
13:56 01015.9 000 00.1 180.5 000.0-400 059 084 029 0032 0518 472 0000 000000 002
13:56 01015.9 000 00.2 180.5 000.0-401 059 084 022 0035 0518 472 0000 000000 065
13:56 01015.9 000 00.1 180.5 000.0-400 059 084 021 0038 0518 496 0000 000000 088
13:57 01015.9 000 00.3 180.5 000.0-401 059 084 022 0035 0569 456 0000 000000 095

13:57 01015.9 000 00.2 180.5 000.0-401 059 084 022 0035 0544 464 0000 000000 097
13:57 01015.9 000 00.2 180.5 000.0-401 059 084 022 0029 0527 448 0000 000000 097
13:57 01015.9 000 00.2 180.5 000.0-401 059 084 022 0032 0571 536 0000 000000 097
13:58 01015.9 000 00.0 180.5 000.0-400 059 084 021 0035 0542 472 0000 000000 097
13:58 01015.9 000 00.0 180.5 000.0-401 059 084 022 0029 0530 416 0000 000000 098

13:58 01015.9 000 00.1 180.5 000.0-401 059 084 023 0029 0537 504 0000 000000 129
13:58 01015.9 000 00.2 180.5 000.0-401 059 084 024 0035 0552 512 0000 000000 173
13:59 01015.9 000 00.2 180.5 000.0-401 059 084 024 0035 0513 528 0000 000000 197
13:59 01015.9 000 00.0 180.5 000.0-400 059 084 024 0041 0564 560 0000 000000 203
13:59 01015.9 000 00.1 180.5 000.0-400 059 084 024 0041 0540 528 0000 000000 203

13:59 01015.9 000 00.2 180.5 000.0-401 059 084 024 0032 0520 456 0000 000000 205
19:00 01015.9 000 00.1 180.5 000.0-400 059 084 024 0035 0520 512 0000 000000 205
19:00 01015.9 000 00.0 180.5 000.0-400 059 084 024 0035 0505 480 0000 000000 205
19:00 01015.9 000 00.2 180.5 000.0-401 059 084 024 0038 0522 448 0000 000000 205
19:00 01015.9 000 00.0 180.5 000.0-400 059 084 022 0035 0515 488 0000 000000 166

19:01 01015.9 000 00.1 180.5 000.0-400 059 084 021 0041 0508 472 0000 000000 121
19:01 01015.9 000 00.1 180.5 000.0-400 059 084 022 0041 0515 392 0000 000000 105
19:01 01015.9 000 00.0 180.5 000.0-400 059 084 021 0035 0554 456 0000 000000 101
19:01 01015.9 000 00.2 180.5 000.0-401 059 084 022 0032 0530 488 0000 000000 099
19:02 01015.9 000 00.1 180.5 000.0-400 059 084 022 0041 0510 416 0000 000000 099

19:02 01015.9 000 00.2 180.5 000.0-401 059 084 020 0035 0557 480 0000 000000 087
19:02 01015.9 000 00.3 180.5 000.0-401 059 084 020 0032 0500 528 0000 000000 059
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19:03 01015.9 000 00.1 180.5 000.0-400 059 084 000 0035 0549 528 0000 000000 026
19:03 01015.9 000 00.2 180.5 000.0-401 059 084 000 0032 0554 456 0000 000000 003

19:03 01015.9 000 00.2 180.5 000.0-401 059 084 000 0032 0518 456 0000 000000 002
19:03 01015.9 000 00.0 180.5 000.0-400 059 084 000 0035 0515 440 0000 000000 002
19:04 01015.9 000 00.2 180.5 000.0-401 059 084 000 0032 0562 472 0000 000000 002
19:04 01015.9 000 00.2 180.5 000.0-401 059 084 000 0032 0515 424 0000 000000 002
19:04 01015.9 000 00.1 180.5 000.0-400 059 084 000 0035 0515 424 0000 000000 002
```

Table 2

Typical Electrodril Strip Recorder Traces

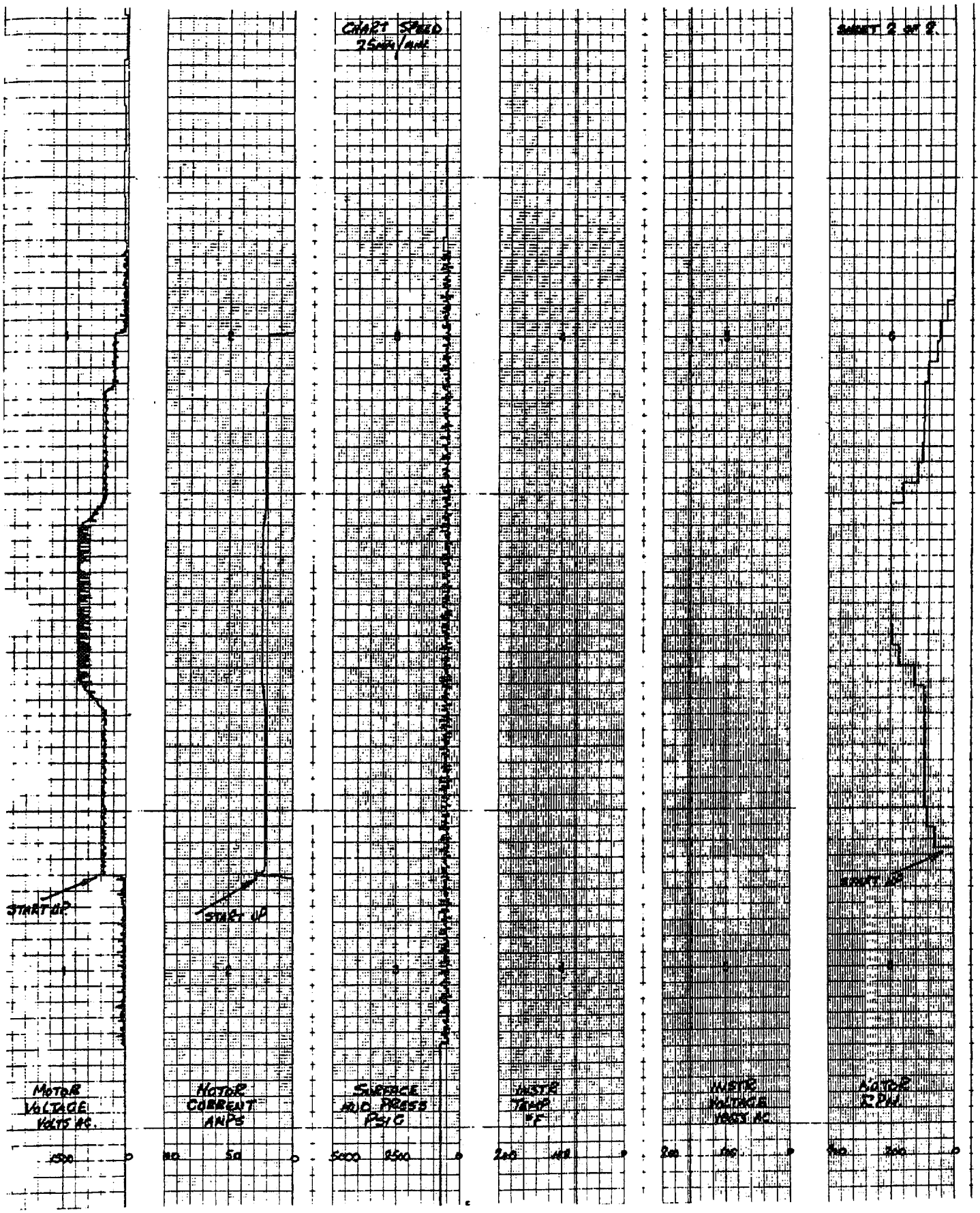


Table 3

Electrodril Instrumentation Data Logger - Explanation of Column Headings

1. "TIME" - local time in hours and minutes
2. "DEPTH" - hole depth in feet
3. "PEN" - penetration rate in feet per hour, averaged over a selected time period. Time period may be changed at will.

DIRECTIONAL PARAMETERS

4. "DRFT" - drift in degrees from vertical
5. "AZMTH" - azimuth in degrees from North
6. "TFACE" - tool face in degrees from North or hole top side or hole bott Reference is selectable

---

7. "MTR" - motor temperature in degrees F
8. "INS" - instrumentation temperature in degrees F
9. "ANN" - mud temperature in the annulus in degrees F
10. "MTR" - current drawn by motor in amps
11. "DPRS" - Δ pressure. Difference between mud pressure in the drill pipe and in the annulus in psi.
12. "SURF" - mud pressure at the circulating head in psi.
13. "VOL" - mud flow rate in gallons per minute.
14. "GAMMA" - gamma log
15. "HANGWT" - system weight in pounds
16. "SPD" - bit speed in RPM

Table 4

The motor temperature and formation gamma count printouts were erroneous since the corresponding downhole measurement channels failed. Also, the drill string hang weight indication was zero since the hang weight sensor did not arrive by test time.

POWER GENERATION

The power generation subsystem for the Deep Drilling System consists of a rented diesel/electric generator (Figure 28) whose output is 440 V AC at 60 Hz. The generator output is fed into a static inverter, the output of which varies dependent upon the selected excitation frequency. The output of the inverter is put through a multitapped transformer (Figure 29) which boosts the output voltage to that required for driving the downhole motor. The on-off control for this system is located in a stand alone drillers console (Figure 30).

The sensitivity of this subsystem to fluctuating motor demands has been exhaustively evaluated and is reported on in Appendix D. These tests were conducted months before the Systems Verification Test at Brown Oil Tools and it remained only to determine the extent of interference, if any, that power switching spikes from the inverter had on the downhole instrumentation.

In general, the power generation subsystem performed very well. No instrumentation data dropouts due to power spikes were recorded. No tests had to be aborted due to failures in the subsystem. Some instability problems were experienced early in the test program at frequencies above 90 Hz. These problems were eliminated however by tuning the control circuits in the inverter.

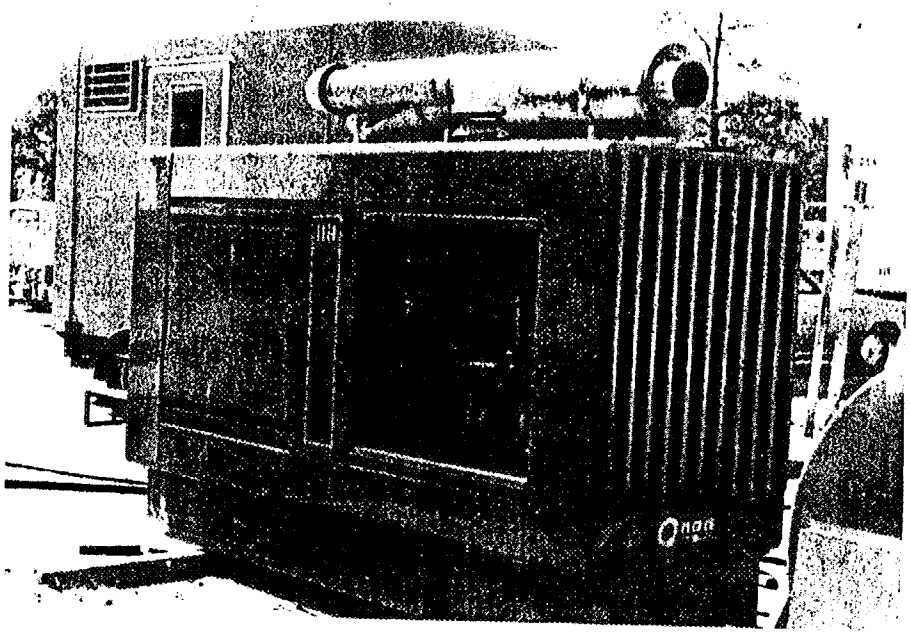


Figure 28

DIESEL POWER GENERATION UNIT

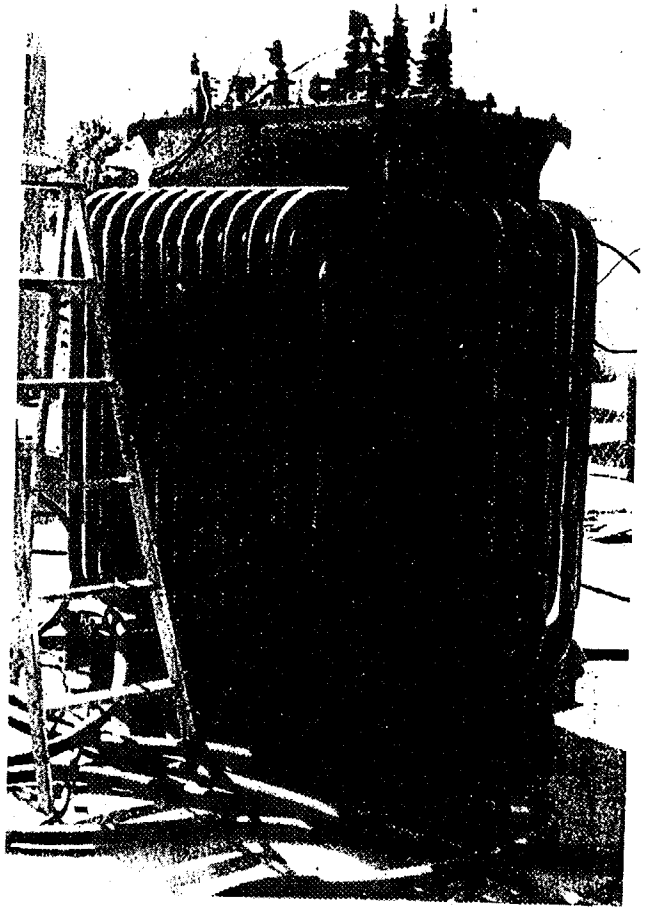


Figure 29

ELECTRODRIL OUTPUT TRANSFORMER

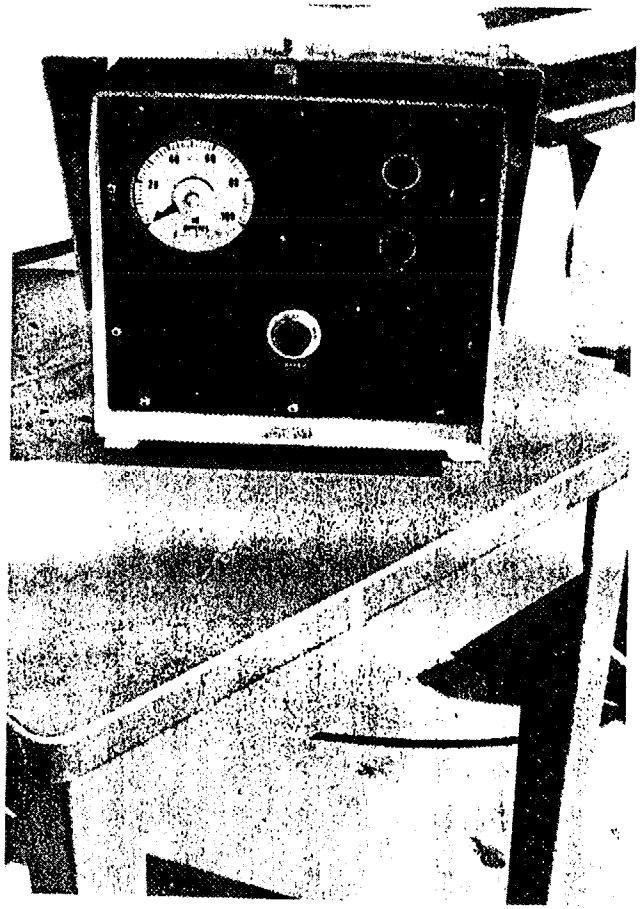


Figure 30

ELECTRODRIL DRILLERS CONSOLE

7.0 CONCLUSIONS

In general, it can be concluded that the Electrodril Deep Drilling System Verification Test program was a success. It can thus be further concluded that the system is ready for field deployment and drilling demonstrations so that drilling performance under operating conditions and the economic viability of the system can be evaluated.

All the system elements of the Deep Drilling System were exercised and evaluated during the Systems Verification Test program. The motor/bit shaft combination, in its newly designed configuration, demonstrated that its seal performance exceeded the design goals. In addition, the oil compensation system demonstrated a useable life between maintenance of at least 100 hours.

The rig floor system performed much better than expected as the flexural characteristics of the power cable exceeded expectations. The ability of the cable/connector combination to traverse the upper and lower cable sheaves reduced cable deployment time enormously.

The power generation equipment supported the test program without failure. Although some instability problems were experienced early in the 100 hour bit shaft test at 90 Hz, subsequent tuning of the inverter control circuits eliminated the problem.

The newly designed and expanded instrumentation subsystem gave an impressive display after an early electronic component failure had been rectified. Further design modidications have been included to enhance the reliability of the system.

The ability to fish the power cable from the drill string was demonstrated and thus eliminated a major concern of some potential clients. It should be noted also that this demonstration is the first of its kind for electric drilling motors, the Russians and French both being unable to fish their power cable because of the method used to suspend it in the drill string.

Numerous cable deployments and motor "bumpings" were demonstrated to industry representatives during the last few days of the Systems Verification Tests. The concensus was that the deployment time had been reduced significantly from the first Phase I demonstration. The rig hands, which had been the crew during the Phase I test series, remarked how much easier the rig floor system was in handling and expressed the view that "new" crews would experience little difficulty in safely picking up the deployment technique.

APPENDIX A

SYSTEMS DESCRIPTION

SYSTEM DESCRIPTION

A schematic of the Deep Drilling System is shown in Figure 1. The System is composed of both downhole and surface components. The downhole components consist of an electric drill motor and its mechanical assemblies; cable and connectors; and the instrumentation assembly. The surface components consist of cable skids; power generation equipment; cable handling equipment; power control equipment; and the telemetry, instrumentation, surface processing, display and control unit. These surface components are generally deployed at a rig site in a manner similar to that shown in Figure 2.

The surface and downhole components have been structured in the Deep Drilling System (DDS) to permit their addition in modular fashion to standard rotary drilling rigs depending upon the objectives of the operator of the rig and the configuration of the equipment at the well site. The system's installation and operating procedures have been designed to be compatible with existing rigs and conventional drilling operations.

The DDS is divided into four basic subsystems, each of which is described in the following test.

POWER GENERATION SUBSYSTEM

This subsystem is the power plant for the total Deep Drilling System. The power requirement increases with well depth. It is not considered practical to utilize rig electrical power. In addition to providing

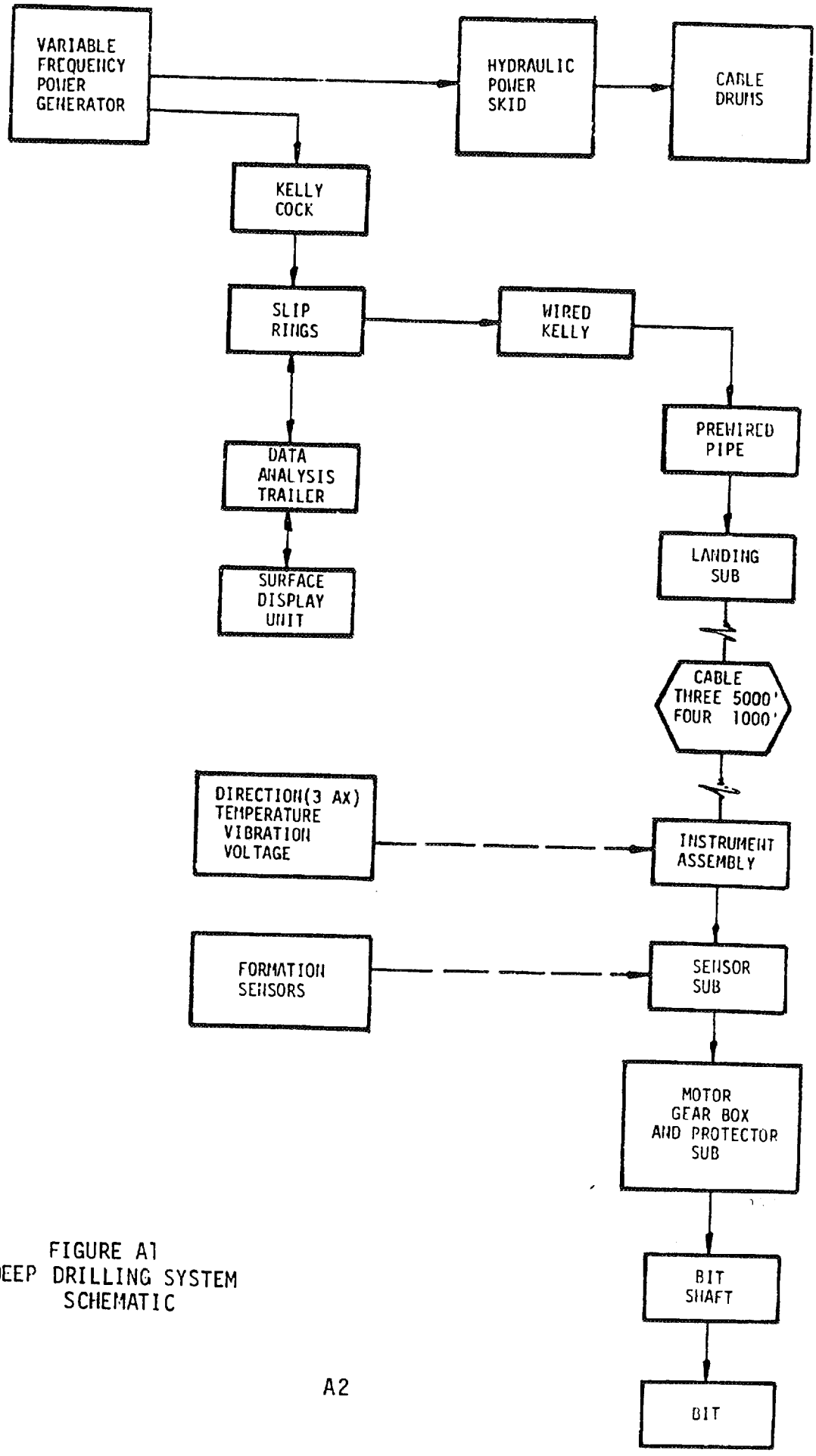


FIGURE A1
DEEP DRILLING SYSTEM
SCHEMATIC

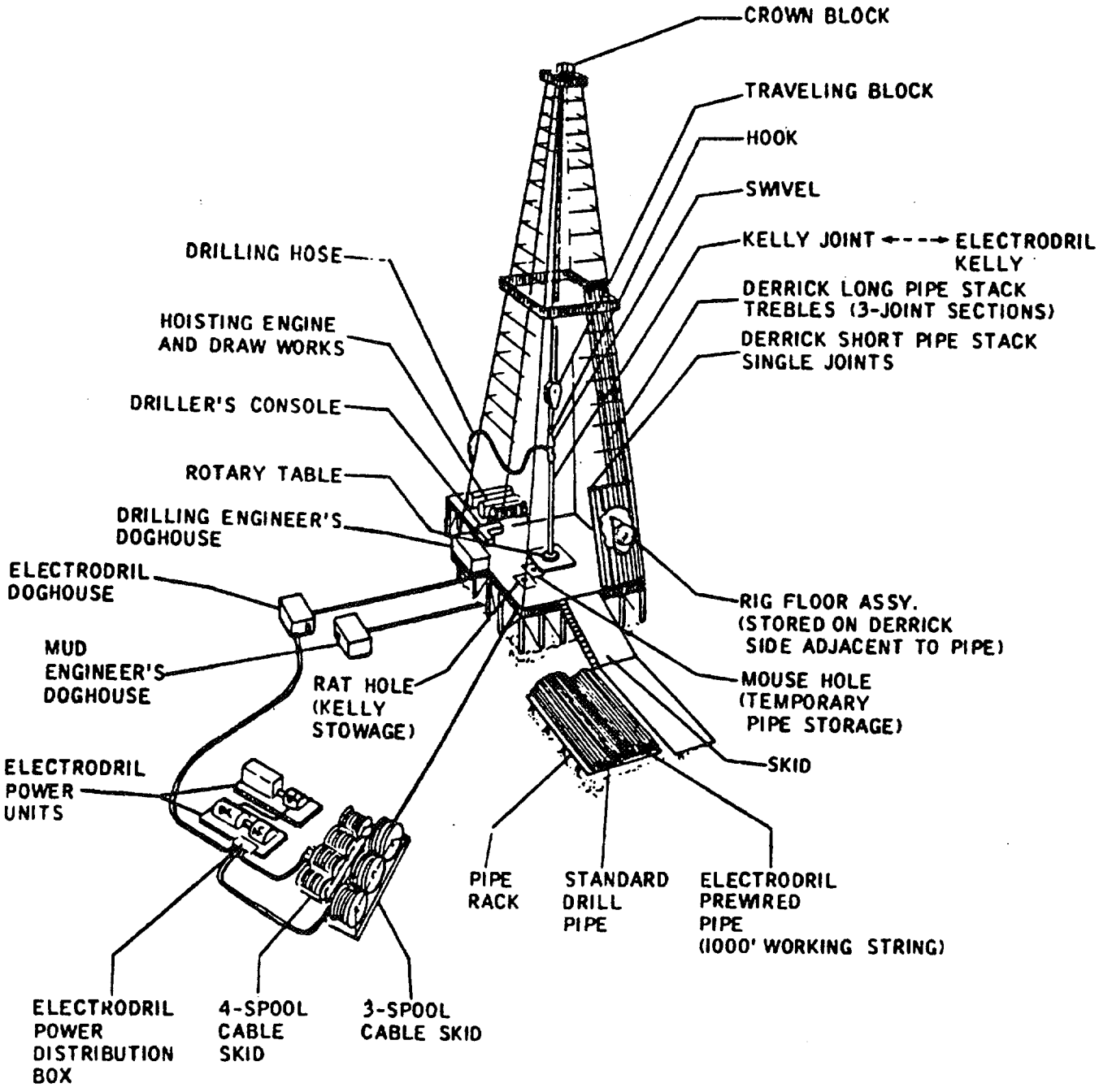


FIGURE A2
SURFACE ELEMENTS
DEEP DRILLING SYSTEM

power for the Electrodril motor, this subsystem provides all auxiliary electrical power (DC and AC) in support of the DDS and includes all the controls, inverters, converters and safeguards to assure correct system performance.

The Electrodril Deep Drilling System power requirements are essentially as follows:

Primary Power:	240V to 3300V, 3Ø, with variable AC frequency ranging from 12 to 120 Hz. Continuous current rating from 22 to 75 amps.
Secondary Power:	208V, 3Ø, 60Hz AC
	110V, 1Ø, 60Hz AC

The satisfaction of these power requirements will be accomplished by the use of a diesel prime mover driving an AC alternator to produce 440V, 60Hz. The 440V AC output is then applied to a static inverter which converts the AC to DC and subsequently "chops" the DC output at varying rates, upon demand, to create variable frequency "pseudo" AC. Control for the DC "chopping" is developed from inputs from the downhole current and voltage sensors. A schematic of this power generation approach is presented in Figure 3.

The power generation scheme is a "demand response" system and as such its relative ability to respond quickly to the power requirements of the Electrodril motor is key to its selection. Given power demand situations in which the power spectra fluctuate rapidly, as in the case for the DDS, the inherent inertia of the familiar "rotary"

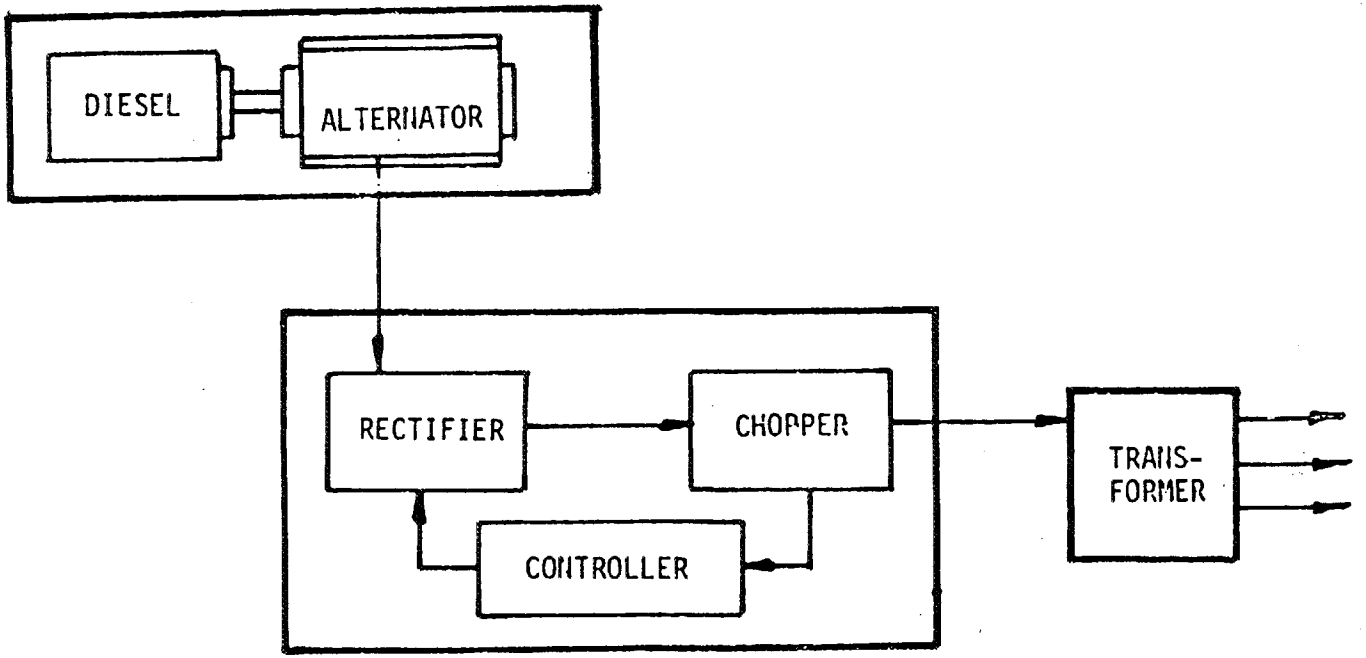


FIGURE A3
STATIC INVERTER POWER GENERATION

system makes it appear unsuitable for Electrodril application. The static inverter system is able to respond to power fluctuations, but the supporting downhole sensory system and surface controllers must be capable of sensing demand and switching frequency levels at a high response rate.

CABLE AND HANDLING SUBSYSTEM

This subsystem consists of the cable, cable reels, connectors, slip rings and devices for the deployment of control of same. This subsystem, of necessity, maintains a flexible configuration as it is the details of the drill rig floor and derrick that dictate to a major extent what subsystem elements are deployed. The number of cable reels used, for example, is dictated by how deep the well is at the time of Electrodril deployment and to what depth the system will be required to drill. A general layout of this subsystem at a typical rig site is shown in Figure 4 and consists of the powered cable spools for deploying the electrical cable downhole and the rig floor system which is designed to facilitate cable deployment in and out of the well and to accommodate the rotating/non-rotating environment surrounding the drill string.

RIG FLOOR ASSEMBLY. The technique for deploying the cable at the rig floor differs from that used in the Phase I Directional System in that the Deep Drilling System is required to provide means for drill pipe rotation to obviate the potential for differential sticking. Pipe rotation will be achieved using the conventional rotary table/kelly combination. Electrical connection to the downhole cable (rotating) and the surface cable (non-rotating) is made through a slip ring assembly located below the rig

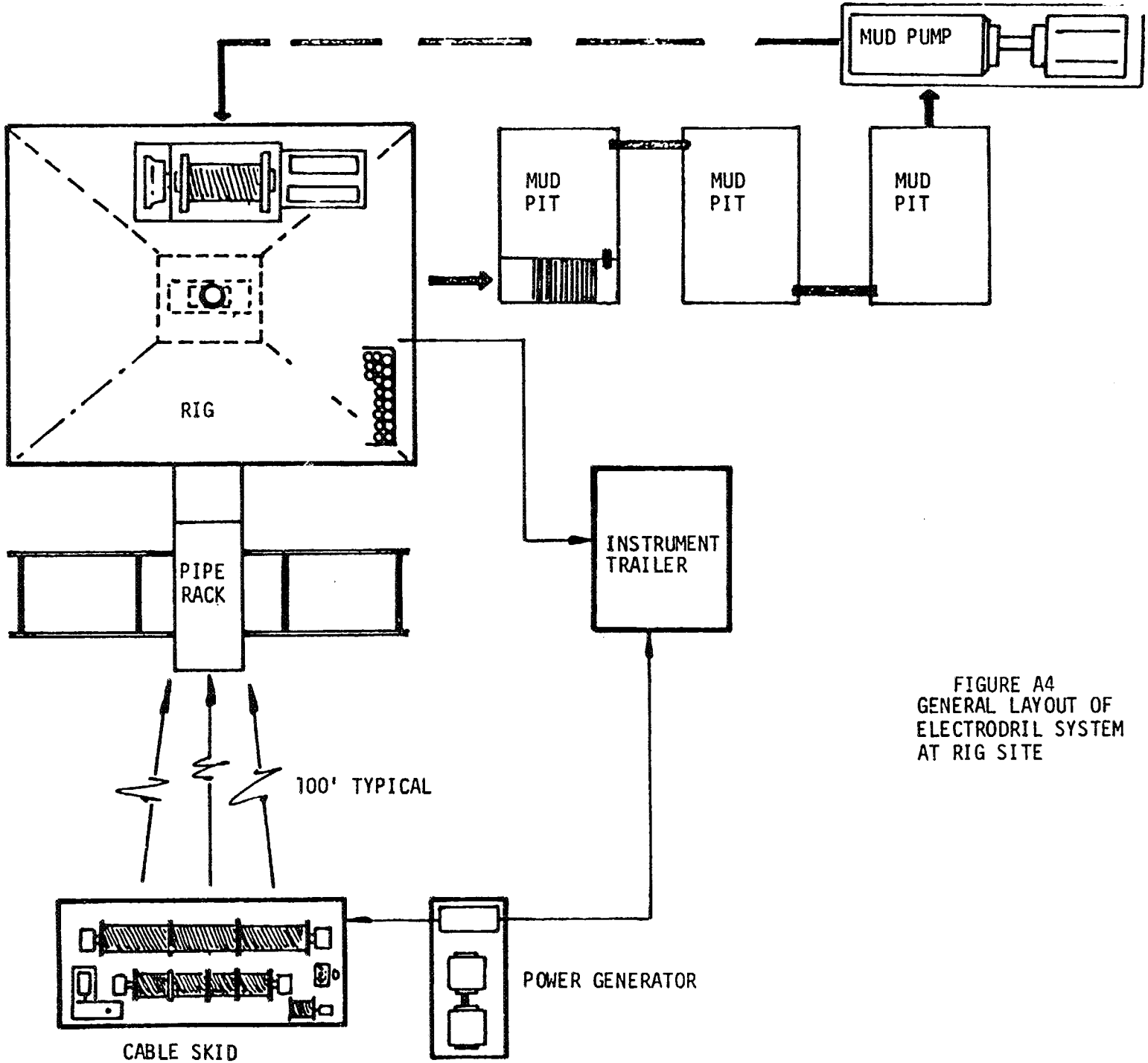


FIGURE A4
GENERAL LAYOUT OF
ELECTRODRIL SYSTEM
AT RIG SITE

power swivel (Figure 5). Mud circulation will be made in the conventional manner through a circulating head above the power swivel. A kelly cock will be inserted between the circulating head and slip ring assembly to provide hydraulic safety.

The hole will be drilled ahead 90 feet, utilizing two prewired dedicated joints of drill pipe and the prewired kelly. These will then be removed and replaced with a 90-foot stand of prewired pipe. This sequence will be repeated 10 times (a total depth of 1000 feet) at which time the prewired pipe is withdrawn and substituted with standard drill pipe and 1000 feet of cable. This prewired pipe is utilized in place of standard drill pipe for the first 1000 feet to maintain electrical continuity with the deployed downhole lengths of Electrodril cable during drilling operations. Each succeeding 1000 feet of hole is drilled in a similar manner to a depth of 5000 feet, at which time the prewired pipe is replaced with standard drill pipe and a 5000 foot length of Electrodril cable is mated downhole with the previously deployed cable. An electrical crossover sub located below the slip ring assembly allows the transition of the electrical cable from inside the drill pipe bore to the outside of the slip ring assembly.

CABLE AND CONNECTORS. The Electrodril cable requires a total of four conductors as shown in Figure 6. To supply downhole electrical power to the motor, three conductors of No. 6 AWG will be used. A smaller center conductor of No. 18 AWG will be used for instrument power and data transmission. The cable will be composed of multistranded conductors to assure cable flexibility and will be housed in a double

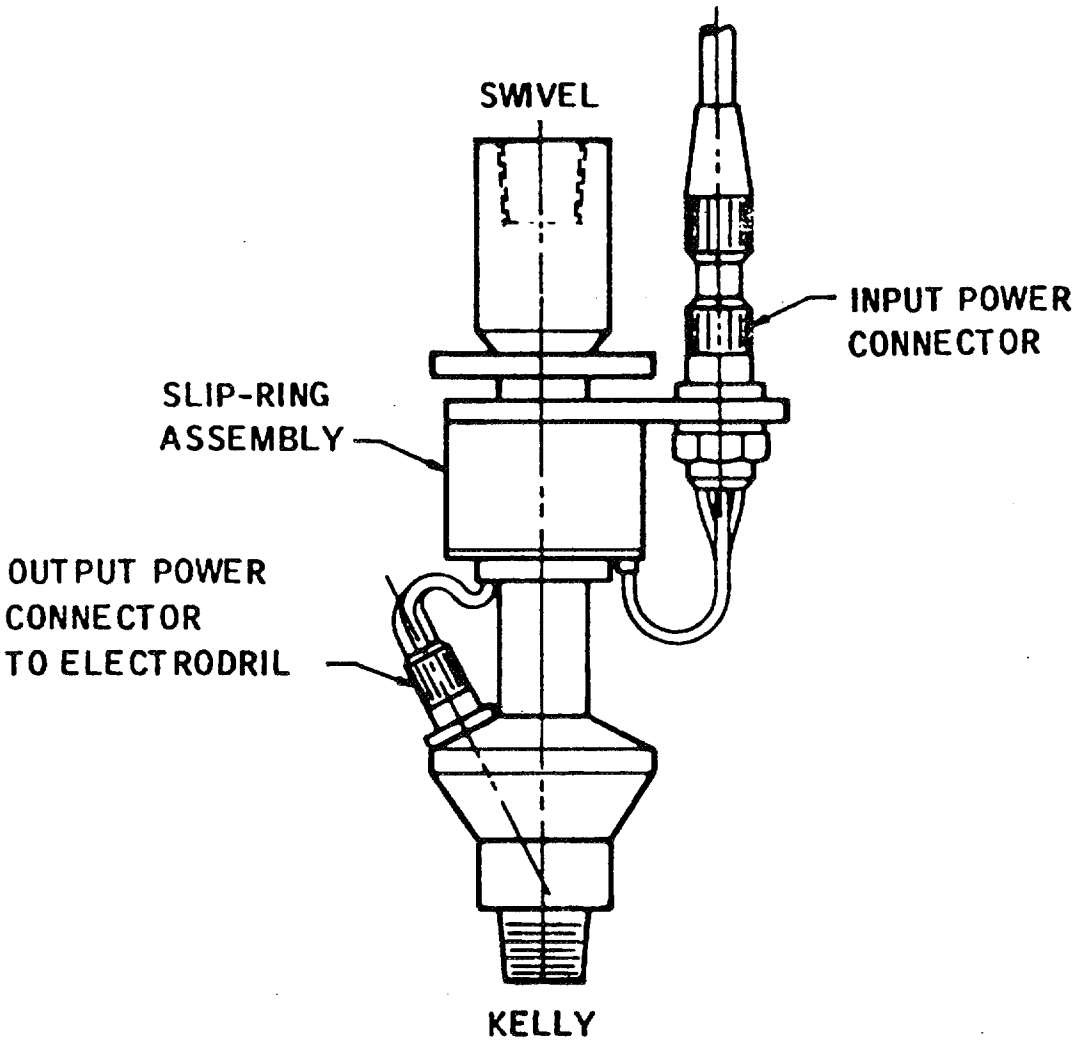


FIGURE A5
ELECTRODRIL SLIP RING
ASSEMBLY

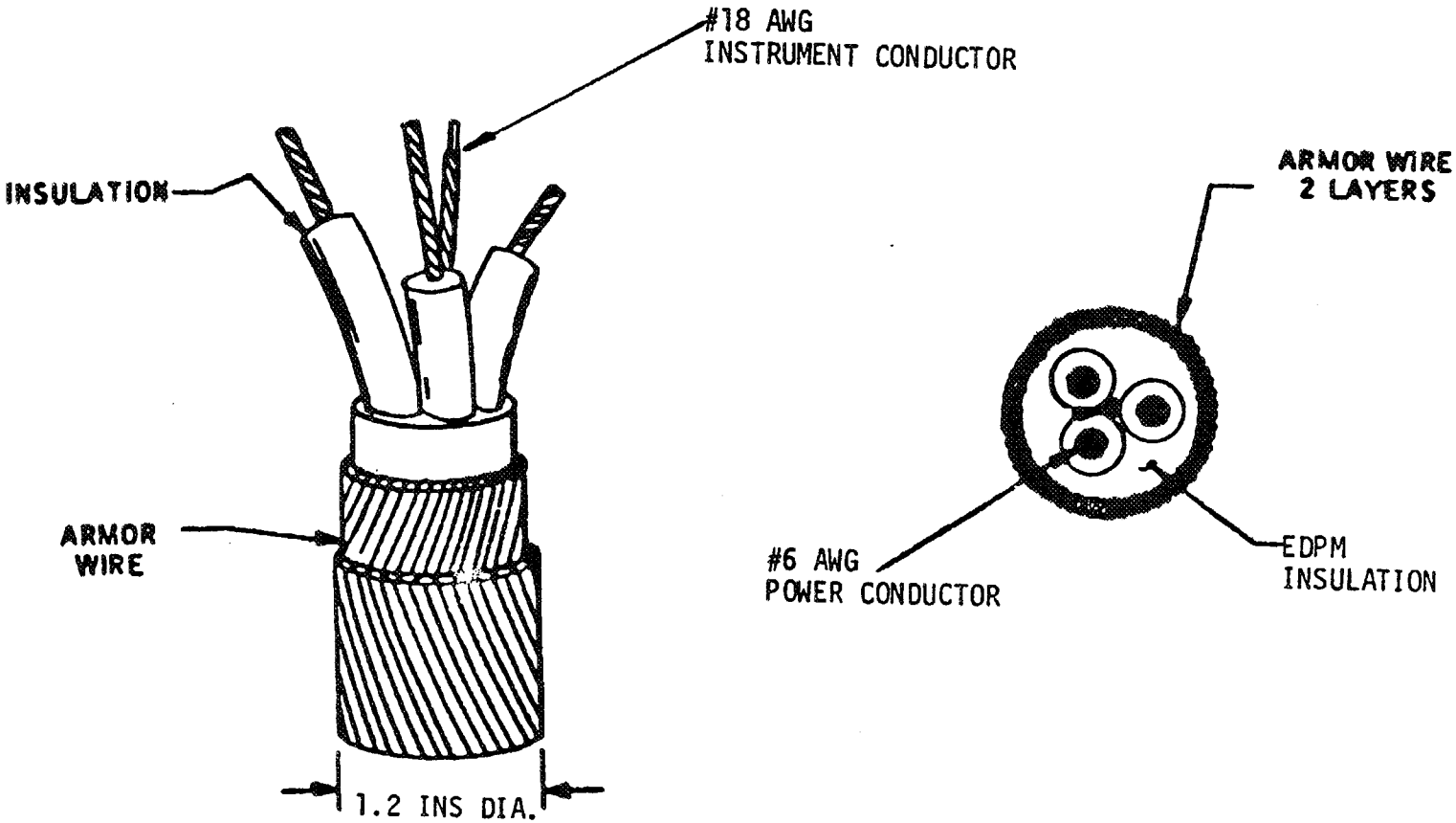


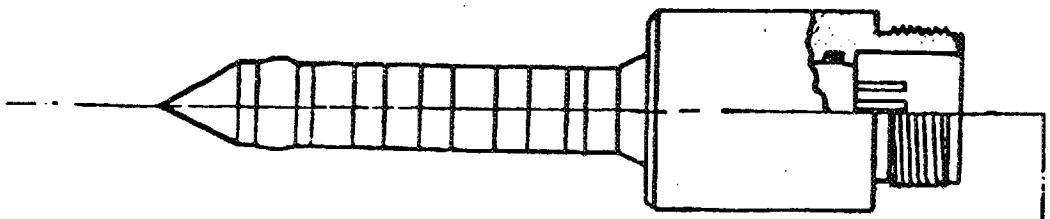
FIGURE A6
ELECTRODRIL DEEP DRILLING SYSTEM
POWER CABLE

layer of torque balanced steel armoring to carry the weight of the cable and provide a return for the instrument power. The cables are connected through specially designed field replaceable connectors (Figure 7) which allows easy assembly of the cable sections while providing high electrical reliability. The cable is supported in the drill pipe by cable hangers which provide cable stability during drilling operations. The hanging weight of the suspended cable is less than 20% of the cable breaking strength.

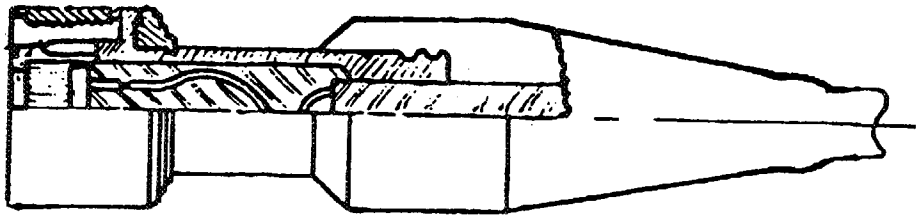
CABLE REELS. The cable reels to be used for the DDS will be required to accommodate a total of 19,000 feet of cable. This will be accomplished using cable reel skid as shown in Figure 8. A total of five reels will be required to hold the 19,000 feet of cable; three 5,000 foot cable reels, and two duplex 1,000 foot reels. In an effort to minimize "open hole" time, cable reel speed has been increased to a maximum of 300 ft/min. This speed appeared to be the maximum practical before hydraulic horsepower and cable strength requirements became prohibitive. Cable bedways on all the reel drums have been incorporated to minimize the lower cable tier crush loads.

MOTOR SYSTEM

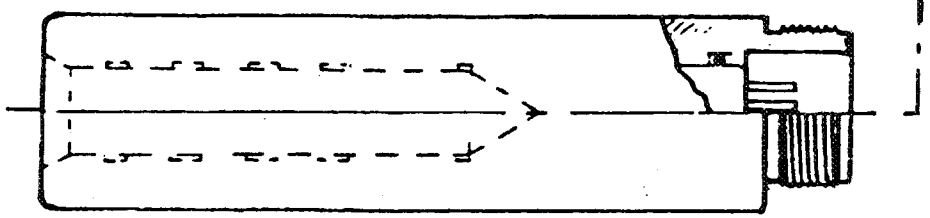
This subsystem contains the downhole drilling elements such as the bit, bit shaft and motor with gearbox. The correct preparation of this subsystem prior to downhole deployment is key to its operational life. The adjustment of pressure compensation bags and gearbox seal lubrication, for example, have marked effects on the motor's downhole life prior to withdrawal and refurbishment. The Phase II Electrodril motor system, excluding the deviation sub and monel collar for the instrumentation,



MALE



CABLE ADAPTER



FEMALE

FIGURE A7
ELECTRODRIL FIELD
REPLACEABLE CONNECTOR

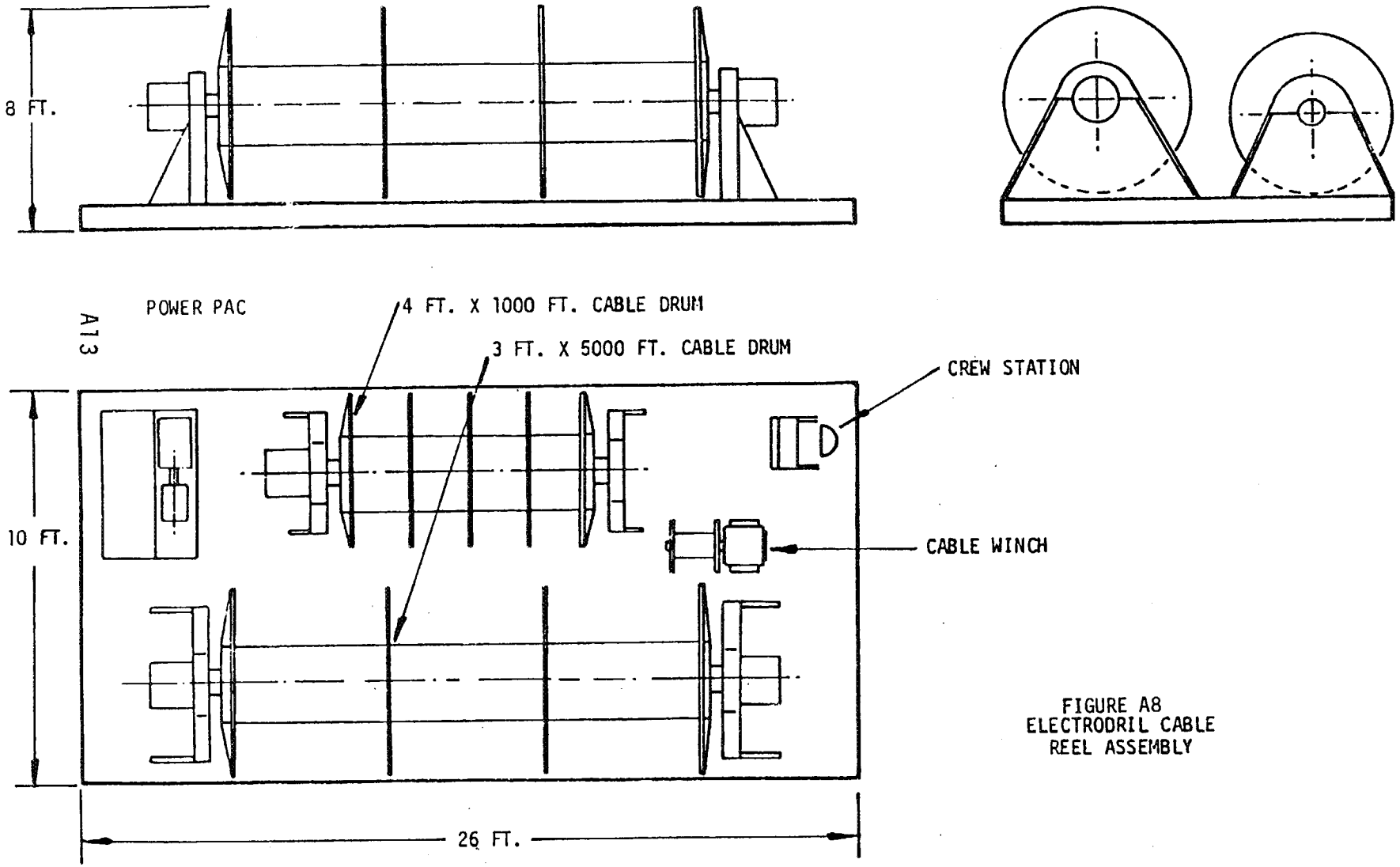


FIGURE A8
ELECTRODRIL CABLE
REEL ASSEMBLY

is a total of 51 feet in length. A breakdown of this assembly, together with pertinent dimensions, is shown in Figure 9. The motor subsystem is electrically protected at the surface. In the event of an overload situation, current sensors will trip the power generation circuit breakers to prevent motor damage. Motor temperature will be sensed downhole and displayed at the surface.

MOTOR

The Phase II Electrodril motor is centered around a standard industrial Reda type 540 submersible pump motor nominally rated at 150 HP at 60 Hz and 1150 volts. At this rating the motor has a speed of 3200 rpm. The motor has been designed to operate over a frequency range of from 30 to 120 Hz. At the low end, the motor is rated at 35 HP at 12 Hz and 230 volts. At the high end, the motor is rated at 285 HP at 120 Hz and 2300 volts. The output of the motor is put through a 16 to 1 reduction gearbox so that the effective speed range for the drilling bit is 40 to 400 rpm.

GEARBOX AND PROTECTOR

The motor gearbox is a double train planetary reduction unit designed and tested to withstand weights on bit of up to 70,000 lbs. and torques in excess of 3,500 lb.-ft. A shock absorber unit is provided to isolate the motor from the shock loads produced by the drilling operation. A slip clutch unit, designed to safeguard the motor in the event the bit is suddenly stopped is also included. Internal oil pressure compensation bags are also provided in this assembly to assure that the internal oil pressure is the same as the mud pressure in the mud tube thus maintaining

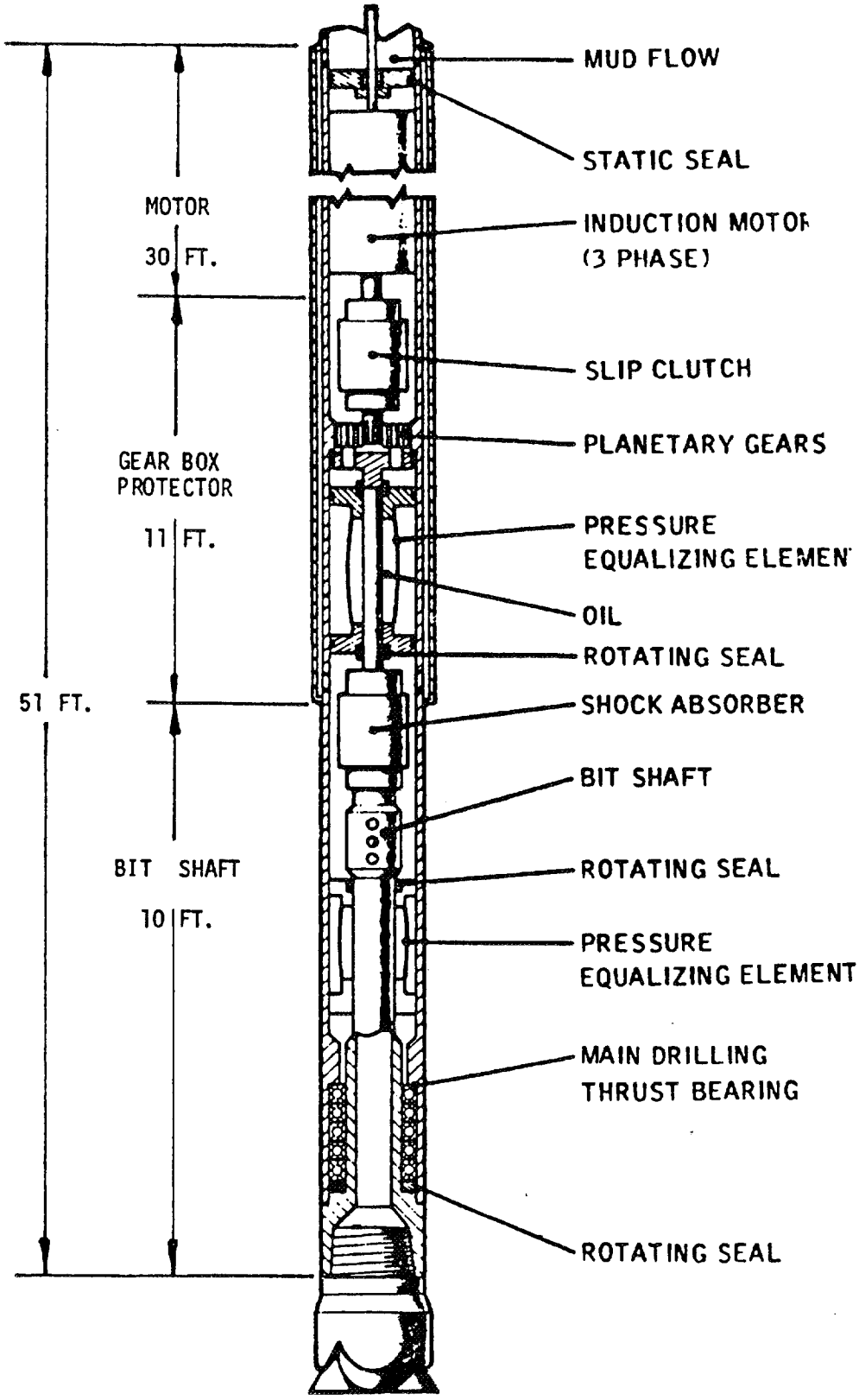


FIGURE A9
285 HP ELECTRODRIL MOTOR ASSEMBLY

A15

an almost zero pressure drop across the lower motor seals. The oil leakage over the lower motor seal is thus held to a minimum and the seal surface wear characteristics are idealized.

BIT SHAFT

The bit shafts used in the Phase I Program will not be used in the Deep Drilling test program as their bearings and seals are inadequate to withstand the higher downhole temperatures and pressures. A new bit shaft has been designed to incorporate metal-to-metal seals capable of withstanding pressure differentials in excess of 2,000 psi and bearings rated to accommodate weights on bit of up to 70,000 lbs. and the more severe downhole environment. In addition, the pressure compensation bag in the new assembly has been designed with sufficient oil capacity to assure lubrication is maintained at least for the life of a diamond bit (i.e. 200 hours). The oil is then replenished each time the drill bits are replaced or at intermediate times when the drill string is removed for other reasons.

INSTRUMENTATION SUBSYSTEM

The Instrumentation subsystem includes all elements of data acquisition, processing, transmission and display. Not all of the data acquired and displayed is from downhole instrumentation. Many Electrodril system parameters are measured at the surface and displayed or recorded. All data received at the data analysis trailer is retrievable. The operational configuration of the data display unit is dictated by the driller's requirements. The instrumentation subsystem block diagram is shown in Figure 10. It remains functionally the same as that demonstrated during

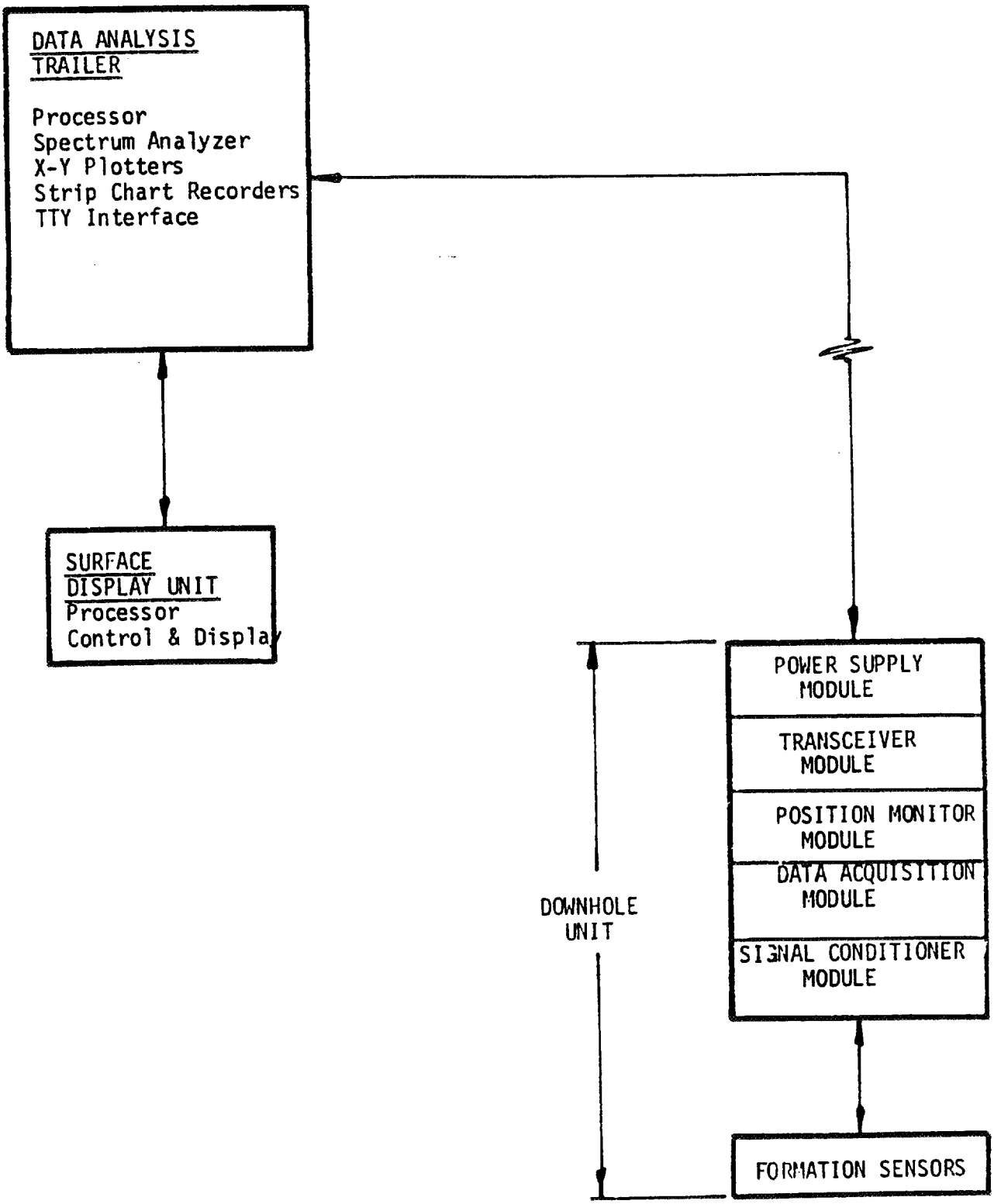


FIGURE A10
ELECTRODRIL PHASE II
INSTRUMENTATION SUBSYSTEM

the Phase I Program. A basic groundrule was to utilize as much of the Phase I instrumentation as possible. Modifications to the downhole instrumentation system include replacing the original position monitor with a new GE 3-axis solid state position monitor, replacing the instrument pressure housing with one designed to operate to 20,000 PSI, developing and adding a sensor package which contains three formation/drilling parameters and adding a motor temperature sensor. More sensors could have been included in the sensor package but would have necessitated a significant modification to the instrument itself. The three sensors are sufficient to demonstrate the feasibility of formation sensing while drilling.

Modifications to the surface equipment include addition of a processor/display/recorder system to the data analysis trailer and modifying the driller's console to handle the higher motor current.

DOWNHOLE INSTRUMENT PACKAGE

The downhole instrument package has been designed to perform the following functions:

1. Receive from the surface 115V AC 60 Hz electric power and convert and distribute same to support the downhole instrumentation.
2. Monitor up to 15 analog plus 11 digital downhole parameters and process (multiplex) this data.
3. Send to the surface processed data in pre-established digital formats.
4. Receive up to 4 commands from surface equipment for execution by downhole auxiliary units.

SURFACE SUPPORT EQUIPMENT

The Surface Equipment receives the downhole data, establishes bit and frame synchronization, checks parity, decides on the data acceptability, performs data transformation, routes and displays data.

The surface equipment transmits commands to the downhole equipment utilizing frequency shift keying of the power source to transmit the data. The correct voltage level downhole is also commanded by the surface equipment and maintained by varying the surface voltage level in proportion to the surface power signal level.

The power supply for the surface equipment utilizes 115 VAC - 60 Hz developed from the Electrodril Power Subsystem. The surface equipment converts this system power to supply the logic and analog power for the surface equipments. The surface equipment power supply also provides the 1000 Hz power for the downhole instruments. Sufficient power is supplied at the surface to assure that 120 volts $\pm$ 12% is received by the downhole unit. The surface support equipment include two data display stations:

1. The display control unit,located on the rig floor in the driller's mud house, displays the three axis hole direction data and has one other display window for other selectable data.

2. The data analysis trailer, where a second microprocessor has been added so that raw downhole data can be decoded, converted, and displayed independently from the rig floor display and control

unit. This feature, which was not available during Phase I, will permit system diagnostics to be performed and enhance the analysis capabilities to support the evaluation of Electro-dril system performance.

APPENDIX B

SYSTEM VERIFICATION TEST PLAN

TEST PLAN

FOR

ELECTRODRIL SYSTEMS VERIFICATION

OF THE

DEEP DRILLING SYSTEM

October 1978

GENERAL ELECTRIC

1.0 OBJECTIVE

The purpose of the Systems Verification Test is to demonstrate the functional compatibility of all the Electrodril system elements and the readiness of the total system to be deployed in operational wells for further evaluation. With the exception of the newly designed bit shaft, the design readiness of the other system elements has previously been demonstrated.

2.0 TEST FACILITY

The Systems Verification test is to be conducted at the Brown Oil Tools,Inc. (BOT) facilities, Houston, Texas. Because of restrictions imposed by the test well configuration, lengths of cable in excess of 1000 feet cannot be hung.

The large derrick will be utilized for the test with the power generation, instrument trailer and cable skid located close to the parking lot facing the rig "V" door. Although a kelly cannot be rotated at BOT, a slip ring assembly and kelly were made part of the Electrodril test configuration because it is anticipated that they will be used in future operational test well sites.

3.0 VERIFICATION TEST REQUIREMENTS

3.1 GENERAL

The Systems Verification Test should be conducted in an orderly and controlled manner to assure that the test data derived is valid and meaningful.

3.2 RATIONALE

The rationale to be followed in this test program is to enter the test well with a minimum Electrodril drill string, to test this baseline system and then add other system elements in a logical sequence. Data will be collected so that procedures can be evaluated and "streamlined" to minimize unproductive rig time in future operational deployments.

3.3 BIT SHAFT

A 100 hour test will be performed to demonstrate the integrity of the newly designed bit shaft. The motor/bit shaft compatibility as well as the capability of the bit shaft to function over the complete speed range of the motor while subjected to a downhole environment will be evaluated. Drill bit hydraulics may be simulated by appropriately plugging its lower end.

3.4 CABLE DEPLOYMENT/CONNECTOR RELIABILITY

Because the ability to reliably make electrical connections in a mud environment is key to a successful system, a series of repetitive cable/connector matings should be made to a submerged motor. After each mating the motor should be "bumped and data collected to evaluate the characteristics of the electrical string.

3.5 CABLE LANDING/PREWIRED KELLY

The motor, with sufficient drill pipe above it, should be deployed so that the 1000-foot cable can be "landed". Data should be collected to allow

determination of cable stretch characteristics as well as drill pipe length tolerance required for cable landing.

After successful landings, the prewired kelly should be joined to the string and the motor turned on. Mud should be circulated at various pressures while the motor is exercised through its power regime.

3.6 DEDICATED PIPE

Dedicated (prewired) joints of drill pipe should be added to the string between the landed cable and kelly after successful completion of Paragraph 3.5. The ability to make mousehole connections to the dedicated pipe should be evaluated. It is this configuration which is to be used to establish the functional reliability of the basic Electrodril Deep Drilling System cable, connectors, kelly and prewired pipe.

3.7 DIRECTIONAL SUB

After successful completion of Paragraph 3.6, the directional sub shall be deployed above the motor. Powering up of the system will provide data to evaluate its ability to sense, process and transmit directional parameters.

3.8 FORMATION SENSOR/HEAT SUB

The ability to provide downhole environment data should be evaluated when the formation sensor/heat sub is added to the string between the directional sub and motor. No attempt should be made to power up the heat sub while it is in cased hole at the BOT facility.

3.9 FISHABILITY

It shall be demonstrated that the Electrodril landed cable can be removed through the drill string bore without removing any pipe. The fishing tool should be capable of latching on to the replaceable male connector while an upward applied force deforms the landing shoe and allows the cable to pass through pipe bores and tool joints on its way to the surface. The fishing tool should be capable of being utilized by fishing contractors.

3.10 SLIP RING ASSEMBLY

It shall be demonstrated that the Electrodril Deep Drilling System can be powered through the slip ring assembly. This would allow the string to be rotated while drilling.

4.0 SYSTEMS DEMONSTRATION

Upon successful completion of the Systems Verification Test, the methods used for deployment, retrieval and fishing should be evaluated by the drill rig crew as well as knowledgeable representatives of industry. Results of the evaluation should be used to streamline future procedures at operational test sites.

APPENDIX C

100 HOUR BIT SHAFT TEST REPORT

ELECTRODRIL

DEEP DRILLING SYSTEM

100 HOUR BIT SHAFT

TEST REPORT

October 1978

GENERAL ELECTRIC

1.0 INTRODUCTION

The bit shaft for the Electrodril Deep Drilling System underwent a complete redesign to improve oil seal life. The chevron type packing previously used did not have adequate service life in a drilling mud environment. Other design goals and specifications for the bit shaft were as follows:

DESIGN GOALS

- 500 hours bearing and seal life
- Ease of assembly and disassembly
- Use of standard bearings and seals
- Keep overall length short as possible

DESIGN SPECIFICATIONS

- Axial loads to 70,000 lbs on drill bit, to 42,000 lbs drill bit hanging weight
- Radial loads to 10,000 lbs
- Temperature, ambient to 500°F
- Pressure differential across bit to 1200 psig (internal pressure higher), to 100 psig (external pressure higher)
- Torque to 3500 foot pounds
- Bit speed 0-600 RPM

Mechanical face seals were selected as the primary oil seals. The lower face seal is pressure balanced designed for pressure differences up to 2500 psig. The upper face seal which is not exposed to a pressure drop is an unbalanced type. The sealing ring and seat for both seals are tungsten carbide.

On the outside (mud side) of both face seals there is a chamber filled with a high temperature grease, with labyrinth seals to slow grease wash out by the drilling mud. The grease in these chambers provides a buffer between the drilling mud and the face seals.

The main thrust bearing is a cylindrical roller bearing with a basic dynamic thrust capacity of 113,000 lbs and a basic static thrust capacity of 231,000 lbs. At 400 RPM and 70,500 lbs on bit the minimum bearing life is 200 hours. The radial bearings are cylindrical roller bearings which have a minimum life of more than 750 hours at 400 RPM and 10,000 lbs radial load. The upper cylindrical roller thrust bearing that takes the hanging loads is more than adequate to meet the design requirements.

The lubrication system for the bit shaft is the same concept as used on the Electrodril motor. Basically it consists of an oil chamber pressurized to the mud pressure within the drill string through a cylindrical shaped elastomer. The usable oil supply is about 1200 cc.

A double cage sprague clutch rated at 4240 ft lbs was included in the bit shaft design. This allows conventional rotary drilling should the need arise. Figures 1 and 2 show fore and aft view of an assembled bit shaft.

2.0 TEST OBJECTIVES

The bit shaft test conducted at Brown Oil Tool was to demonstrate a 100 hour capability of both the motor and bit shaft in a simulated well environment

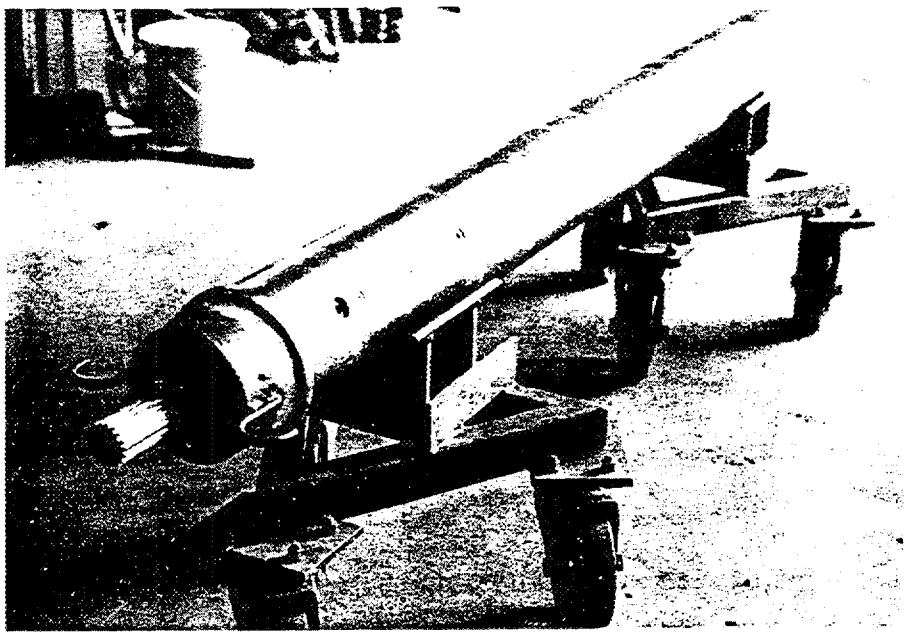


FIGURE C1

BIT SHAFT VIEWED FROM UPPER END WITH LIFTING RING ATTACHED

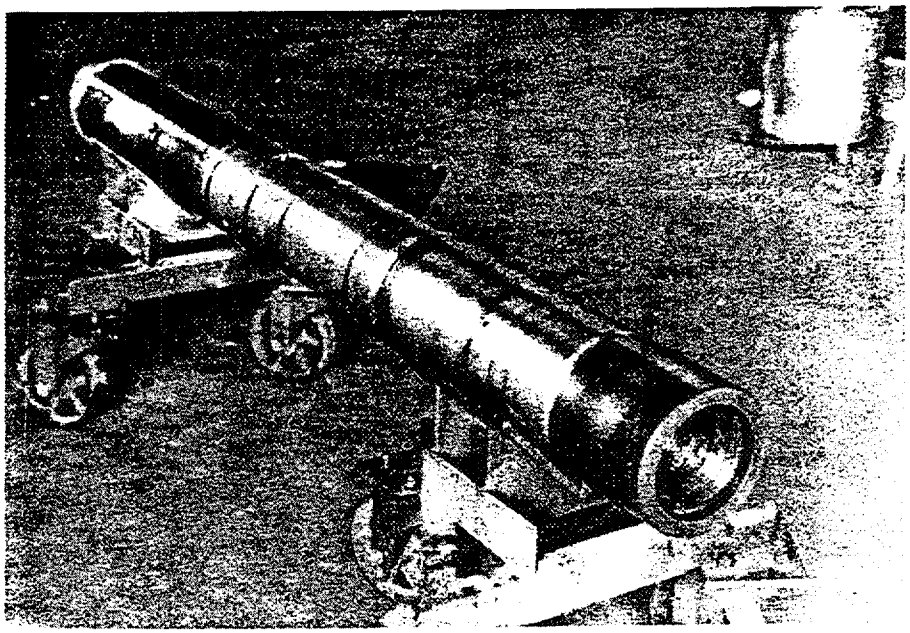


FIGURE C2

BIT SHAFT VIEWED FROM LOWER END

and thus demonstrate readiness of the subsystem for field deployment.

3.0 TEST SUMMARY

The 100 hour bit shaft test was successfully completed during the Electrodril integrated system test. The bit shaft test started on 19 October and was completed on 25 October 1978. Mud pressure during test was generally 650 psig. Bit shaft speeds were varied during the test from 100 to 320 RPM.

The post test inspection of the bit shaft revealed no drilling mud intrusion across the face seals. Lube oil loss during the test was approximately 400 cc. No appreciable seal or bearing wear was noted.

Appendix C1 contains the detailed test report including the initial bit shaft test which started on 18 September and was terminated after 1 1/2 hours when it was noted there was drilling mud in the oil.

APPENDIX C1

100 HOUR BIT SHAFT TEST

DETAILED TEST REPORT

1st BIT SHAFT TEST

The 100 hour test was started on 18 September at Brown Oil Tools. The bit shaft and motor assembly was lowered into the well with two joints of 4 1/2" X hole drill pipe. A cable packoff and circulating head was used to facilitate mud circulation and routing of the motor conductors out of the drill pipe. A bull plug with a 0.5 inch diameter orifice was on the bottom of the bit shaft for mud pressure control.

Due to an electrical hookup problem the motor and bit shaft assembly were pulled from the well after 1 1/2 hours of running. It was then noted that drilling mud was in the bit shaft oil. The test was terminated and the bit shaft returned to the shop for disassembly.

Disassembly revealed that at the time of test termination, mud was entering into the bit shaft oil chamber both through a ruptured oil bag (see Figure 1) and the upper face seal. The mud was exiting the bit shaft oil chamber across the bottom face seal.

The snap ring holding the stationary point of the bottom face seal had failed and allowed the seal faces to part (see Figure 2). When the bottom seal failed the mud pressure drop normally taken across the lower pressure balanced seal was then taken across the unbalanced upper seal which is designed for pressures of no more than 250 psi across the seal. The increased pressure on the seal increased the drag on the faces until the set screws holding rotating part of the face seal to the shaft failed. When the rotating part of the seal stopped, the rotating shaft destroyed the O-ring in the rotating part of the

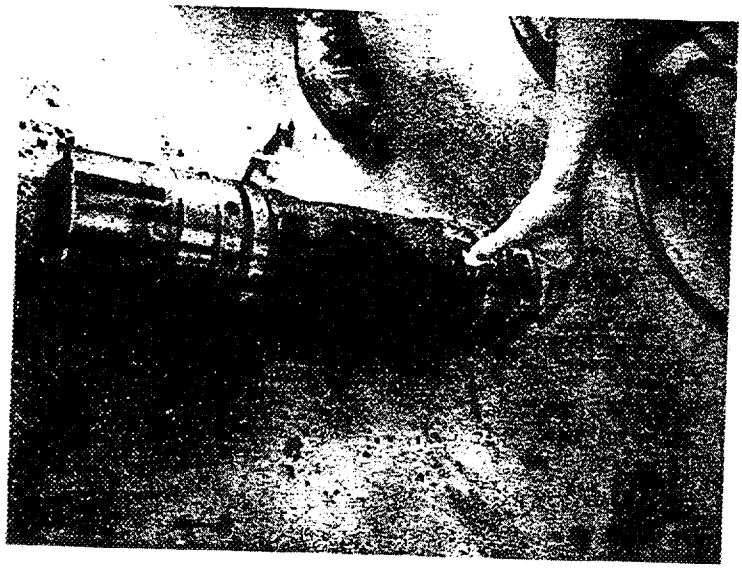


FIGURE C1.1

RUPTURED OIL BLADDER BAG

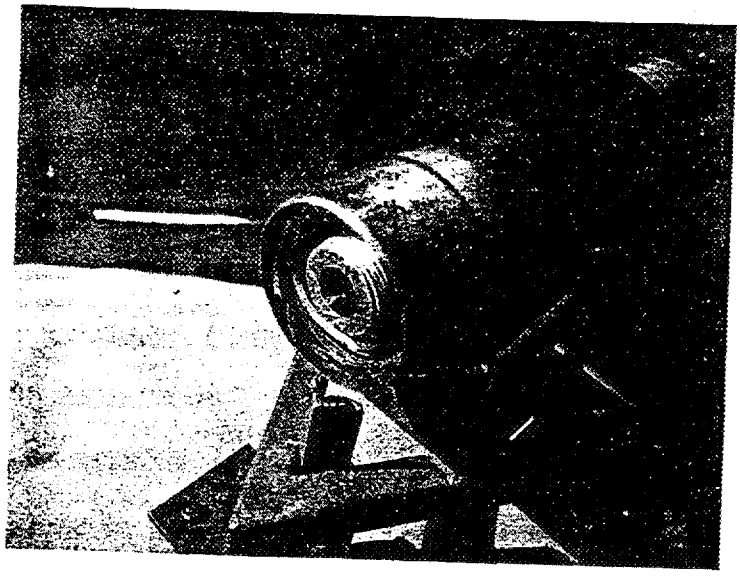


FIGURE C1.2

BOTTOM OF BIT SHAFT SHOWING BROKEN FACE SEAL RETAINING RING

seal and the seal integrity. The oil bladder rupture was a natural result of the increased pressure across the bladder.

2nd BIT SHAFT TEST

This bit shaft test was an integral part of the Electrodril integrated system test at BOT and was started on 19 October 1978. The test configuration was as shown in Figure 3.

The installation sequence went as follows:

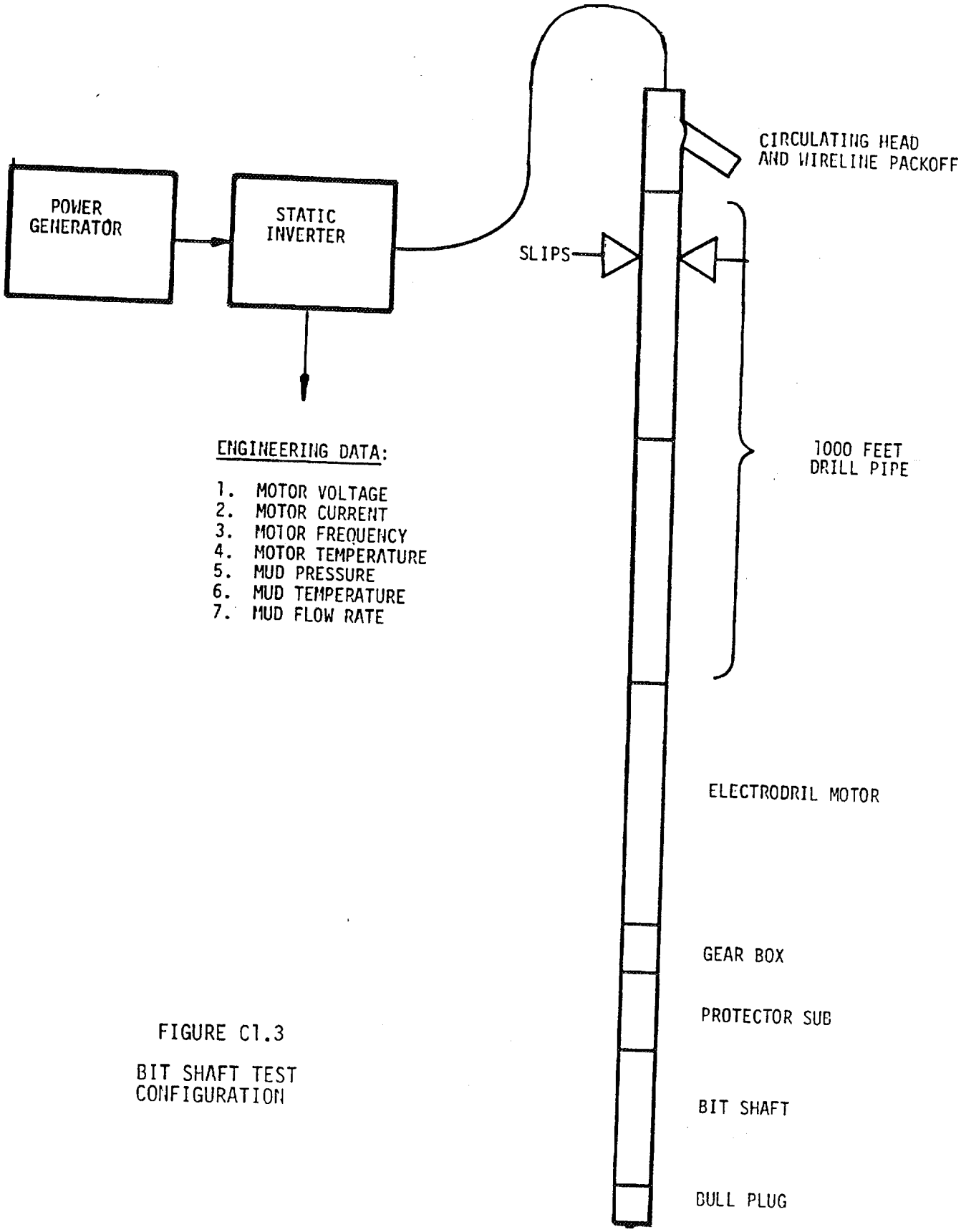
10-19-78

1400 hours — The bull plug with a 0.5 inch diameter orifice was installed on the bottom of the bit shaft and the bit shaft was installed on the motor assembly while hanging in the rig.

1518 hours — 1000' of drill pipe and cable landing were run in well on top of the motor/bit shaft assembly.

1617 hours — 1000' of electrical cable installed in drill pipe and mated to the top of motor assembly.

1641 hours — Prewired kelly and electrical crossover sub installed; mechanically and electrically connected to the drill pipe and motor assembly.



ENGINEERING DATA:

1. MOTOR VOLTAGE
2. MOTOR CURRENT
3. MOTOR FREQUENCY
4. MOTOR TEMPERATURE
5. MUD PRESSURE
6. MUD TEMPERATURE
7. MUD FLOW RATE

FIGURE C1.3

BIT SHAFT TEST CONFIGURATION

10-19-78

1653 hours Circulating head installed on Kelly.

1702 hours Cable from static inverter connected to the electrical crossover sub.

1705 hours Final electrical checks made and motor was turned on for a moment (bumped) to verify.

1706 hours Mud line connected to the circulating head.

1714 hours Electrodril motor started at 30 Hz.

1717 hours Mud pump started.

1726 hours Mud pressure came up to approximately 500 psig (drill pipe filled).

1728 hours Mud pressure up to approximately 800 psig.

1730 hours Mud pump shut down to fix leak in mud return line (rig problem).

1736 hours Mud pump back up, pressure approximately 650 psig.

START OF 100 HOUR BIT SHAFT TEST

Motor voltage	593 volts	30 Hz
Motor amps	24 amps	

10-19-78

1750 hours	Motor voltage frequency upped to 60 Hz		
	Motor voltage	1150 volts	60 Hz
	Motor amps	26 amps	
	Mud pressure	650 psig.	

1910 hours — Test stopped - inverter tripped out

Problem with Kelly cable. Kelly and electrical crossover sub removed from test configuration. Second 1000' of cable was mated with the 1000' of cable in well. A circulating head and cable pack off was installed on top of the 1000' of drill pipe.

10-21-78

1006 hours	Test restarted		
	Motor voltage	593 volts	30 Hz
	Motor amps	24 amps	
	Mud pressure	650 psig	

1132 hours — Inverter shut down to replace current transducer. Mud pumps stayed on.

10-21-78

1202 hours	Test restart		
	Motor voltage	593 volts	30 Hz
	Mud pressure	640 psig	
	Motor temperature	190°F-200°F	

10-22-78 Continuous running - all stable for 24 hours.

10-23-78

0735 hours Test stopped to replace defective valve in mud pump.

0910 hours Test restarted at 30 Hz. Motor temperature 206°F.

1300 hours Motor voltage frequency upped to 60 Hz. 1170 volts Motor temperature stabilized at 218°F.

1542 hours Test stopped for mud pump repair.

1839 hours Test restart motor voltage frequency at 60 Hz, 1170 volts, mud pressure 650 psig.

10-24-78 All stable with no interruptions during this 24 hours. Motor temperature up to 222°F.

10-25-78

2027 hours — Motor voltage frequency upped to 80Hz, 1533 volts, mud pressu 650 psig.

2038 hours — Motor voltage frequency varied from 65 Hz to 96 Hz during thi period. Motor temperature high was 238°F.

2055 hours — End of test.

See Figures 4, 5 and 6 for running time summaries.

DATE AND TIME	MOTOR VOLTAGE FREQUENCY AND MUD PUMP PRESSURE	TIME	ACCUMULATED TIME
10/19			
1736 hours Test start	30 Hz-650 psig	----	0
1750 hours	60 Hz-650 psig	14 min	14 min
1910 hours Stop	60 Hz-650 psig	1 hr 20 min	1 hr 34 min
10/21			
1106 hrs Start	30 Hz-640 psig	----	1 hr 34 min
1132 hours Stop		26 min	2 hr
1202 hours Start	30 Hz-640 psig	----	2 hr
10/22			
10/23			
0735 hrs Stop		43 hr 33 min	45 hr 33 min
0190 hrs Start	30 Hz-650 psig	----	
1300 hours	60 Hz-650 psig	3 hr 50 min	49 hr 23 min
1542 hours Stop		2 hr 42 min	42 hr 5 min
1839 hours Start	60 Hz-650 psig	----	
10/24			
10/25			
2027 hours	80 Hz-650 psig	49 hr 48 min	101 hr 53 min
2038 hours	65-96 Hz-650 psig	11 min	102 hr 4 min
2055 hours Stop		17 min	102 hr 21 min

FIGURE C1.4

BIT SHAFT TEST TIME SUMMARY

DATE	TEST TIME
10-19	1 hour 34 minutes
10-21	12 hours 24 minutes
10-22	24 hours
10-23	19 hours 28 minutes
10-24	24 hours
10-25	20 hours 55 minutes
Total	102 hours 21 minutes

FIGURE C1.5

TEST TIME BY DATE SUMMARY

MOTOR VOLTAGE FREQUENCY	TEST TIME
30 Hz	48 hours 03 minutes
60 Hz	53 hours 50 minutes
80 Hz	11 minutes
65-96 Hz	17 minutes
Total	102 hours 21 minutes

FIGURE C1.6

TEST TIME AT MOTOR VOLTAGE FREQUENCY

APPENDIX C2

ELECTRODRIL

DEEP DRILLING SYSTEM

100 HOUR BIT SHAFT TEST PLAN

GENERAL ELECTRIC

Thermal Systems Programs

Houston, Texas

INTRODUCTION

During the development of the Electrodril Deep Drilling System equipment requirements, the need was identified for a new bit shaft design to accommodate higher weights on bit, mud pressures, higher downhole temperatures and to exhibit a functional life between routine maintenance of at least 100 hours.

Such a bit shaft has been designed and is currently in the process of assembly. It is planned in the near future to test this new bit shaft assembly with the 285 HP Electrodril motor in a test well at Brown Oil Tools Inc., Houston, Texas. This report documents the test plan for this bit shaft test.

TEST CONFIGURATION

A block diagram of the system elements under test, together with all necessary supporting equipment is shown in Figure 1.

The bit shaft and motor assembly (Figure 2) will be lowered into an 8 1/2" diameter test well at BOT and assembled with two joints of 4 1/2" X hole drill pipe. This downhole assembly will be held in the well at this depth using slips. A cable packoff and circulating head (Figure 3) will be used to facilitate mud circulation and routing of the motor conductors (cable) out of the drill pipe.

The motor conductors (cable) will be routed directly to a variable frequency power converter (static inverter) which is connected to the basic diesel driven,

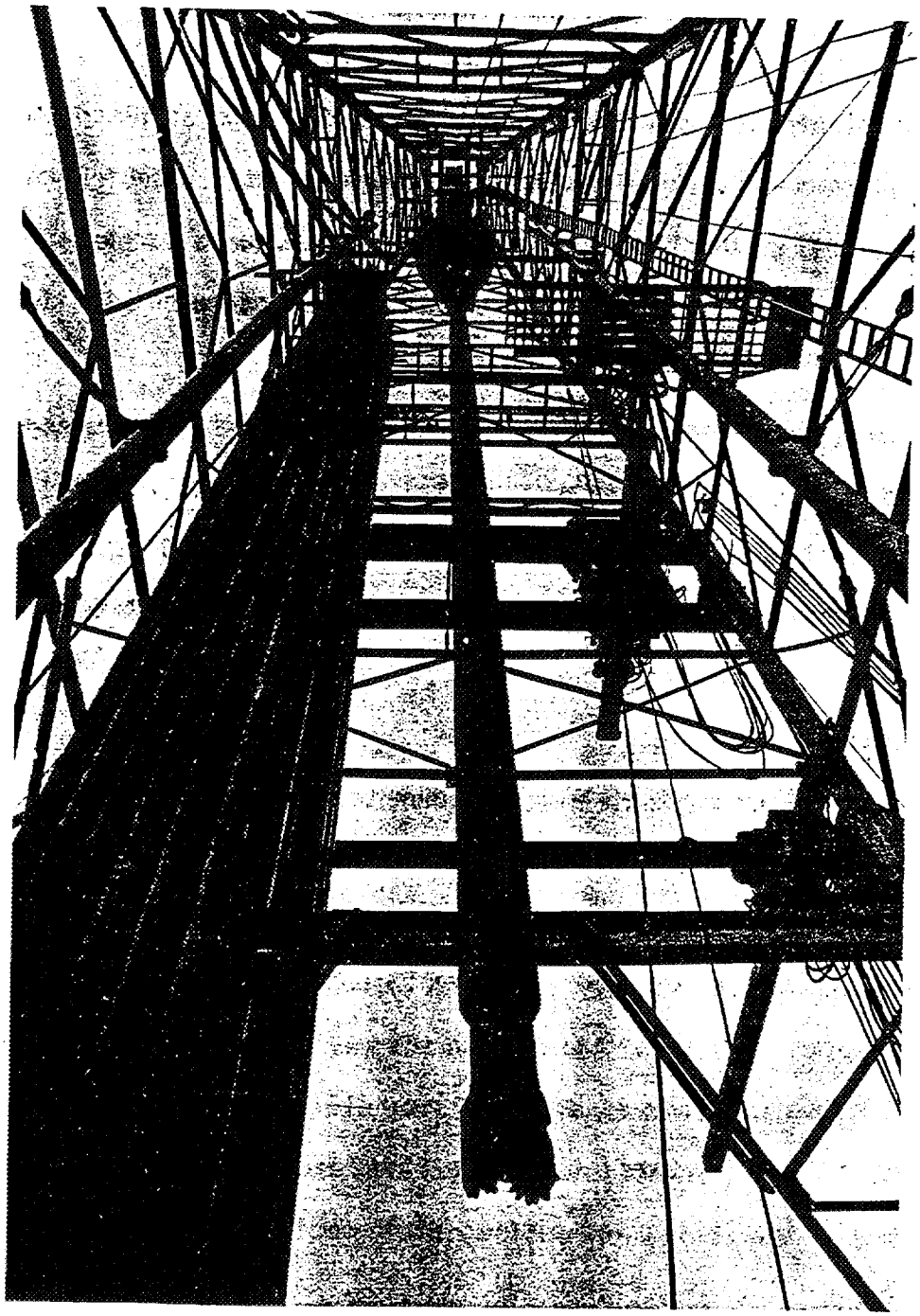


FIGURE C2.2

MOTOR AND BIT ASSEMBLY

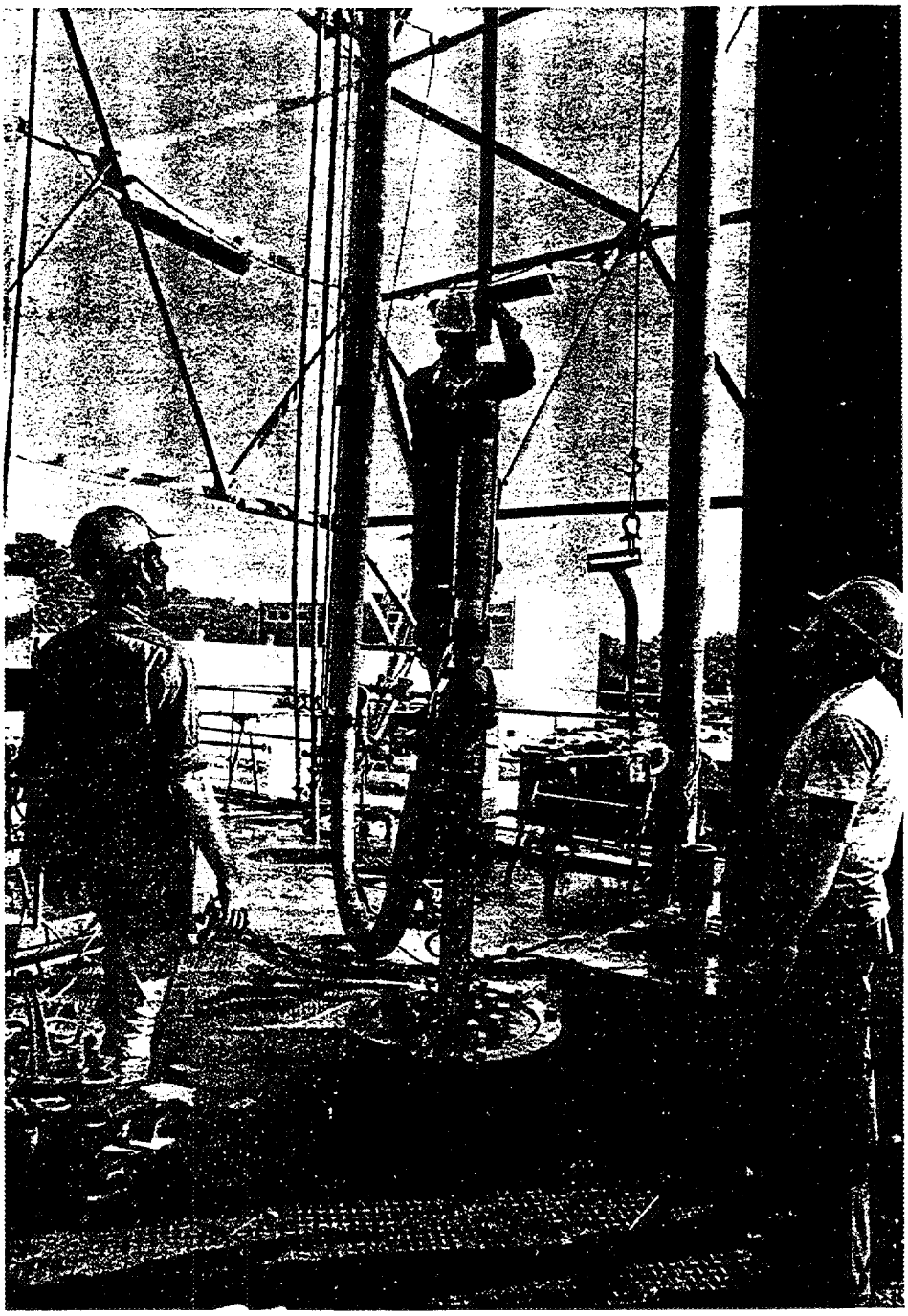


FIGURE C2.3

CIRCULATING HEAD, WIRELINE PACKOFF

AND CABLE CLAMP WITH CABLE

power generator. All electrical power necessary to support the Electrodril bit shaft test will be provided by the skid mounted power generator with the exception only of 115V AC lighting power which will come from the BOT rig.

TEST PLAN

The basic objective of the bit shaft test is to accrue 100 hours of running time while circulating mud at realistic pressures to demonstrate the adequacy of the basic bit shaft design to maintain its functional capability. Upon completion of the 100 hour test it is planned to selectively disassemble the bit shaft and motor elements to determine component wear and efficacy of seals.

In addition to this basic test, it is planned to vary the motor speed by varying its excitation frequency. This will be done through the static inverter. The cadence for this motor speed variation is:

Test Hour	Motor Excitation Freq.
000 thru 020	30 Hz
020 thru 100	60 Hz
100 thru 102	90 Hz
102 thru 103	120 Hz

The additional test hours at the higher excitation frequencies were run intentionally so as not to jeopardize the basic 100 hour bit shaft test.

Mud circulation throughout the test will be maintained at 400 gpm and 700 psig. A nominal 10 lb. mud will be used during the test. Mud is circulated in the conventional manner through the drill string. At the bottom of motor/bit shaft assembly a bull plug with a 0.5 in. diameter orifice will be used for pressure control.

DATA ACQUISITION

A number of parameters will be monitored during the planned 100 hour bit shaft test. These parameters will be in addition to the empirical data obtained by virtue of the 100 hours of rotation applied to the Motor/Bit Shaft assembly while in a simulated downhole environment.

The parameters to be continuously monitored will be:

1. Impressed motor voltage
2. Impressed motor current
3. Impressed motor frequency
4. Motor core temperature
5. Input mud temperature
6. Input mud pressure
7. Mud pump flow rate

APPENDIX D

POWER GENERATION TEST REPORT

FINAL REPORT

INTEGRATED TEST FOR VARIABLE FREQUENCY SCR AC DRIVES AND SUBMERSIBLE AC INDUCTION DRILL MOTORS

November 1978

1.1 SUMMARY

This report documents the results of a test program conducted on Emerson Electric AS 4590 static inverter and a Reda 540 series submersible pump motor. The purpose of this test program was to evaluate the transient response characteristics of the motor/inverter combination so that control circuits could be designed for the Electrodril Deep Drilling System.

The specific objectives of the test program were to determine:

a. The compatibility of "AC Variable Frequency Static Inverter Drive Systems" to Electrodril applications.

b. The drill motor losses attributable to oil sheer (windage) at various motor speeds and with different lubricants.

c. Drill motor starting current requirements at low frequency.

d. Drill motor HP and temperature rise with respect to various power frequencies, loads and cooling flow rates.

e. Effects of the "Static Inverter Wave forms" upon the downhole telemetry system operation.

f. The effects of cable IR losses to motor terminal voltage regulation requirements.

1.2 BASIC TEST RESULTS

1.2.1 COMPATIBILITY OF AC STATIC INVERTER DRIVES TO ELECTRODRIL APPLICATIONS

The Emerson AS 4590 drive unit performed satisfactorily for all the 20 HP Reda motor test. The inverter was utilized to operate the 20 HP motor from 15 Hz to 113 Hz under various loads, cable lengths and types of lubricants with no serious perturbations. From the basis of these tests, it is concluded that an AC static inverter drive is satisfactory as the prime drill motor drive unit for actual field drilling applications.

Later tests using the drive unit with a Reda 150/285 HP motor proved the ability of the drive to run large submersible pump motors. Some instability of the drive unit with the larger motor did occur at higher frequencies i.e., (82 - 90 Hz); however, discussions with Emerson indicate this could be stabilized tnrough internal adjustments to the drive unit.

1.2.2 LUBE OIL VISCOSITY CONSIDERATIONS

The test series has been completed and in general there were no significant surprises. As expected from TRW Reda's previous analysis, automatic transmission fluid (ATF) provided a 1% increase in the motor's efficiency under full load and about 8% under idle conditions. It must be realized however, that the selection of ATF for an Electrodril lubricant was based upon the gear box requirement for an anti foaming high temperature non gumming lubricant. Since the motor and gear box are connected together, one lubricant must suffice for both. The purpose of this test was to determine if ATF would provide more or less oil sheer (windage) in the motor at the high RPM's and therefore be more or less efficient.

Starting current requirements based upon these tests indicates there should be no problems starting Electrodril motors with size #6 cable to 20,000' depths providing the motor step-up transformer has the volts/Hz capability at 5 Hz to allow for cable IR drop. In reality this means the core of the transformer requires extra iron to keep from saturating at the lower frequencies/voltages.

1.2.4 DRILL MOTOR HP OUTPUT AND TEMPERATURE RISE

The purpose of these tests was to measure the HP output of the drill motor at various operating frequencies and to monitor its temperature under loaded conditions. Typically motors operated with variable speed AC drives are operated from very low speeds up through their normal operating frequency. Assuming the motor can be kept cool and electrically sound, advancing frequency and voltage in a linear relationship, (i.e., constant V/Hz) causes an increase in speed, constant torque output and therefore increased horsepower.

Dynamometer testing of the 20 HP motor indicated that the motor will produce 30 HP at 90 Hz, minus windage losses, and 40 HP at 120 Hz minus windage losses. Windage loss does increase significantly above 30 Hz, decreasing the available produced HP. Core temperature at 90 Hz under a full load condition did not exceed 240°F.

1.2.5 EFFECTS OF STATIC INVERTER WAVE FORMS ON DOWNHOLE TELEMETRY

A 20 HP motor was exercised through 2700' of size #10 power cable with the telemetry system functioning. A full range of motor speeds and dynamomet loading produced no data dropouts as observed upon the downhole telemetry. While this test only drew a maximum of 40 amps through the cable vs 75 amps of the large motor, no major problems are anticipated with the telemetry syste over longer cable lengths and higher currents.

1.2.6 EFFECTS OF CABLE IR DROP TO MOTOR TERMINAL VOLTAGE REGULATION REQUIREMI

Operating the 20 HP motor through 2700' of size #10 cable under various loads provided no significant problems in the ability of the inverter voltage regulator to maintain correct motor terminal voltage. It must be realized however, that three direct sense lines from the motor terminals were provided back to the inverter. 2700' of size #10 cable coupled to the 445V 20 HP 29 A Reda,motor simulatates about 8000' of size #6 cable coupled to the 150 HP Reda motor.

In actual downhole applications the motor terminal voltage will be sensed by a downhole carrier current telemetry system and relayed to the surface via the motor power leads.

2.0 INTRODUCTION

2.1 GENERAL

A series of tests was outlined in the early summer of 1978 to determine the

feasibility of using variable frequency (Static Inverter SCR) drives for Electrodril downhole drill motor primary power applications.

Until these tests were initiated, primary power was always supplied to the downhole drill motor from a fixed frequency power source, i.e., (60 Hz), or in the case of the Cullen/Continental Emsco tests during the early '70's, from a large rotary variable frequency generating system.

Since the Cullen/Continental Emsco test, the advancement of solid state AC drives has been followed very closely. The reasons for this are as follows:

a. Electrodril performance is enhanced considerably by providing variable speed capability. Early attempts to accomplish variable speed capability utilized large heavy rotary power generating equipment of which the performance was considered marginal. A smaller, lighter weight solid state system was envisioned, but not available at the power levels required during early Electrodril testing. Technical advances over the years allow manufacturers now to provide light weight small, high horsepower drives.

b. Cable IR drop below 10,000' in a typical Electrodril system becomes significant. The reason for this is the optimized tradeoff of power cable size vs mud flow requirements through the center of the drill pipe. Any power system utilized to this depth must have the capability of sensing the downhole motor voltage and responding to its demands quickly or else

the motor could stall. Rotary systems with their inherent inductance and hysterisis cannot respond to voltage changes too rapidly. Solid state AC drives usually operate from a phase controlled DC rectifier assembly. The phase controlled rectifier assembly can be slewed in voltage fairly rapidly, making it an excellent for Electrodril power applications.

2.2 TESTING TIME FRAME AND REQUIREMENTS

The application of solid state AC drives to the Electrodril system could not have been possible several years ago. As mentioned previously, the reason for this was the unavailability of high horsepower units. The technical uncertainties associated with rotary systems leave some doubts as to the ability of such systems to function at the greater depths.

Therefore, an investigation into applications of AC drives to the Electrodril system was undertaken. In March 1978 Emerson Electric and TRW Reda were invited to participate. After final negotiations, the equipment was delivered in July 1978. Testing was commenced about the third week of July and continued until the second week of September 1978. Additional tests at Brown Oil Tools continued until November 1978.

2.3 OBJECTIVES

The objectives of these test programs were then as follows:

2.3.1 COMPATIBILITY OF SOLID STATE AC STATIC INVERTER DRIVES TO THE ELECTRODRIL SYSTEM

To determine if solid state drives were technically and economically feasible to apply to Electrodril technology vs rotary power generating systems.

2.3.2 MOTOR EFFECTS

To monitor the motor loaded and unloaded at low and high frequency/voltage inputs to ascertain:

a. The horsepower developed at each frequency (RPM & TORQUE)

b. Windage and friction losses with different lubricants.

c. Heating effect at high RPM's/frequency with various cooling flow rates.

2.3.3 STARTING

To determine starting current requirements of the Reda motors at low frequencies so inverter starting circuitry and output transformer requirements could be specified.

2.3.4 TELEMETRY EFFECTS

To determine if motor operation at different frequencies and loads will affect the downhole telemetry monitoring system.

2.3.5 VOLTAGE REGULATION REQUIREMENTS

To verify that the voltage monitoring and regulation circuitry of the Emerson AS 4590 can respond to cable IR loss and maintain the motor terminal voltage.

3.0 TECHNICAL APPROACH

3.1 GENERAL

A test tank was fabricated to hold the 20 HP motor upright in a flow of water while testing it for oil sheer or windage. See Figure D1. In addition, another test stand was fabricated to couple the assembled motor, gear box and protector assembly to a dynamometer. See Figure D2. Figure D3 is the basic schematic for the testing series. Minor changes in the test stand configuration or schematic to fit any particular test will be as described in each test.

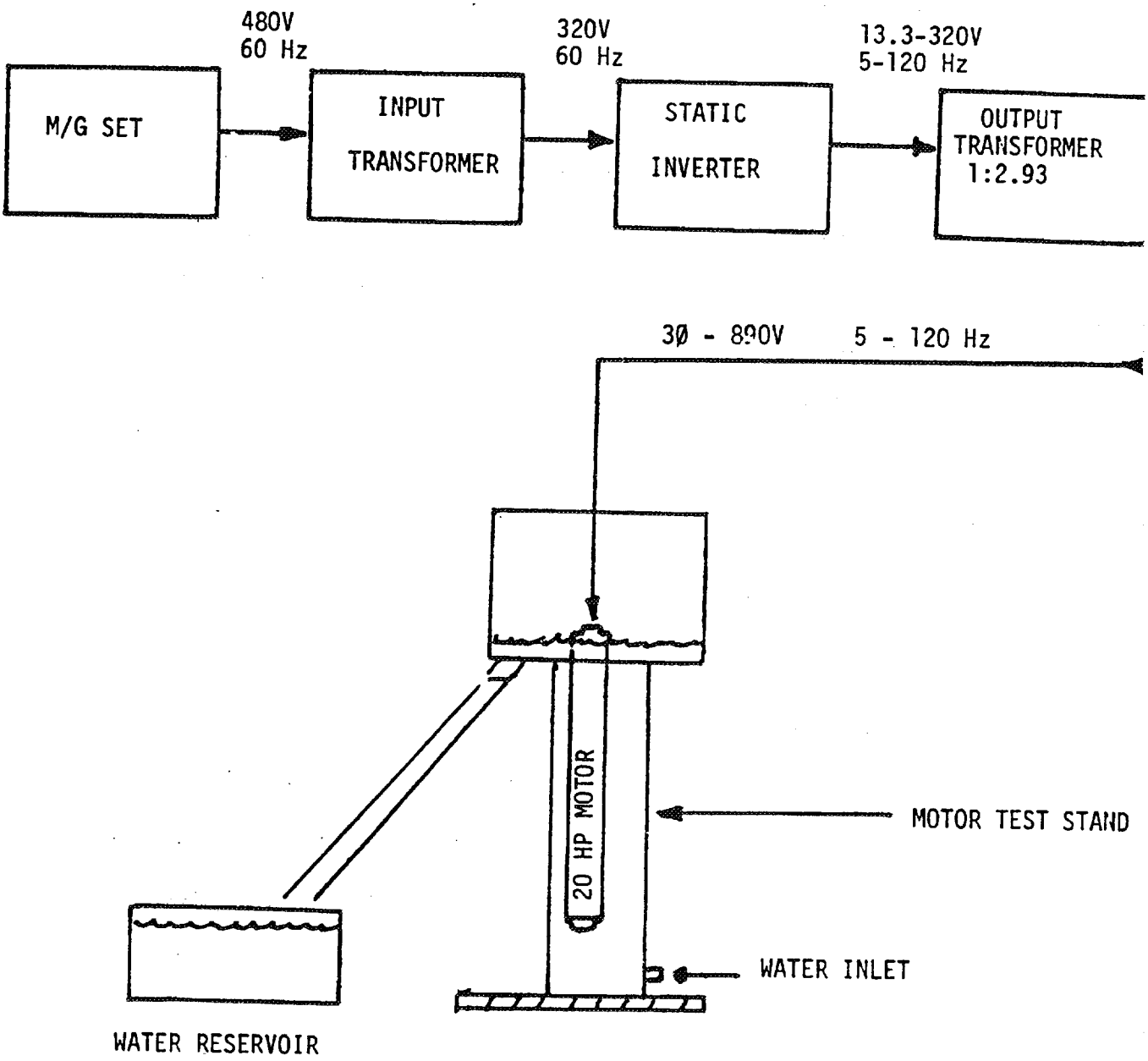
3.2 INSTRUMENTATION

3.2.1 SPECIAL INSTRUMENTATION

Special instrumentation was required for the motor current and motor voltage monitoring. The special instrumentation was necessary due to the non-standard frequency outputs of the static inverter and the DC components of the 6 step wave form provided by it.

To read the RMS output of the static inverter/transformer to the motor, HP 3400A True RMS voltmeters were utilized. These voltmeters provide a true RMS reading of the voltage wave form supplied to them regardless of its complexity.

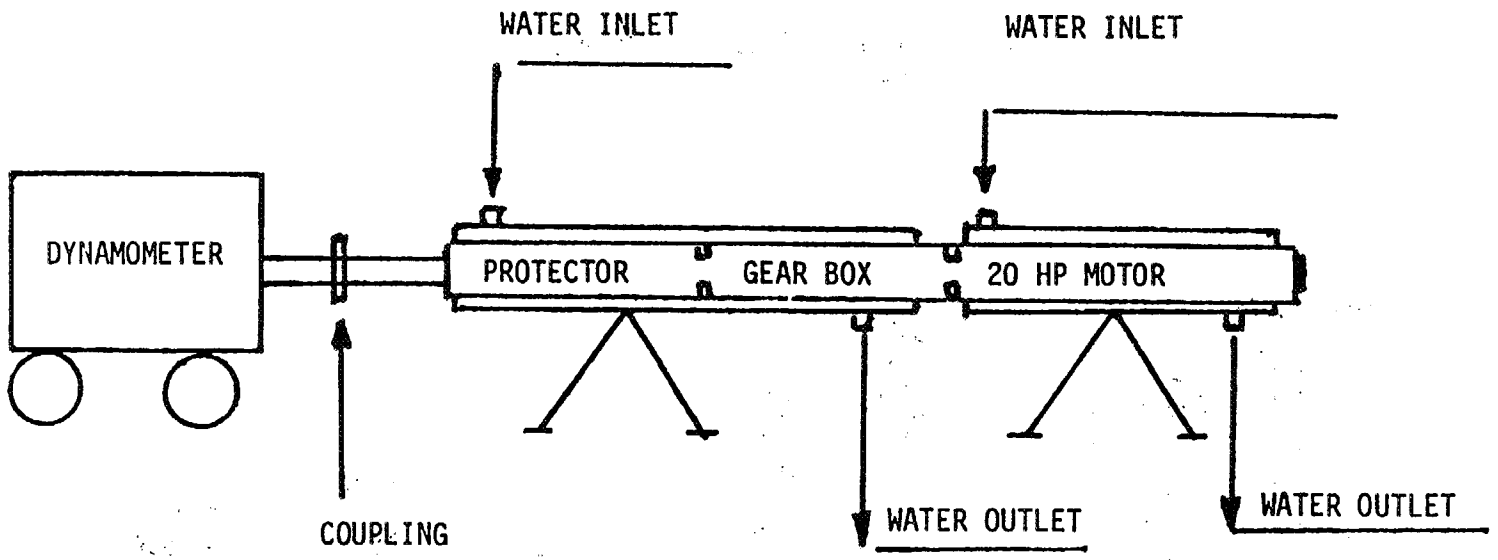
A Columbia AC/DC clamp-on ammeter was used for motor current measurements to insure accuracy at different frequencies and with the DC components of the six step inverter wave form.



TEST STAND BLOCK DIAGRAM

Test #1, 2, 3, 4

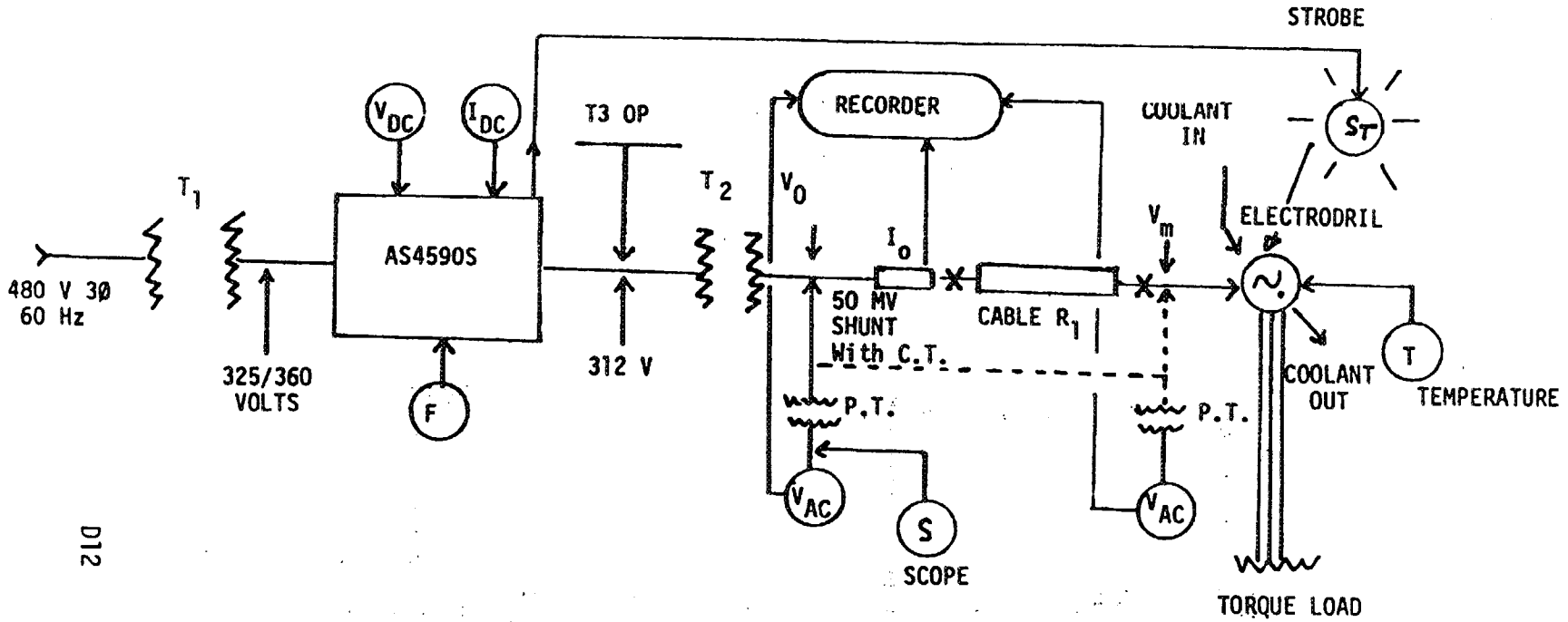
FIGURE D1



HORIZONTAL TEST STAND

TEST #5, 6, 7, 8

FIGURE D2



D12

FIGURE A9
285 HP ELECTRODRIL MOTOR ASSEMBLY

3.2.2 STANDARD INSTRUMENTATION

All other instrumentation utilized for testing was standard off shelf manufactured items available through typical test equipment supply channels.

3.2.3 INSTRUMENTATION SYMBOLS AND CONNECTION

Refer to Figure D3. In the referred schematic each instrumentation bubble is designated with a symbol and an arrow to the point connected within the test figure. An explanation of the symbols, where the instrument is attached or what it is measuring and where it may be found in the date sheet is presented on Page D42.

3.3 TESTS PERFORMED

3.1.1 GENERAL

The following tests were performed to satisfy the objectives as spelled out in Section 2.0 and as summarized in Section 1.0:

A. Motor oil sheer (windage) Test - Reda #2 Mineral Oil

	Remarks
Test #1 - up frequency	20 HP motor connected directly to inverter/ transformer - no gear box, protector assemb test stand #1
Test #2 - down frequency	

B. Motor oil sheer (windage) test - Dexron ATF

	Remarks
Test #3 - up frequency	Same as Item A. above
Test #4 - down frequency	

C. Gear box and protector losses

Test #5 - 20 HP motor gear box and protector connected directly to inverter. No load on dynamometer.

D. Dynomometer Test A

Test #6 - 20 HP motor - gear box and protector connected directly to inverter and dynamometer

E. Dynomometer Test B

Test #7 - 20 HP motor - gear box and protector assembly connected through 2700' of size #10 cable to inverter and to dynamometer

F. Motor locked rotor and low frequency starting current test

Test #8 - TBA

3.4 TEST DESCRIPTIONS AND RESULTS

3.4.1 OIL SHEER AND WINDAGE TEST #1, 2, 3, 4

Tests 1, 2, 3 and 4 were accomplished utilizing the test stand shown in Figure 3.1.1. The 20 HP motor was exercised through a series of frequency ranges with Reda #2 mineral oil and Dexron ATF as lubricants under no load conditions. Data sheets for tests 1, 2, 3 and 4 show static readings for each of these tests at different operating points. For analysis purposes the down frequency of each test (2 and 4) was utilized, the lubricant in each case being at maximum operating temperature.

As can be seen in test 2 down frequency, the motor requires 6600 watts to idle at 113 Hz and 1500 watts to idle at 60 Hz. This basic test verifies within reason that the oil sheer and frictional losses within the motor increase as the square of the RPM or frequency ratio. Therefore, operating the motor at 30 Hz produced 1/4 the losses from windage and friction than operating it at 60 Hz and 120 Hz operation will produce four times or more the losses experienced at 60 Hz.

One might conclude then that assuming the motor can be kept cool, operation at double the frequency, i.e., (120 Hz), does not produce double the horsepower or 40 HP due to the increase in frictional and windage losses. In reality the smaller Reda motors are only about 70% or so efficient but are conservatively rated. It may be assumed that at 60 Hz operation and 29 amps the 20 HP motor will produce at least 21 HP and at 120 Hz would produce about 42 HP. The extra loss will cause the motor actually to produce only 36.78 HP or about a 14% loss in optimum output.

If these calculations were transferred to the 150 HP 540 REDA motor series, it would be logical to assume a 260 HP output of the large motor, i.e., (150 HP) when operating it at 120 Hz.

Differences in the amount of idle wattages between Reda #2 mineral oil and ATF may seem large at first (8%) under idle conditions. When the differences in idle wattages are compared to the loaded run wattages however, only a 1% difference between Reda mineral oil and Dexron ATF can be seen. This difference drops to less than 1/2% at temperatures above 300°F due to the different viscosity index curves of the different lubricants. It can be assumed the Reda motors will run satisfactorily with Dexron ATF as a lubricant with about a 1% efficiency increase.

3.4.2 GEAR BOX AND PROTECTOR ASSEMBLY LOSSES TEST #5

In order to ascertain the predicted motor and gear box/protector assemblies

horsepower output into the dynamometer, the motor and gear box assembly was operated horizontally at no load for test #5, see Figure 3.1.2. By subtracting the idle motor wattage requirements from that with the gear box and protector assembly, the actual loss in the gear box and protector can be predicted.

The following differences were recorded between the motor idle and motor idle with the gear box/protector.

Frequency	Watts Δ	HP Consumed
@ 30 Hz	1500	2.1
@ 60 Hz	5600	7.5
@ 90 Hz	17300	23.1 (22-23)(1)
@ 113 Hz	21900	29.35 (28-29)(1)

(1) Changes with temperature significantly

While not exactly linear to the assumption that the losses due to windage and friction will be as to the square of the increased ratio, the above values do bear some relation to this theory.

It may be assumed that at high RPM's, (7200 from the motor) at 120 Hz, the gear box/protector loss will be about 30 HP. Therefore the horsepower required to drive the gear box must be subtracted from the total system to arrive at actual

shaft HP output for any motor frequency combination. If the 21 HP motor operating at 90 Hz is equivalent to about 32 HP, a 22 HP gear box loss would leave about 10 HP available. At 90 Hz, the shaft RPM is 323 producing 200 pounds at 29 amps motor current. This is about a 12 HP output and within reason to the expected results. At 60 Hz the gear box loss would be 21.0 HP - 7.5 = 13.5 HP output. In test #6 the actual motor assembly output was 217 RPM x 320' lbs divided by 5250 = 13.2 HP.

The significance of the above information can be utilized in determining the total system performance, efficiency and thermal distribution.

3.4.3 DYNAMOMETER TEST A #6

The first test using the dynamometer, test #6, was accomplished to ascertain the developed motor horsepower at various frequencies minus the gear box and protector section losses. At a 29 amp motor current drain:

90 Hz produced a HP output of 13.5 Hp

60 Hz produced a HP output of 13.22 HP

30 Hz produced a HP output of 7.8 HP.

See data sheet 5.1.C Test #6

It is quite obvious that in the case of a 20 HP motor driving the gear box/protector assembly, no significant HP output is available by increasing frequency. The reason for this is that the increased horsepower produced by the motor is consumed by the additional losses in the gear box and protector.

Since the gear box and protector losses are constant however, their losses are less significant when using the larger field deployed Electrodril motors of 60 (120) and 150 (300) HP ratings.

3.4.4 DYNAMOMETER TEST B #7

The purpose of the dynamometer test #7 was to introduce cable IR drop into the system to ascertain if the inverter sense and voltage control circuitry could maintain proper motor terminal voltage under step load.

If proper motor voltage cannot be maintained during intermittent loading of the motor, torque output will drop with a resultant stalling of the motor. See test data sheet 5.1 C Test #7.

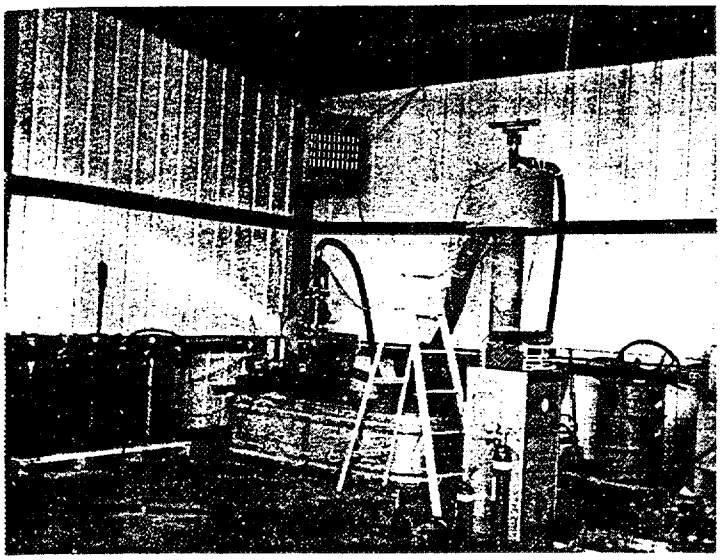
All data taken on this sheet indicated the ability of the static inverter to maintain proper motor terminal voltage under various loads. The cable length chosen was 2775 feet of size #10 power cable. Transposition of this data to effective other motor and cable combination/lengths may be found in Section 5.4.

3.4.5 LOCKED ROTOR AND STARTING TORQUE TEST #8

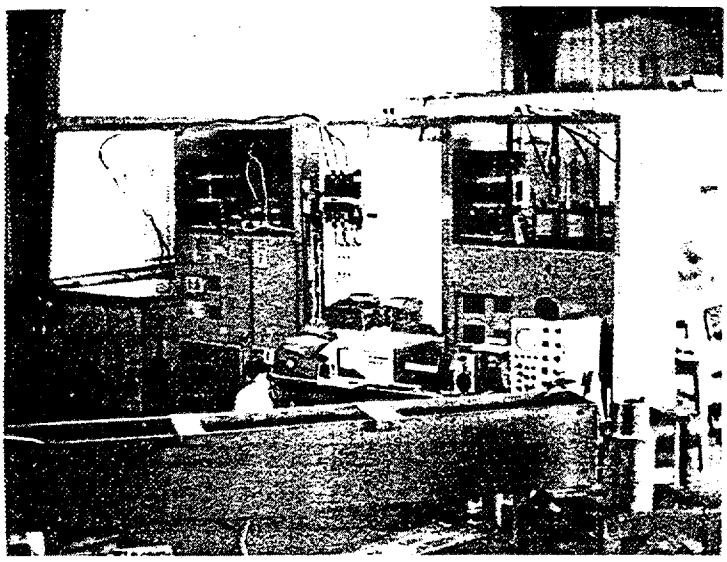
The dynamometer loading was slowly adjusted upward until the motor refused to start. This occurred at about 125 foot pounds. Then the loading was backed off until reliable starting could be obtained at 105 foot pounds. See data sheet for test #8.

If the 20 HP Motor can produce 105 foot pounds of starting torque, it may be assumed the 150 HP motor will produce over 700 foot pounds when started with comparable voltage, frequency and current parameters. Considering the motor and bit will be lifted off bottom in Electrodril applications, no starting problems are anticipated.

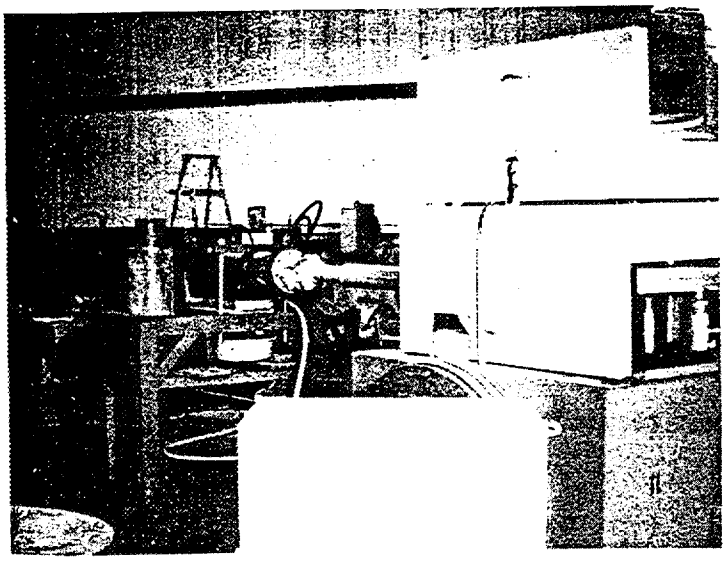
TEST STAND PHOTOGRAPHS



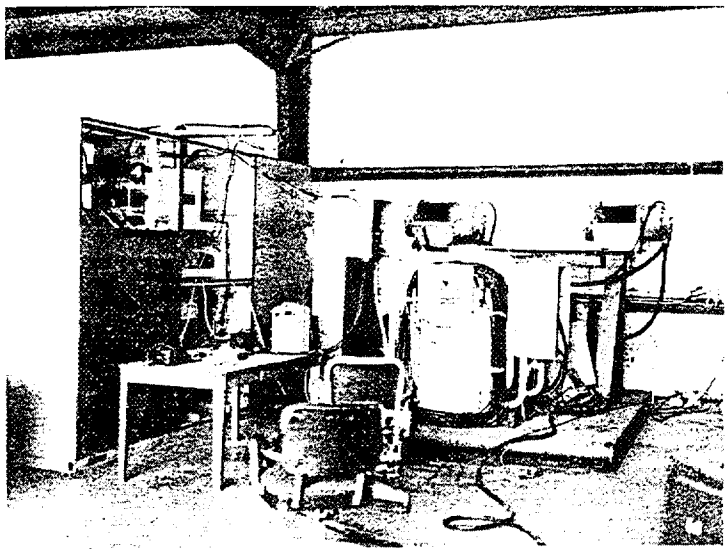
OIL SHEER TEST STAND
TEST #1,2,3,4



HORIZONTAL DYNAMOMETER
TEST STAND TEST #5,6,7,8



REAR VIEW OF DYNAMOMETER CONNECTED
TO 20 HP MOTOR



REAR VIEW OF INVERTER SHOWING
STEP UP TRANSFORMER

FIGURE D4

4.0 TEST DATA

4.1 GENERAL

The following test data sheets are the raw data as taken in tests #1 through # In addition to the test data sheets, strip chart recordings were taken of vari parameters in real time. Since the test data strip chart recordings are so bulky, they cannot be reproduced for this report. The REDA 20 HP 540 series motor used for the test was REDA part No. #63268-7 rated at 445 V 3 phase AC 60 Hz and 29 amps.

4.2 MOTOR TEMPERATURE MEASUREMENTS

NOTE: All motor temperature measurements shown in the attached data sheets wer taken with a thermocouple mounted either in the very top of the motor or gear box assembly in the motor lubricant.

In an effort to determine true motor core temperature additional tests were made utilizing a wheatstone bridge to measure the motor's stator resistance. Comparing the cold stator resistance to the hot running resistance gives the motor's true core temperature. When the true motor temperatures were calculate they showed that when the lubricant was at 187 - 190°F, the core of the motor was at 240°F, or about 26 percent higher. It can therefore be assumed the actual motor temperatures were about 26 percent higher than those shown in the attached data sheets. In no case did the test temperatures exceed the Electrodril maximum allowable motor temperature of 300°F.

OIL SHEER TEST
REDA #2 OIL

Date/Time 8/1/78
Motor Type/HP 540 REDA 20 HP
Motor Oil REDA #2
Motor Serieal No. _____

DATA SHEET 5.1A TEST # 1 - Up in Freq

Freq. Hz	Vo Volts RMS	Vin Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Watts Input	Torque Ft Lbs	Load	Mtr Temp Time
113		750	8.0	328	37.5	7700 7200		No Load Note: Watts drop as motor heats	See 5.1D
90		632	7.1	270	29.5	5000 4750		No Load	
60		420	6.4	184.5	18.5	2500		No Load	
30		210	5.0	94	9.0	1100		No Load	
15		105	3.2	49	7	400		No Load	
10	To give Normal Excita-tion							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

OIL SHEER TEST
REDA #2 OIL

5.1 D MOTOR TEMPERATURE LOG

Date/Time 8/1/78

TEST 5.1A #1 Up Freq

Motor Type H.P. REDA 540-20HP
Motor Oil REDA #2
Motor Serial No.

Cooling Medium, water, Rate none

Fo	Vm	Load	Temp 2 Min	4 Min	6 Min	10 Min	15 Min +	Comments
30	210	0	106F 84.6	Mtr Tank				Start Temp 84.6
60	420	0			130 86.8	Mtr Tank est.		
90	632	0				153 90	Tank	
113	750	0					174 96	Tank
15	105	0		93 83				Mtr & Tank allowed to cool before 15 Hz test

OIL SHEER TEST
REDA #2 OIL

Date/Time 8/1/78
Motor Type/HP 540 REDA 20 HP
Motor Oil REDA #2
Motor Serial No. _____

DATA SHEET 5.1A TEST # 2 Dwn Freq

Freq. Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Watts Input	Torque Ft Lbs	Load	Mtr Temp Time
113	890 890 890	750	7.5	238	36	6600		No Load 40 HP Overload	See 5.1D
90	667.5 667.5 667.5	630	6.4	270	24.5	2900		No Load 30 HP Overload	
60	445 445 445	430	5.3	182	11	1500		No Load 20 HP Overload	
30	222.5 222.5 222.5	215	3.8	92	2	400		No Load 10 HP Overload	
	111.25 111.25 111.25							No Load 5 HP Overload	
10	To give Normal Excitation							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

OIL SHEER TEST
REDA #2 OIL

5.1 D MOTOR TEMPERATURE LOG

Date/Time 8/1/78

Motor Type H.P. 540 REDA 20 HP
Motor Oil REDA #2

TEST

Motor Serial No.

Cooling Medium, water, Rate 0

Fo	Vm	Load	Temp 2 Min	4 Min	6 Min	10 Min	15 Min	Comments
113	750	0					184F	Mtr hot from test #1 Up Freq
							107F	2nd Figure Tank Temp
90	630	0					179	
							117	Tank
60	420	0					166	
							123	Tank
30	215	0					152	
							127	Tank

Date/Time 8/1/78
Motor Type/HP 540 REDA 20HP
Motor Oil DEXRON ATF
Motor Serial No.

DATA SHEET 5.1B TEST # 3 UP FREQ

Freq. Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Watts Input	Torque Ft Lbs	Load	Mtr Temp Time
113		780	8.0	328	27.5	7200 6300		No Load. Note: Watts drop as Mtr heats	See 5.1D
90		630	7.1	270	29?	4800		No load	
60		420	6.0	184	17	2300		No load	
30		212	4.4	93	6.5	800		No load	
15		106	2.8	48	3.8	300		No load	
10	To give Normal Excitation							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

5.1 D MOTOR TEMPERATURE LOG

OIL SHEER TEST ATF

Date/Time 8/1/78

TEST 5.1B #3 Up Freq

Motor Type H.P. REDA 540 20HP

Motor Oil

Cooling Medium, water, Rate 0

Motor Serial No.

Fo	Vm	Load	Temp 2 Min	4 Min	6 Min	10 Min	15 Min +	Comments
15	106	0		94.7 89	Mtr tank			
30	212	0			104 89	mtr Tank		
60	420	0				122 90	Tank	
90	630	0					144 91.8	Tank
113	780	0					177 101	Tank

OIL SHEER TEST ATF

Date/Time 8/1/78
Motor Type/HP 540 REDA 20HP
Motor Oil DEXRON ATF
Motor Serial No.

DATA SHEET 5.1B TEST # 4 DWn Freq

Freq. Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Watts Input	Torque Ft Lbs	Load	Mtr Temp Time
113		770	7.3	327	34	6100		No Load	See 5.1D
90		630	6.2	268	24	3700		No Load	
60		420	5.2	182	10.5	1400		No Load	
30		212.8	3.8	92	0	300		No Load	
10	To give Normal Excita-tion							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

OIL SHEER TEST ATF

5.1 D MOTOR TEMPERATURE LOG

Date/Time 8/1/78

TEST 5.1B #4 dwn Freq

Motor Type H.P. 540 REDA 20HP

Motor Oil DEXRON ATF

Cooling Medium, water, Rate 0

Motor Serial No.

Fo/Hz	Vm	Load	Temp 2 Min	4 Min	6 Min	10 Min	15 Min +	Comments	
113	770	0				Mtr Temp	181	Mtr Hot from Test	#3 up Freq
							110	Tank Temp	
90	630	0					177		
							118	Tank	
60	420	0					164		
							124	Tank	
30	212.8	0					154		
							126	Tank	

IDLE TEST WITH GEAR BOX

Date/Time
Motor Type/HP REDA 540-20HP
Motor Oil DEXRON ATF
Motor Serial No.

DATA SHEET 5.1B TEST # 5 Up Freq

Freq. Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Watts Input	Torque Ft Lbs	Load	Mtr Temp Time
100	741	680	24.5	299	120	26,500		No load	187°
90	667.5	620	26	271	94	21000		No Load	136
60	445	424	15.2	186	52	8500		No load	105°F
30	222.5	220	8.5	96	19	2500		No load	92°F
10	To give Normal Excitation							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

IDLE TEST WITH GEAR BOX

Date/Time
Motor Type/HP REDA 540 20HP
Motor Oil DEXRON ATF
Motor Serial No.

DATA SHEET 5.1B TEST # 5 Dwn Freq

Freq. Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Watts Input	Torque Ft Lbs	Load	Mtr Temp Time
113	741	680	24.5	299		28 KW		No Load	187°F
90	667.5	620	26	271	94	21,000			185°F
60	445	424	12.5	184	40+	7KW		No load	170°F
30	222.5	220	6.5	93	10	1.8KW		No load	161°F
10	To give Normal Excitation							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

DYNOMOMETER TEST

Date/Time 8/22/78

) CABLE LENGTH 0-MTR DIRECT TO INVERTER

Motor Type/HP REDA 540-60HP - 20HP

G RESISTANCE - 0

Motor Oil DEXRON ATF

)NDUCTOR SIZE N/A

Motor Serial No. ———

DATA SHEET 5.1 C TEST #6

).Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc - Amps DC	Slip RPM	Torque	Load	KW Input	Mtr Temp
								No Load 120 HP O/L		
89	740	740	32.5	328	120	323	220'lbs	No Load 60 HP O/L to	33 KW 31 KW	163°F
60	500+	500+	28,4	226	96	216-217	320'lbs	No Load 15 HP O/L to	19.5 KW 20 KW	125°F
30	219	219	34	96	120	105-108	380'lbs	No Load 10 HP O/L	9-10KW	102°F
								No Load		
								Stalled		

;heck system performance with step load changes and various RI cable lengths. Visicorder ;hould be at least 2" peak to peak sensitivity and enough horizontal speed for good 'esolution of wave shapes.

MOTOR START TEST

R 1 CABLE LENGTH 2775'

LEG RESISTANCE - 3

CONDUCTOR SIZE #10

Date/Time 8/22/78

Motor Type/HP REDA 540-60HP - 20 Hp

Motor Oil DEXRON ATF

Motor Serial No. _____

DATA SHEET 5.1 C TEST #6A-2

Freq.Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc - Amps DC	Slip RPM	Torque	Load	Mtr Temp
120								No Load	See
120								120 HP	5.1D
120								O/L	
60								No Load	
60								60 HP	
60								O/L	
15								No Load	
15								15 HP	
15								O/L	
10								No Load	
10								10 HP	
10								O/L	
5			28 pk					No Load	
5			28 pk					Stalled	

Check system performance with step load changes and various R1 cable lengths. Visicorder should be at least 2" peak to peak sensitivity and enough horizontal speed for good resolution of wave shapes.

DYNOMOMETER TEST WITH CABLE

R 1 CABLE LENGTH 2775

LLG RESISTANCE - 3

CONDUCTOR SIZE #10

Date/Time 8/22/78

Motor Type/HP REDA 540-20HP

Motor Oil DEXRON ATF

Motor Serial No.

DATA SHEET 5.1 C TEST #7

req.Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc - Amps DC Col		Slip RPM	Torque	Load	KW Input	Mtr Temp
90	764	650	24+	329	115	P	329	0	No Load	27	See
90	810	650	35	353	160	P	323	200+	30 HP	41	5.1D
90	824	640	38	363	165	P	320	240+	O/L	48	
60	500	440	14.5	216	63	52	220	0	No Load	10	
60	580	440	30	259	125		213	320	20 HP	27	
60	604	444	34	272	140		210	370	O/L	32	
30	260	224	8.5	113.4	26	26	111	0	No Load	3.5	
30	364	230	28.5	163	120	100	106	380	10 HP	16.5	
30	390	230	34	177	140		105	460	O/L	21	
15	136	118	4.4	60		14	N/K	0	No Load	1.8	
15	244	124	24	113	100	98	N/K	380	5 HP	9.5	
15	260	124	26+	118	120	P	N/K	420+	O/L	11.5	
									No Load		
									Stalled		

Check system performance with step load changes and various RI cable lengths. Visicorder should be at least 2" peak to peak sensitivity and enough horizontal speed for good resolution of wave shapes.

DYNOMOMETER TEST WITH CABLE

5.1 D MOTOR TEMPERATURE LOG

Date/Time 8/22/78

TEST 5.1C #7

Motor Type H.P. REDA 540-20HP

Motor Oil DEXRON ATF

Motor Serial No.

Mtr Cooling Medium, water, Rate 8 gal/min

Fo	Vm	Load	Temp 2 Min	4 Min	6 Min	10 Min	15 Min +	Comments
30	224	0		92F				30Hz Test Run First
30	230	380'lbs			99.6F			
30	230	460'lbs				106 F		
60	440	0					126	60 Hz 2nd
60	440	320'lbs					136	
60	444	370'lbs					142	
15		0					132	15 Hz 3rd
15		370'lbs					122	
15	124	420					121	
								Shut Down Cooled off
90	650	0			141+			90 Last
90	650	200+			170			
90	640	240+			178			

STARTING TORQUE TEST

Date/Time
Motor Type/HP REDA 540 20 HP
Motor Oil ATF
Motor Serial No:

DATA SHEET 5.1B TEST # 8

Freq. Hz	Vo Volts RMS	Vm Volts RMS	Io Amps RMS	Vdc Volts DC	Idc Amps DC	Slip RPM	Torque Ft Lbs	Load	Mtr Temp Time
5	180(1)	68(1)	28 +	85(1)			N/A	No Load	See 5.1D
5	190(1)	68(1)	28.5+	89(1)			105	Max	
5	190(1)	68	29 +	89(1)			125	Stalled	
10	To give Normal Excita-tion							No Load 3.33 HP Overload	
5	To give Start Torque Req							No Load 1.7 HP 1.7 HP Stalled	

(1) Voltage starts at 0 - increases to this value then drops off as motor starts to run.

Note: Measure motor temperature rise at full load every 2 minutes to extrapolate temperature rise curve - if necessary use separate data sheet 5.1D - show cooling medium and rate.

5.0 CONCLUSIONS

5.1 APPLICABILITY OF SOLID STATE AC DRIVES TO SUBMERSIBLE MOTOR APPLICATIONS

As mentioned in the summary, there seems to be no doubt that solid state AC variable frequency drives are applicable to driving submersible AC induction motors such as that used for Electrodril. The test series and subsequent Brown Oil Tools 100 hour bit shaft test proved conclusively the ability of the solid state drive to operate the downhole motor satisfactorily. Not only did the tests prove basic operation of the motor but they also verified the relationship of the constant torque, variable speed/HP relationship offered by providing variable frequency/voltage. Therefore, operating the Electrodril motor at 30 Hz provides 1/2 speed and 1/2 HP from that at 60 Hz, and 90 Hz operation provides 1 1/2 times the speed and horsepower as that of operating at 60 Hz. Of course the limiting factor is the cooling capability of the motor when operated above its rated frequency and horsepower. For Electrodril applications, the tests indicate that it seems possible to operate to 90 Hz without heating problems. At speeds above 90 Hz, heating problems could be encountered if mud flow and mud temperature are not sufficient for the heat removal.

Certainly one problem associated with operating an electrical induction motor drilling at extreme depths is cable IR drop. If the power system cannot sense and respond to the motor terminal voltage requirements quickly, the motor will stall, drawing excessive locked rotor current. Static inverter AC drives usually operate with phase controlled DC rectifier assemblies. With proper sense and control circuitry, these phase control rectifier assemblies can

slew the inverter output voltage to compensate for the cable IR drop as motor loading or current increases. All testing indicated an excellent ability to accomplish motor terminal voltage control with the Emerson AS 4590 drive. It is felt with large bulky rotary equipment that high response voltage control would be difficult due to the inductance and hysterisis of the generator field.

5.2 MOTOR AND GEAR BOX LUBRICANTS

During the Cullen/Continental Emsco Electrodril test of the 1969/1970 time period, it is reported that gumming or shellacking the gear box occurred under heavy loads of high RPM. In an effort to reduce the gumming, Exxon Dexron "Automatic Transmission Fluid" was selected as a gear box lubricant instead of Reda mineral oil.

Since the motor and gear box are an integral component, filling the gear box with ATF also means filling the motor with ATF.

There has been concern over the years as to the lubricating qualities of the ATF and how it would affect motor efficiency. The test series just performed showed no excessive wear on the motor from operating it at high RPM's with ATF as a lubricant. In addition, efficiency of the motor was increased from 1 to 1/2%, depending on temperature, by utilizing automatic transmission fluid.

5.3 STARTING CURRENT CONSIDERATIONS

The Electrodril power transmission system is of necessity fairly inefficient. Mud flow requirements down the center of the drill pipe dictate that the power cable be reasonably smaller than that which would be required for efficient

power transmission. Considering that the motor inrush current can be 5 times the running current when starting at 60 Hz, it can be seen that starting even the 60 HP motor at 60 Hz would be depth limited.

Tests with the variable frequency AC static inverter drive indicate that starting current is reduced to rated running current or less by starting the motor at 5 Hz. These tests collaborate data provided by Baylor engineering over ten years ago estimating the starting current at 5 Hz to be the Electrodril motor's rated loaded running current at 60 Hz.

It then can be assumed that starting of Electrodril motors at depths of over 20,000 feet can be accomplished easily when using variable frequency AC drives. The only requirement associated with using such a low starting frequency is that the inverter must operate through an output motor step-up transformer. In order to allow for cable IR drop at starting, i.e., (5Hz), the inverter output transformer must be able to handle a high V/Hz ratio at 5 Hz. Engineering-wise, this means providing the transformer with a much larger core than would normally be necessary in a 60 Hz operation. In essence this is no particular problem other than the transformer has to be specially wound which makes it somewhat larger than a normal 60 Hz transformer of equal rating.

5.4 EFFECTIVE SIMULATION OF VARIOUS MOTOR AND CABLE COMBINATIONS BASED ON THE 20 HP MOTOR TEST

The 20 HP 445 VAC 3 phase 60 Hz REDA submersible pump induction motor was tested with the static inverter connected through 2775 feet of size #10 power cable in test #7 . The 20 HP motor is rated for 29 amps under fully loaded conditions. Size #10 cable exhibits about three ohms per leg per 2775 feet.

The voltage drop then equals:

29 x 3 x 1.732 = 150 V drop between any two power legs.

150 V is 33.70 percent of the 445 60 Hz required motor voltage.

Therefore exercising the small motor with 2775 feet of size #10 cable is the same voltage drop wise as exercising the 60 HP motor through 6755 feet of size #10 cable based upon the following calculations.

60 HP REDA motor is rated 32 amps at 1200 volts 60 Hz AC

33.7 percent of 1200 V = 404 ÷ 1.732 = 233

233/32 = 7.2964 ÷ 1.1 = 6,755 feet

In addition, the 150 HP Reda motor is rated at 75 amps 1150 VAC 60 Hz.

33.7 percent of 1150 V = 387.55 1.732 = 223/75A. = 2.9334 ÷ .41

Ω's (size #6 cable resistance per 1000') = 7,276 feet

Neglecting any loss in the step-up transformer one can assume the 20 HP motor test simulates operating the 150 HP motor then to a depth of 7,276 feet utilizing size #6 power cable with a resistance of .41 ohms per 1000 feet.

FIGURE D5

DATA SYMBOLOGY

Vdc Inverter DC Buss voltage - Digital voltmeter connected to inverter DC Buss (all data sheets)

Idc Inverter DC Buss current - Clamp on ammeter in DC Buss circuit (Some data sheets).

F Inverter output frequency - frequency counter attached to inverter master oscillator (all data sheets).

V_o Inverter/transformer RMS output to cable or motor.

V_m Motor terminal voltage - RMS voltmeter attached to motor terminals. (all data sheets).
Note: Vo and Vm will be the same where R_1 (cable) is not included.

I_o Current output to motor - Columbia AC/DC clamp on ammeter (all data sheets)

T_o Motor temperature - thermocouple mounted in the lubricant at the top of the motor (all data sheets).

T_c Torque load - Dynamometer reading in foot lbs of torque (as applicable data sheets)

S_1 Motor slip or RPM - Reading on RPM meter of dynamometer. May be compared to frequency of voltage applied to motor vs synchronous RPM operation (as applicable data sheets).

C_f Coolant flow in GPM - Type coolant and approximate flow rate (as applicable data sheets).

R_1 Cable resistance in ohms per leg - (as applicable data sheets)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1979—671-020/12

124pp

307108

COO-4033-19
Distribution Category UC-92a

ELECTRODRIL SYSTEM FIELD TEST PROGRAM
PHASE II TASK C
DEEP DRILLING SYSTEM DEMONSTRATION

FINAL REPORT

October, 1979

Work Performed for the Department of Energy
Under Contract EY-76-C-02-4033 A 006

GENERAL ELECTRIC COMPANY
SPACE DIVISION
P. O. Box 58408
HOUSTON, TEXAS 77058

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1.0 SUMMARY

This report documents the results of the Phase II Task C drilling demonstration program which was conducted from November 1978 to July 1979. This operational demonstration of the Deep Drilling System was the culmination of over two years of Department of Energy, industry, and General Electric effort. The demonstration program was structured to evaluate both the technical and economic viability of the Electrodril System. In planning the program, maximum advantage was taken of the lessons learned in conducting the Phase I program. Equipment design modifications, identified as desirable during the Phase I program, were incorporated into the Phase II system design. These modifications were aimed at making the drilling system a better operational tool by ruggedizing the design at the points where maximum wear or crew handling could be expected.

To assure that the actual drilling demonstrations were effective, site selection criteria (Appendix A) and site-specific detailed test plans (Appendix B) were developed. In addition, definitive measures of system effectiveness were established to form a baseline against which the Electrodril System performance could be judged and the ultimate technical and economic utility of the system could be evaluated. This data is also embodied in each site-specific test plan and is presented in the pertinent appendices of this report.

The first operational demonstration of the Electrodril Deep Drilling System was conducted on an Exxon well site near Beaumont, Texas. The Electrodril System was deployed on April 7, 1979, in a 9 7/8 inch hole at a depth of 6973 feet. The downhole motor and instrument assembly were connected to one 5000-foot cable,

one 1000-foot cable and eight 90-foot stands of prewired drill pipe. A series of surface equipment calibration runs were made by electrically energizing the downhole assemblies. No drilling was attempted at this time. After satisfactorily completing these calibration runs, the motor was re-energized to begin the drilling process. It was at this point that an electrical failure in the downhole system was identified and the demonstration was aborted on April 14, 1979. Appendix C documents the Site I Test Report.

The Electrodril System was returned to Houston and refurbished. The primary cause of the system failure at Beaumont was identified as a connector in the instrument harness assembly. The harness assembly was, consequently, refurbished and retested. The Electrodril System was subsequently made ready for a second demonstration, with preparations completed in Mid-May 1979.

The second demonstration of the Electrodril Deep Drilling System was conducted on a Shell well near McCook in South Texas. The Electrodril System was deployed on June 27, 1979 in a 9 7/8 inch hole at a depth of 5220 feet. The downhole motor and instrument assembly were connected to one 5000-foot cable. This drill string makeup had approximately 20 feet of the electrified kelly remaining to be drilled down. After initial system calibration, the kelly was drilled down without incident. During this time, all downhole data was transmitted and displayed at the surface in the data analysis trailer and the driller's display unit. The process of adding a 30-foot prewired joint to the drill string, however, was unsuccessful due to electrical problems.

The decision was made to drill ahead conventionally an additional 60 feet using the Electrodril motor and bit, to a point where a prewired 90-foot stand of pipe could be introduced. The 90-foot dedicated pipe was picked up, added to the string and checked electrically. Drilling continued until a short developed in the 90-foot stand. The shorted stand was replaced and the kelly was once again drilled down. An additional 60 feet was drilled by conventional means because of continuing electrical-mating problems with the reworked 30-foot dedicated joints. At this time it was determined that the resistance to ground below the top of the 5000-foot cable had degraded to the point where equipment damage could result if power were applied. The decision was made on July 1, 1979, to come out of the hole after approximately 60 feet of hole was made by electrical bit rotation.

The Electrodril System was returned to Houston July 4, 1979, and an intensive failure investigation was conducted. The results indicate that the primary cause for the system failure at McCook centered around the failure of the female field replaceable connector. The failures are primarily precipitated by water ingress into the core of the connector causing a high electrical leakage to ground. Not all of the female connectors tested had failed; those that passed the initial post test analysis were subjected to an additional series of mated and unmated pressure tests from which it was concluded that the fundamental design of the field replaceable connector is sound. The Site II Test Report is contained in Appendix D.

A secondary problem was found when the motor and bit shaft were disassembled. An upper seal insert and a lower seal O-ring had failed. A fix has since

been made to prevent recurrence but it is not covered in this report. The problem is discussed more fully in Appendix D.

The connector failures experienced at McCook have been attributed to process problems in manufacturing. The manufacturer is now aware of the problem and a new series of connectors is being made for evaluation during the first quarter of calendar year 1980 under Phase II, Task C-1.

2.0 INTRODUCTION

Electrodril is an advanced drilling system incorporating a downhole electric drill motor and a downhole sensor and telemetry system. The downhole motor provides high horsepower and torque at the bit face in combination with high rotational speed and the ability to vary this speed as required between 40 and 400 rpm The sensor and telemetry system provides real time (MWD) surface readout of downhole parameters. Sixteen channels of data are updated twice per second.

The Phase II Electrodril Deep Drilling Demonstration program has been executed in three distinct tasks. The initial Phase II Task A effort, begun in July 1977, encompassed the engineering, design and preprocurement documentation activity required for the procurement of long-lead-time equipment. Task B included final design reviews of key system elements, the completion of all engineering documentation and release for fabrication. This procurement process was begun in April 1978. In addition, Task B included the assembly and subsystem testing of the Deep Drilling System and concluded with system verification testing of the total system at the Brown Oil Tools test facility, Houston, Texas. This Task B effort was successfully concluded in September 1978.

This report covers the Phase II Task C effort which followed the successful completion of the systems verification test of the Deep Drilling System and consisted of two drilling system demonstrations under operational conditions at two separate well sites. These two drilling demonstrations were concluded in the first and second calendar quarters of 1979.

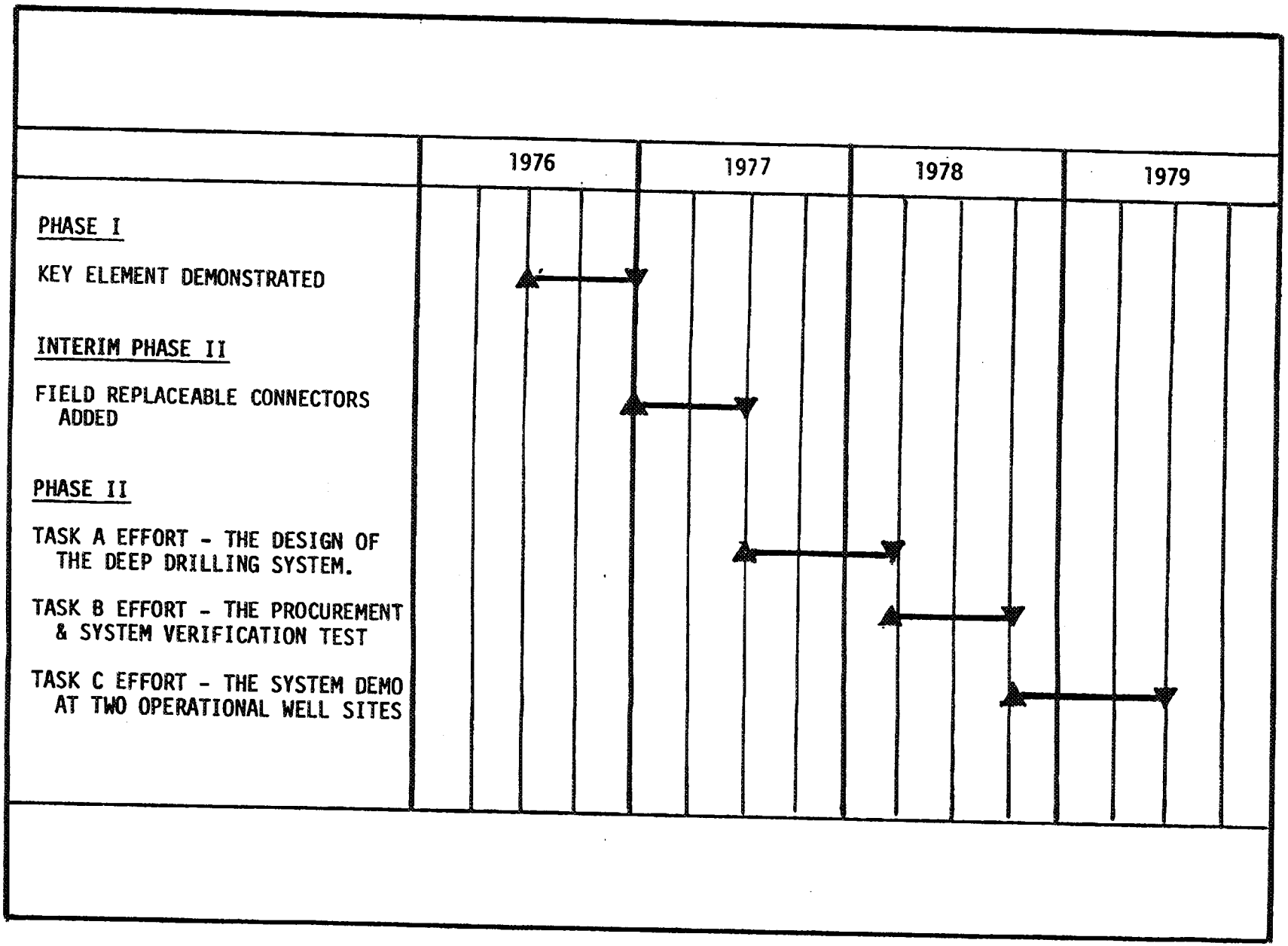

TABLE 1
SUMMARY PROGRAM SCHEDULE

3.0 PROGRAM OBJECTIVES

The objectives of the Phase II Deep Drilling System demonstration program have long been established:

° Electrodril System Operational Performance. Establish the integrity of system's functional performance in terms of the capability of all subsystems to sustain drilling operations within the constraints of expected subsystem life and maintenance requirements.

° Electrodril System Economic Performance. Determine the economic viability of the system as a function of the operating performance characteristics derived from the planned deep drilling demonstrations.

Task C objectives can be summarized as follows:

° The development of the detailed planning, procedures, and measures of system effectiveness necessary to optimize the conduct of the operational demonstration of the Deep Drilling System.

° The implementation of the Deep Drilling System demonstration program at three operational drilling sites. The three-site demonstration was cut back to two sites in December 1978 due to funding limitations.

Specific objectives of the Task C effort are detailed below:

TEST PLANNING

1. Develop a set of drill site selection criteria to assure that Field Test demonstrations are each conducted in formations having known characteristics

so that performance measurements are consistently obtained and meaningful.

2. Develop a uniform set of measures of effectiveness so that the system and operational test data derived will provide a valid and consistent yardstick against which system performance can be evaluated.

3. Develop a test plan for each operational test site.

FIELD TEST DEMONSTRATION

1. Demonstrate the capability of the 285-HP Electrodril System using variable frequency power and its associated power cable deployment and retrieval system in deep,tough formations.

2. Demonstrate the capability of the 285-HP Electrodril System, with its instrumentation and telemetry system to drill effectively in tough formations.

4.0 PROGRAM PLANNING

In preparation for the two-site drilling demonstration, a series of planning documents was developed. These documents were developed to facilitate the objective selection of the drill sites and the orderly conduction of the Electrodril System evaluation.

The first document, presented in Appendix A, was one in which drill site selection criteria were developed. These criteria were not site-specific but identified preferred site characteristics. Three general well site areas were identified, representing an increasing order of drilling difficulty. The preferred hole dimensions for each well site were identified, as were the operational deployment depths best suited to an Electrodril demonstration, commensurate with well safety.

A generic test plan was then developed which restated the demonstration objectives and delineated the preferred cadence of system deployment. From this skeletal document, site specific test plans were written for each of the two finally selected drilling sites. These documents are presented in pertinent appendices of this report.

Measures of system effectiveness were also developed to assure that the information obtained during each Electrodril demonstration would permit meaningful performance evaluation of the system. These measures of system effectiveness were grouped into three categories: Economic, Functional and Safety. This data is also embodied in each site-specific test plan and is presented in the pertinent appendices of this report.

5.0 BASELINE SYSTEM DESCRIPTION

A schematic of the Deep Drilling System is shown in Figure 1. The System is composed of both downhole and surface components. The downhole components consist of an electric drill motor and its mechanical assemblies; cable and connectors; and the instrumentation assembly. The surface components consist of cable skids; power generation equipment; cable handling equipment; power control equipment; and the telemetry, instrumentation, surface processing, display and control unit.

These system components have been structured to permit their addition in modular fashion to standard rotary drilling rigs depending upon the objectives of the operator of the rig and the configuration of the equipment at the well site. The installation and operating procedures for Electrodril have been designed to be compatible with existing rigs and conventional drilling operations.

A detailed description of the Deep Drilling System can be found in the U.S. Department of Energy document BETC-4033-3.

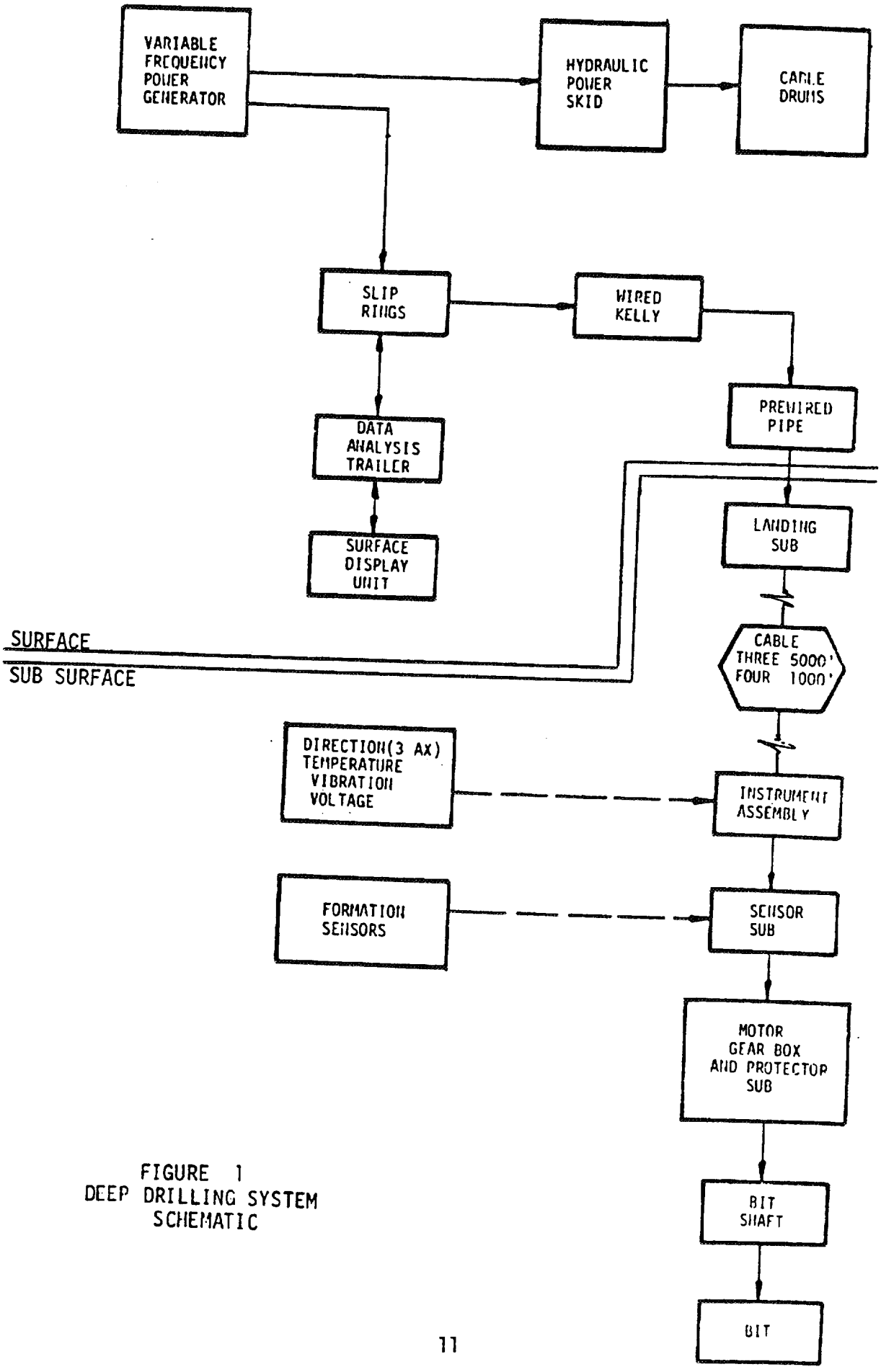

FIGURE 1
DEEP DRILLING SYSTEM
SCHEMATIC

6.0 SYSTEM DEPLOYMENT METHOD

Two basic activities are necessary to receive the Electrodril at a rig site -- the deployment of the ground support equipment in the vicinity of the rig and the assembly in the rig of some key Electrodril elements. These two basic activities can be done independently.

A general layout of the surface elements of Electrodril is shown in Figure 22. Typically, this ground support equipment is deployed more than 100 feet away from the rig. There is the need, however, to accommodate 1000 feet of "dedicated" drill pipe on the pipe rack. In addition, an electric power cable is run from the Electrodril power generating equipment to the base of the rig, up a derrick leg and along the standpipe and mud hose to the rig swivel. This cable will eventually be mated to the slip ring assembly which will be located above the kelly (Figure 23).

There are two primary assembly tasks to be accomplished in the rig before Electrodril is deployed:

1. Eleven 90-foot stands of drill pipe must be assembled and electrified with standard Electrodril cable and connectors. One stand serves as a spare in the event it is needed.

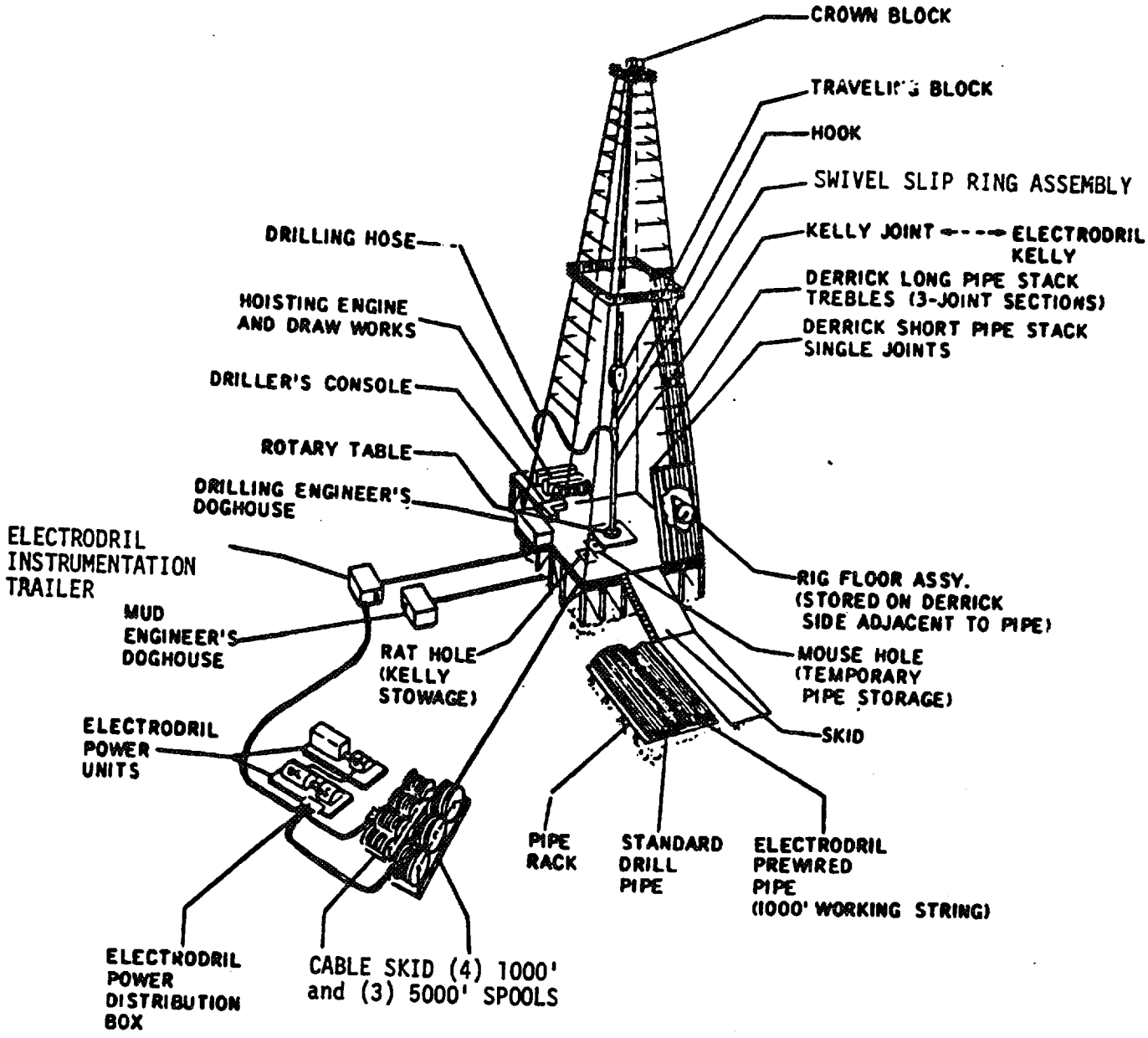

FIGURE 2
SURFACE ELEMENTS
DEEP DRILLING SYSTEM

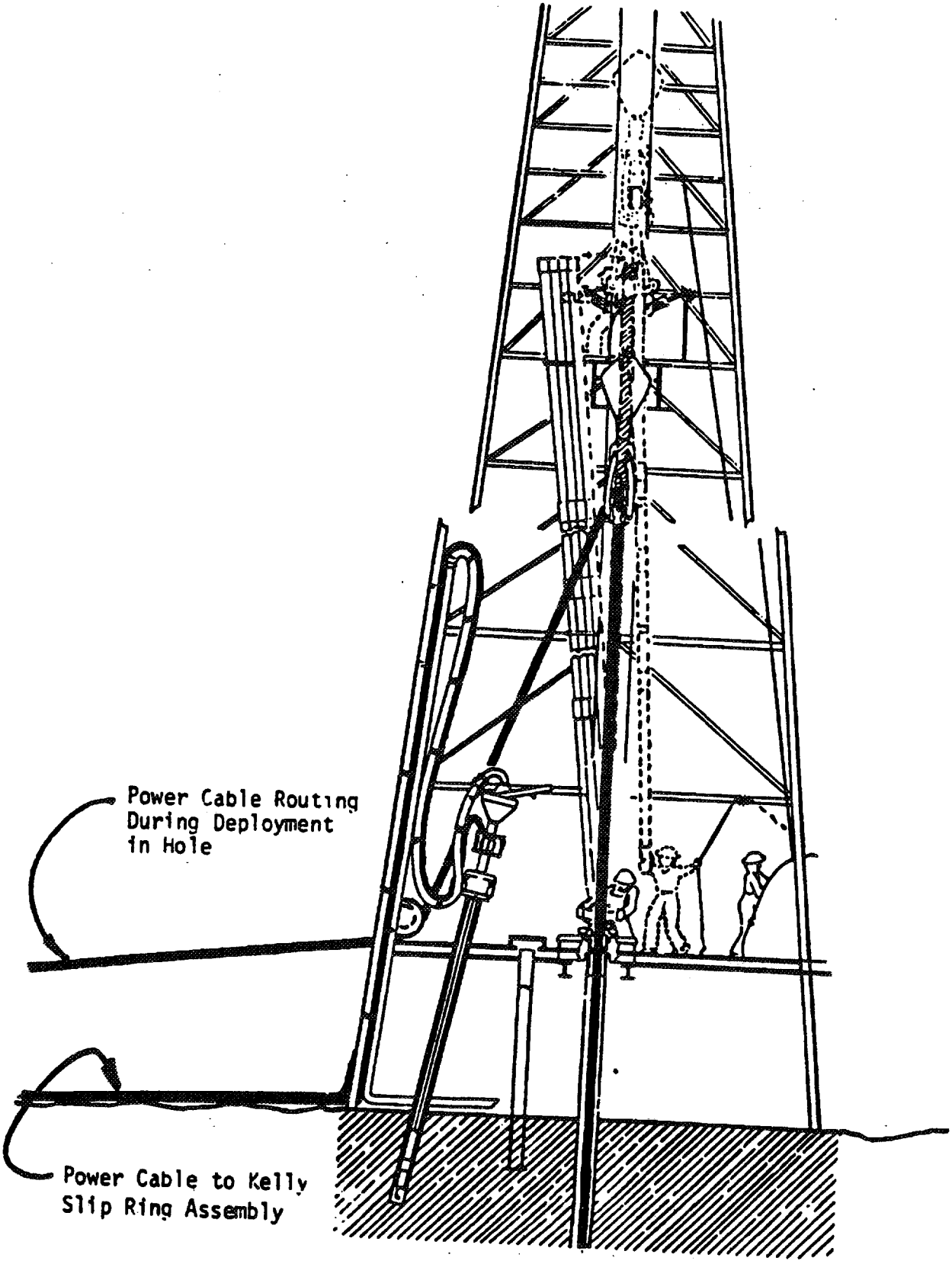

FIGURE 3
Showing Routing of Electrodril
Power Cable

2. The kelly must likewise be electrified with standard cable and connectors, and the slip ring assembly must be installed between the kelly and swivel.

Assembly of the eleven 90-foot stands of dedicated (prewired) drill pipe is accomplished using the 1000 feet of drill pipe delivered with the Electrodril equipment. The use of this drill pipe is necessitated only because the length of each joint has been carefully measured and the mating cable lengths have been cut and terminated to suit a particular three-joint combination. This 1000 feet of pipe is run in the hole as part of the conventional string during normal drilling operations. As the drill string is pulled out, 90-foot stands of the Electrodril pipe are isolated prior to deployment of the Electrodril system and electrified by suspending the mating cable/connector lengths and securing them into each stand. Each completed prewired stand is then stood back in the rack.

The electrification of the kelly is accomplished by threading an electrical cable through the kelly bore. The upper end of the cable is brought out of the bore by a special crossover sub and terminated at a connector. The slip ring assembly is mounted on this crossover sub and electrical connections made between the connector and slip ring. The top of the slip ring is mated with the electrical cable that runs up the derrick and along the mud hose.

To minimize the time consumed in these assembly activities, the preferred cadence is to separate and "setback" the 11 dedicated (prewired) stands, then to electrify the kelly, set it in the rat hole and finally pick up the motor subsystem and leave it in the slips ready to be run in the hole.

After completion of the previously described preparations, Electrodril is ready for downhole deployment. If the "in rig" preparations are done in the recommended sequence, the motor subsystem will be in the slips and ready to go down hole.

The instrumentation subsystem is first mounted to the top of the motor and the combined Electrodril downhole assembly is lowered until the top of the non-magnetic collar is in the slips. An electrical check is made at this time to assure the system is in functional order. Upon successful completion of these electrical checks, approximately 5000 feet of rig drill pipe is run in the hole on top of two special collars and the motor/instrumentation assembly. During this process an accurate pipe tally must be kept, as the length of drill pipe run in the hole must match that of the cable which is to be installed in it. The Electrodril system inventory provides sufficient pup joints of various lengths to facilitate matching drill string and cable lengths. At the completion of the length-matching task, a special landing sub is installed on the drill pipe to facilitate the suspension of the power cable.

The rig floor and traveling sheaves (Figures 24 and 25) are then installed, in a similar manner to that used for conventional wireline logging operations. In addition, a prewired sinker bar with a female connector attached is set in the drill pipe in special slips (Figure 26), and the Electrodril power cable is brought over from the cable skid and mated to it (Figure 27). The power cable is routed under the rig floor sheave and over the traveling sheave similar to conventional wireline logging procedures.

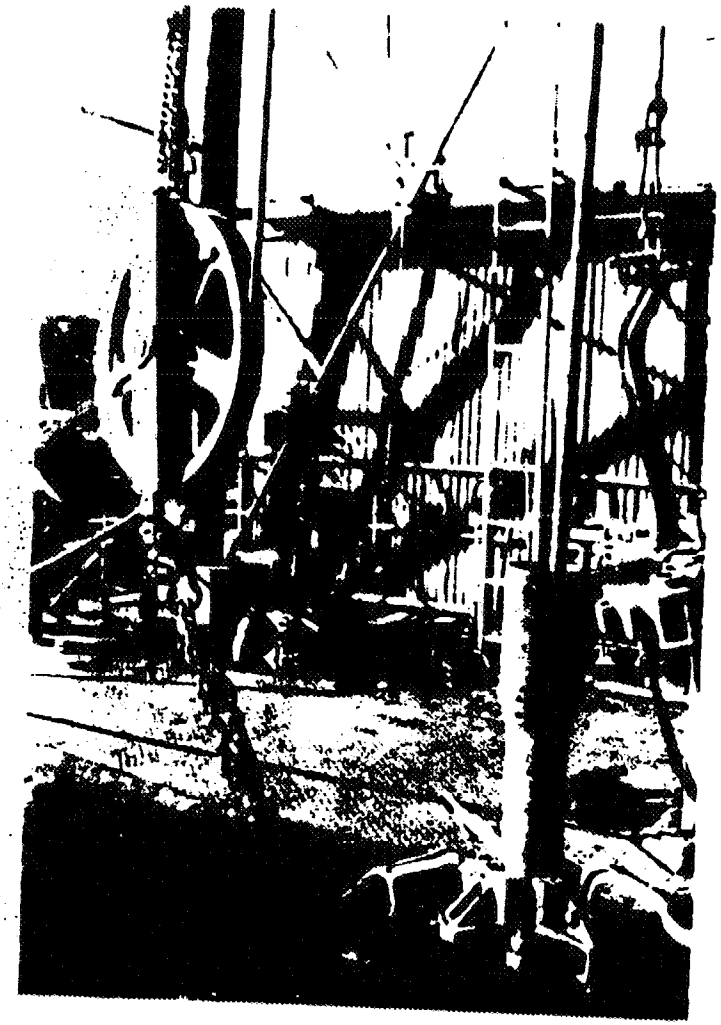

Figure 4

ELECTRODRIL RIG FLOOR SHEAVE

Figure 5

ELECTRODRIL TRAVELING SHEAVE

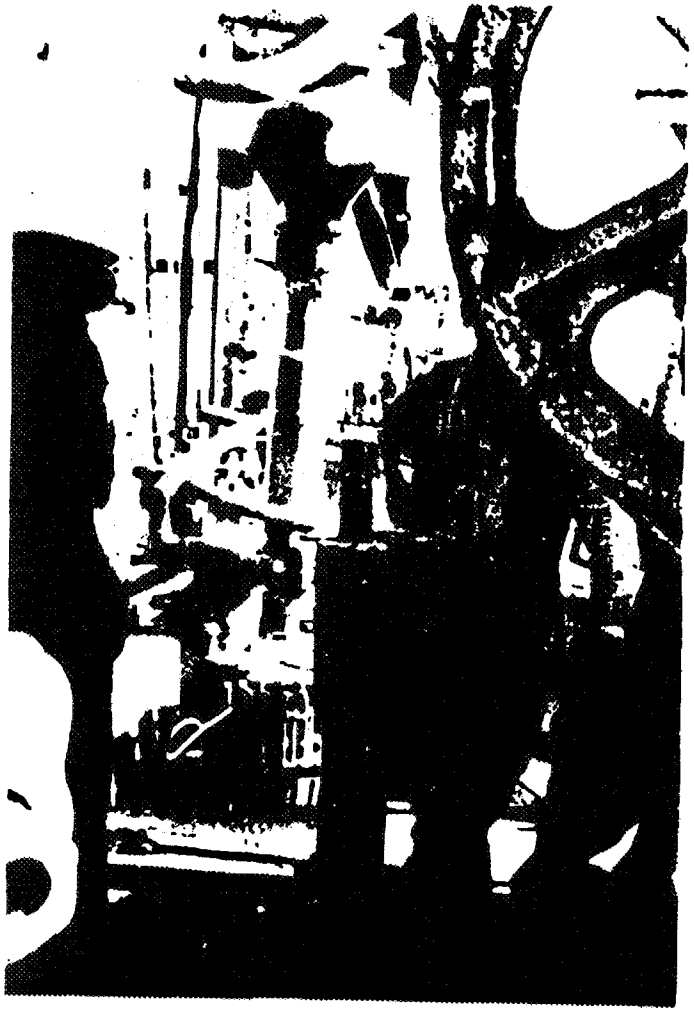

Figure 6

SINKER BAR IN SPECIAL SLIPS
SUSPENDED IN DRILL PIPE

Figure 7

CABLE ADAPTOR BEING PREPARED
FOR SINKER BAR

With the power cable and sinker bar mated, the assembly is run into the hole. Cable deployment can be accomplished at up to approximately 400 feet per minute although towards the end of the cable run-in procedure, care must be exercised by utilizing a fairly slow cable speed to provide greater control. At the point where the cable is about to be run off the cable reel (Figure 28), the reel is stopped so that the cable end can be removed from its reel attachment. The cable is secured in the drill pipe using special cable slips (Figure 29). These cable slips allow the cable end to be slackened off, removed from the reel and attached to a wire rope. The wire rope, which is mounted on a stinger winch, controls the final deployment of the cable over the sheaves into the landing sub. At this point the downhole male connector is mated with the female connector at the end of the cable length being deployed. Just prior to seating the cable, the slips are used to permit the attachment of the cable landing shoe and male connector (Figure 30).

This cable deployment process is repeated, depending on depth, until the bit is on bottom and a cable/connector string connecting the Electrodril downhole assembly (motor assembly and instrumentation subsystem) is at the rig floor level. Electrodril power cable is provided in lengths of 5000 feet and 1000 feet and shorter lengths are available by using prewired 90-foot stands and 30-foot joints. Once the system is fully deployed and checked electrically, the prewired kelly (Figures 31 and 32) is attached, and the downhole motor is turned on using the driller's console (Figure 33).

After the kelly has been drilled down, a conventional mousehole connection is made first with one and then with the second of the prewired Electrodril 30 foot

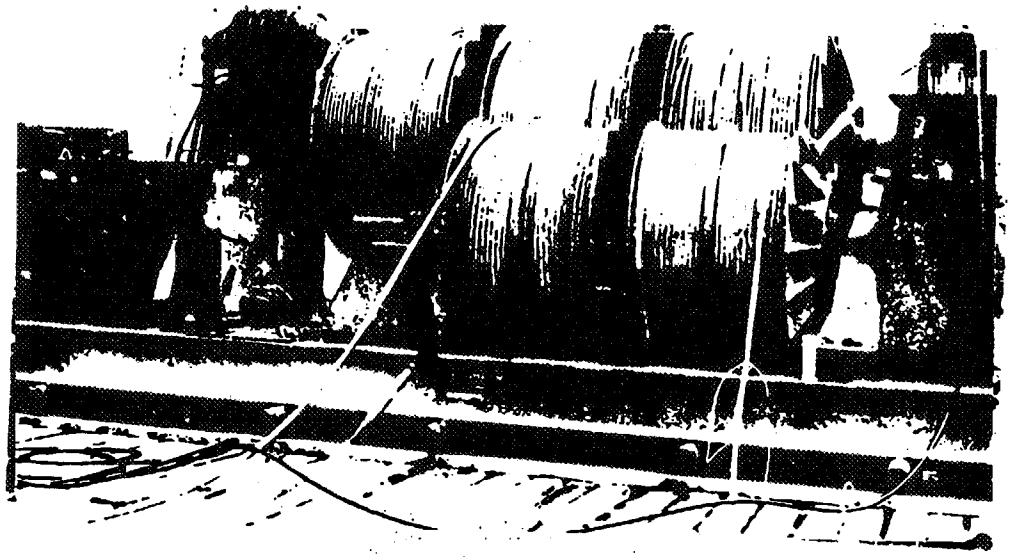

Figure 8

ELECTRODRIL POWER CABLE SKID
CAPACITY - 19000 FEET

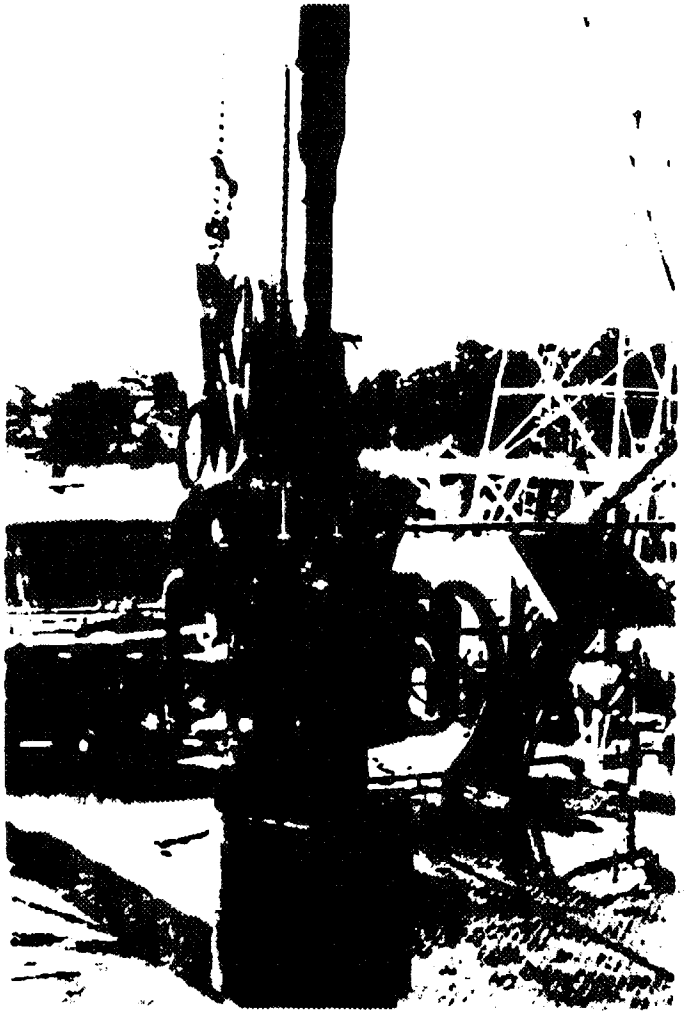

Figure 9

ELECTRODRIL CABLE SLIPS

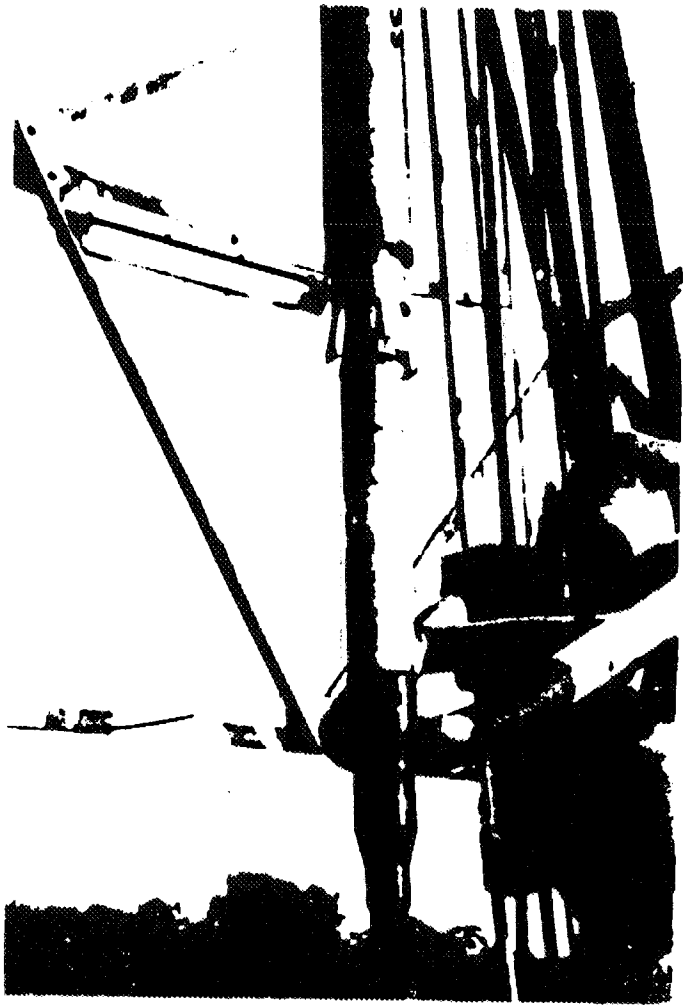

Figure 10

UPPER END OF POWER CABLE SHOWING
LANDING SHOE

Figure 11

CABLE CROSSOVER ABOVE KELLY

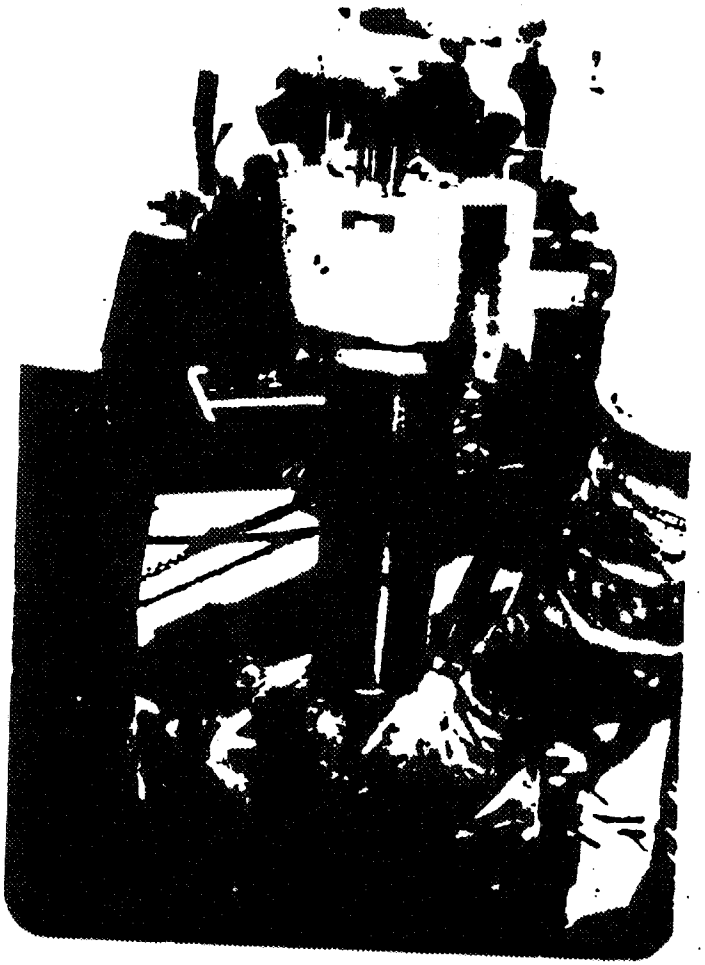

Figure 12

SLIP RING ASSEMBLY INSTALLED
ABOVE CABLE CROSSOVER

Figure 13

ELECTRODRIL DRILLERS CONSOLE

joints and drilling is continued. When 90 feet has been drilled with the kelly and two prewired 30-foot joints, the kelly is set in the rat hole and two prewired 30-foot joints are laid down and replaced by one of the prewired 90-foot stands. The kelly is then picked up and drilling is continued. When 1000 feet has been drilled, all ten 90-foot lengths of prewired pipe and the two prewired 30-foot lengths are set back from the hole and 1000 feet of conventional drill pipe is run into the hole. A landing sub and pup joints are used to make the pipe tally fit the length of cable to be deployed. A 1000 foot length of Electrodril cable is then deployed in a similar manner to that previously described. Drilling again proceeds, using the kelly, the two prewired joints and the prewired 90 foot stands until another 1000 feet has been made. When 5000 feet of hole has been drilled, four 1000 foot cables, ten 90-foot stands and two 30-foot prewired joints will have been deployed. These are all removed in sections, and rig drill pipe is run back in. A 5000-foot length of Electrodril cable is then deployed, landed and checked electrically. Drilling then continues as before. It should be noted that, to minimize time, bit trips will be used as much as possible to facilitate these pipe manipulations. At any time the 1000-foot and 5000-foot lengths of cable can be removed from the pipe with a wireline fishing tool. To accommodate this requirement, the 90-foot stands of prewired pipe are run in the hole on top of a safety joint.

7.0 SITE I RESULTS SUMMARY

The first Task C drilling demonstration site was the Exxon I.C.H. Matthews Well Number 1 located near Beaumont, Texas. Transportation of the Electrodril Deep Drilling System to this Beaumont site began on April 4, 1979. General views of the rig site are shown in Figures 34 through 38. Initial plans called for the deployment of Electrodril at a depth of 5876 feet after 2000 feet of surface casing had been set. Bit size to be used with Electrodril was 9 7/8 inches.

Surface deployment of Electrodril was completed April 7. The downhole assembly was then tested electrically on the surface. During this surface checkout of the system, a problem was diagnosed in the voltage control unit, which necessitated return of the instrument sub to Houston for repair. While this repair was being made, Exxon continued rotary drilling.

Electrodril was subsequently deployed at 6973 feet with 6000 feet of cable (one 5000-foot and one 1000-foot length) and eight 90-foot stands of prewired drill pipe to hole bottom. This drill string with the Electrodril downhole system was checked electrically and found to be operationally ready. The motor was started and shut down five times to calibrate the motor control servo loop. At the time the drilling demonstration was to begin, the motor failed to start. An electrical short was isolated to the downhole assembly below the armored cable. Consequently, the Electrodril demonstration was discontinued.

The electrical short was located in the lower instrument sub power connector (Figures 39 and 40). The failure was in the connector harness rather

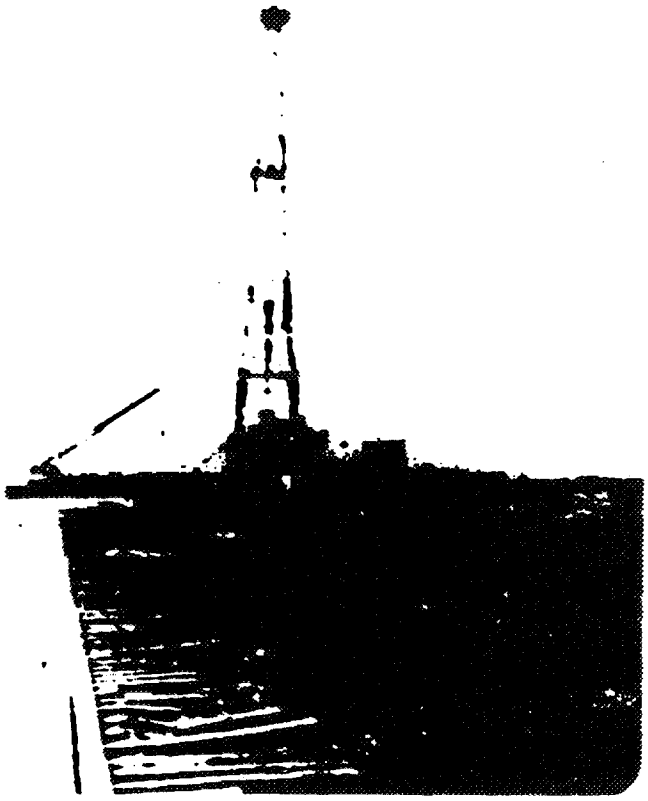

Figure 14

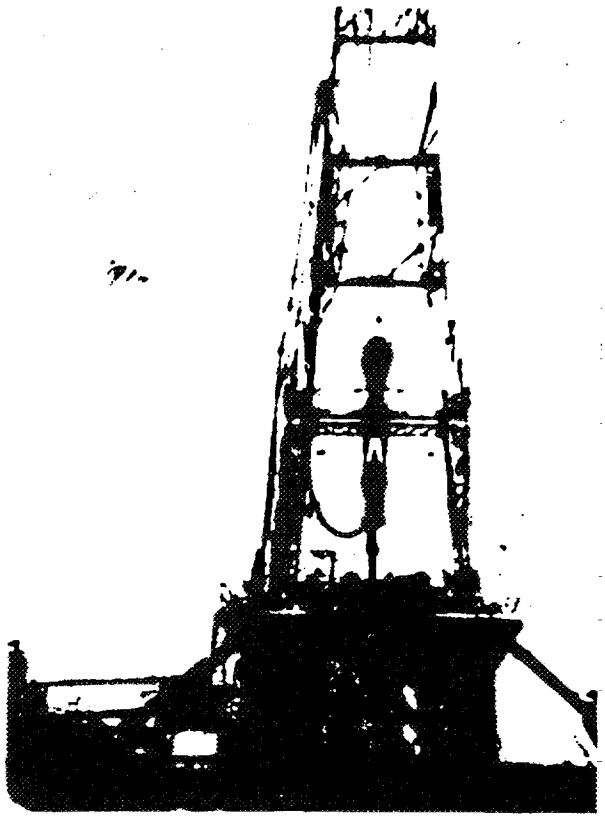

Figure 15

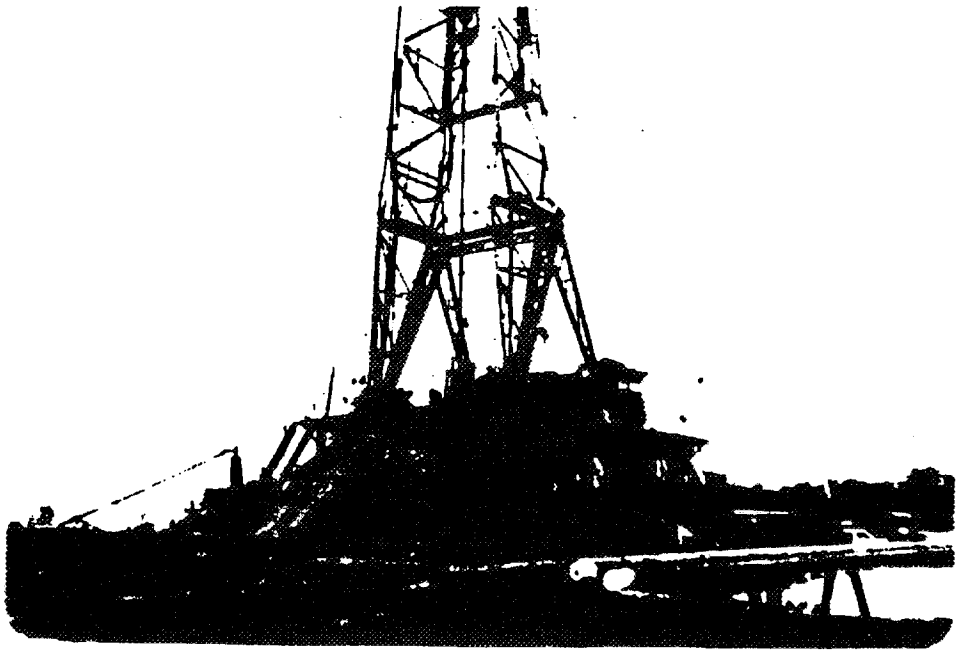

Figure 16

GENERAL VIEWS OF BEAUMONT TEST SITE

Figure 17

ELECTRODRIL MOTOR AND INSTRUMENT ASSEMBLIES
AT BEAUMONT TEST SITE

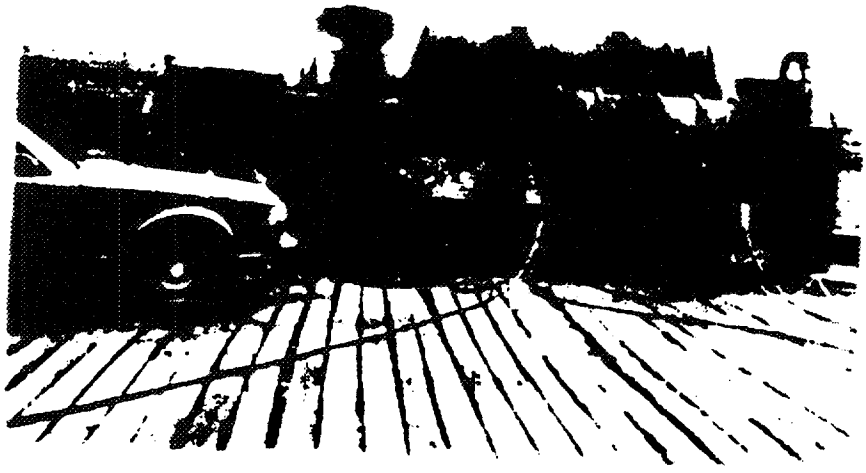

Figure 18

ELECTRODRIL CABLE SKID WITH 19,000 FEET OF CABLE
AT BEAUMONT TEST SITE

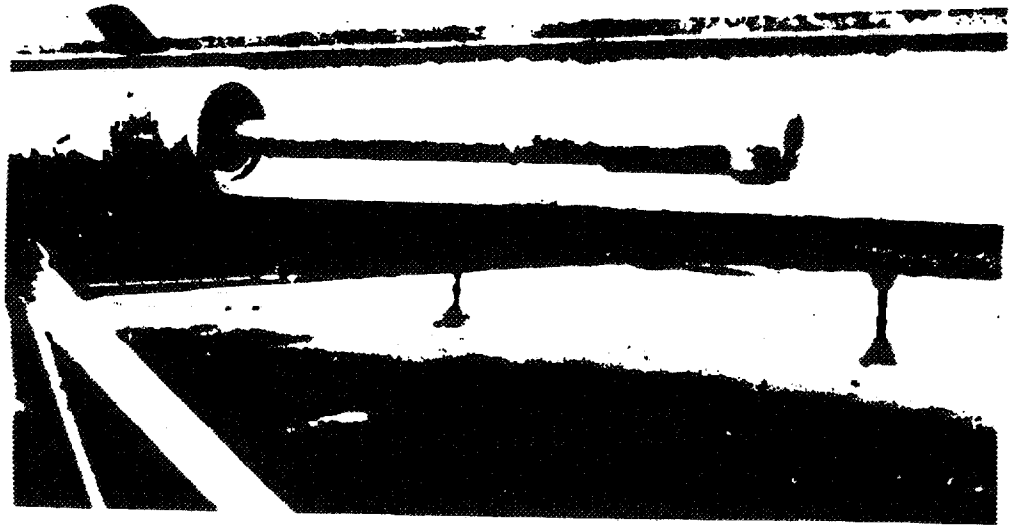

Figure 19

LOWER INSTRUMENT SUB POWER CONNECTOR ASSEMBLY

Figure 20

POWER CONNECTOR

than in the field replaceable connector proper. The probable cause of this connector failure is centered around a mechanical interference in the multi-pin mating connector adaptors, which impaired complete makeup of the connector. A more complete failure analysis is presented in Appendix D.

Despite this connector failure and the resulting shutdown of the demonstration, a number of significant accomplishments were achieved:

- The cable reel skid was successfully used for the first time to deploy and retrieve a 5000-foot cable.

- The actual deployment of a 5000-foot cable was also a first, proving the cable armoring capability and the stinger winch's ability to retrieve the cable.

- In addition, the rig floor system (i.e., both sheaves and the method of control) was successfully exercised for the first time using the 5000-foot cables.

- Although the motor voltage servo control loop had been extensively exercised, the full capability of the loop and its transient response characteristics could not be fully evaluated except in a full downhole deployment. The five successful motor starts at 7000 feet depth before connector failure represent a major technical accomplishment. In addition, the ability of the servo loop to shut itself down immediately after cable failure attests to the correct design of the automatic shutdown circuit in the static inverter.

The final downhole configuration included:

one - 5000-foot cable

one - 1000-foot cable

eight - 90-foot stands

one - 45-foot electrified kelly

This configuration represents a total of 12 "Bayonet" cable connectors plus those in the instrument assembly and motor. At the time of cable deployment, before connector failure, there was resistance to ground of approximately five megohms or better on each leg of the power conductors. This was a remarkable achievement and proves the soundness of the basic connector design.

The experience gained during the deployment process indicated very strongly that in a fully operational situation, Electrodril deployment can be accomplished within a reasonable time frame and without excessive cost consequences.

8.0 SITE II RESULTS SUMMARY

The second Task C Drilling Demonstration site was the Shell Martinez Well Number 4 in the La Copita Field, Starr County, Texas. Transportation of the Electrodril Deep Drilling System to this well site began on June 25, 1979. General views of the rig site are shown in Figures 41 through 43. Plans were to deploy Electrodril at the 5180 foot depth after surface casing had been set. Bit size to be used by the Electrodril was 9 7/8 inches with three 11/32-inch diameter jets.

Surface deployment of the Electrodril was completed June 27, and a surface test of the downhole assembly was successfully concluded June 28. The voltage control servo loop was also successfully exercised at this time using the static inverter, the downhole sensing unit and 5000 feet of cable.

Electrodril was deployed downhole on June 29 at a depth of 5220 feet. Initial makeup of the drill string was the bottom hole assembly comprising the motor and instrument assemblies, 17 drill collars (including two Electrodril collars), and sufficient drill pipe to land 5000 feet of cable. The electrified kelly was made up on this assembly and drilling commenced at 12:30 a.m. The remainder of the kelly was drilled down (21 feet) with the motor running at 60 rpm and with 8000 lbs. weight on bit. During this process, all aspects of the downhole instrumentation subsystem functioned properly. Samples of the real time data received, displayed and recorded in the instrumentation trailer are shown in Table 2 and Figure 44.

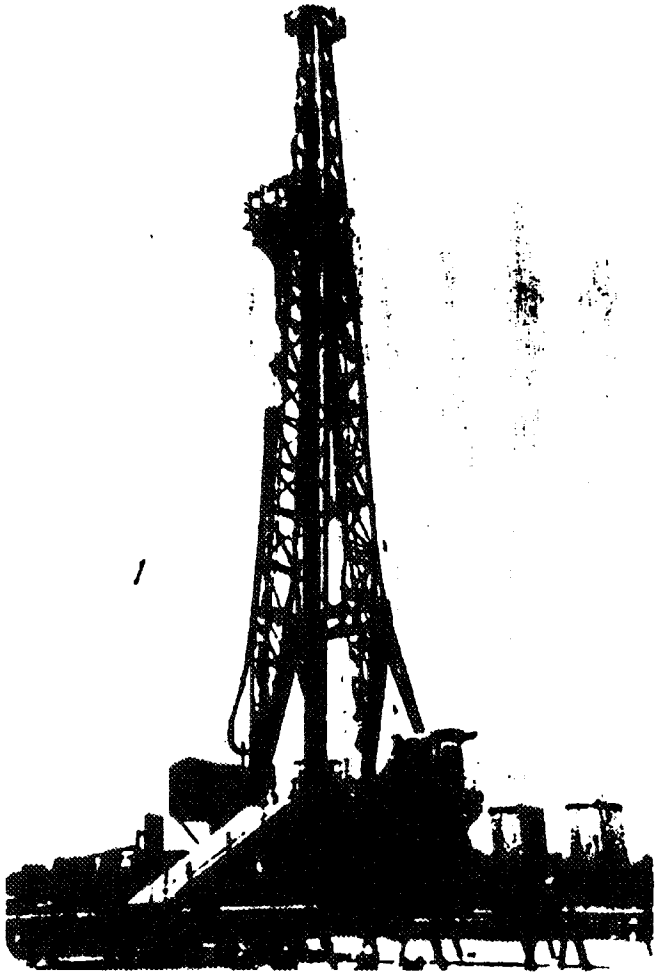

Figure 21

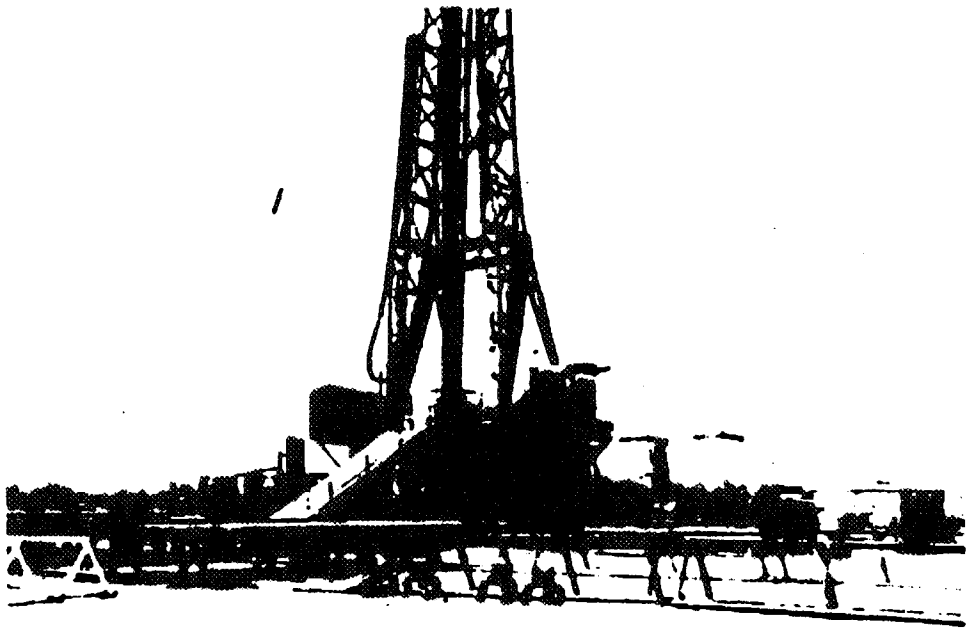

Figure 22

GENERAL VIEWS OF RIG AT MC COOK SITE

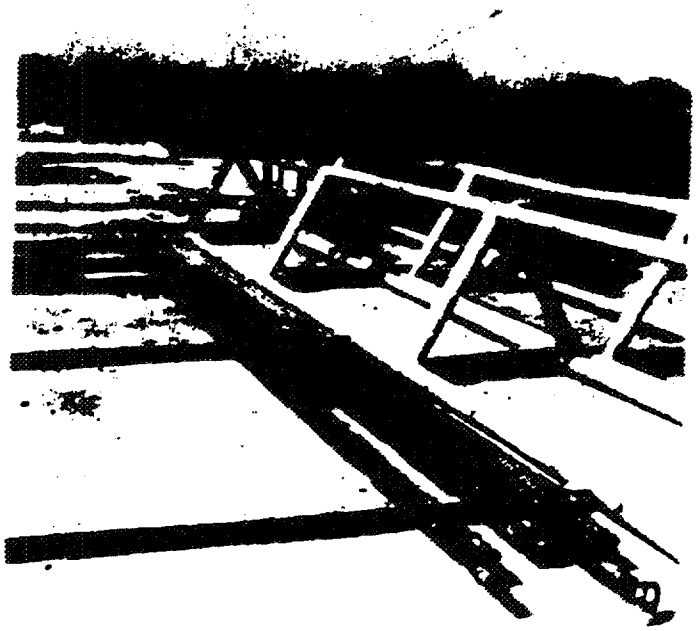

Figure 23

ELECTRODRIL MOTOR AND INSTRUMENT ASSEMBLIES
ON PIPE RACK WITH SINKER BAR BELOW

COMPANY: GE FIELD: LACOPITO LEASE: MARTINEZ1
WELL NO: HARKINS#1TY: STARR STATE: TX DATE: 07/01/79

TIME HR:MN	DEPTH FEET	PEN F/H	DRFT DEG	AZMTH DEG	TFACE DEG	MTR DGF	INS DGF	ANN DGF	MTR AMP	DPRS PSI	SURF PSI	VOL GPM	GMMA CNT	HANGWT POUNDS
00:32	05203.3	000	00.3	219.0	000.0	151	131	147	000	1417	1862	465	0043	000000
00:32	05203.3	000	00.0	339.0	000.0	152	130	147	000	1409	1858	465	0042	000000
00:32	05203.3	000	00.4	230.6	000.0	152	130	147	000	1259	1683	370	0042	000000
00:32	05203.3	000	00.8	078.8	000.0	152	130	147	001	1418	1953	412	0044	000000
00:33	05203.3	000	00.9	094.6	331.7	152	130	147	000	1418	1955	423	0043	000000
00:33	05203.3	000	00.3	309.5	000.0	152	130	147	001	1418	1841	402	0041	000000
00:33	05203.3	000	00.8	308.9	000.0	152	130	147	022	1428	1849	402	0047	000000
00:34	05203.3	000	00.7	306.9	000.0	152	131	147	021	1417	1840	455	0045	000000
00:34	05203.3	000	01.6	263.4	234.5	151	131	147	021	1407	1836	455	0047	000000
00:34	05203.3	000	00.5	104.0	000.0	151	130	147	000	1418	1824	412	0047	000000
00:34	05203.3	000	01.0	354.2	349.4	151	130	147	000	1428	1841	423	0048	000000
00:34	05203.3	000	00.5	360.0	000.0	151	130	147	000	1428	1818	423	0048	000000
00:35	05203.3	000	00.5	124.3	000.0	151	130	147	000	1428	1825	391	0048	000000
00:35	05203.3	000	00.4	109.4	000.0	151	130	147	000	1428	1831	370	0043	000000
00:35	05203.3	000	01.6	295.2	053.1	151	130	147	000	1428	1814	370	0044	000000
00:35	05203.3	000	00.3	360.0	000.0	151	130	147	000	1428	1824	423	0044	000000
00:36	05203.3	000	00.2	180.0	000.0	151	131	147	000	1445	1823	412	0043	000000
00:36	05203.3	000	01.0	176.2	301.6	150	130	147	000	1428	1816	370	0040	000000
00:36	05203.3	000	00.3	360.0	000.0	151	131	147	000	1445	1814	349	0042	000000
00:36	05203.3	000	01.0	162.9	142.4	150	130	147	000	1428	1807	402	0046	000000
00:37	05203.3	000	00.1	281.8	000.0	150	130	147	000	1437	1812	381	0047	000000
00:37	05203.3	000	00.7	102.1	000.0	151	131	147	000	1445	1815	402	0046	000000
00:37	05203.3	000	00.3	081.2	000.0	150	130	147	000	1428	1801	381	0046	000000
00:38	05203.3	000	00.9	169.3	118.3	150	130	147	000	1447	1797	402	0050	000000
00:38	05203.3	000	00.7	273.0	000.0	150	130	147	000	1437	1805	423	0048	000000
00:38	05203.3	000	00.4	076.7	000.0	150	131	147	000	1445	1797	434	0044	000000
00:38	05203.3	000	00.4	041.3	000.0	150	130	147	000	1437	1779	434	0042	000000
00:39	05203.3	000	00.6	237.0	000.0	150	130	147	000	1437	1796	455	0044	000000
00:39	05203.3	000	00.8	196.0	000.0	150	130	147	000	1437	1775	465	0046	000000
00:39	05203.3	000	00.8	017.1	000.0	150	130	147	000	1437	1738	423	0045	000000
00:39	05203.3	000	00.4	360.0	000.0	150	130	147	000	1447	1805	381	0043	000000
00:39	05203.3	000	00.6	125.5	000.0	150	130	147	000	1447	1813	370	0045	000000
00:40	05203.3	000	00.8	076.3	000.0	150	130	146	000	1456	1808	391	0041	000000
00:40	05203.3	000	00.4	082.8	000.0	150	130	146	000	1456	1826	370	0041	000000
00:40	05203.3	000	00.3	229.1	000.0	150	130	146	000	1456	1824	444	0045	000000
00:40	05203.3	000	00.4	180.0	000.0	150	130	146	000	1456	1818	455	0045	000000
00:41	05203.3	000	00.3	360.0	000.0	150	130	146	000	1456	1814	402	0045	000000
00:41	05203.3	000	00.7	304.4	000.0	150	130	146	000	1447	1816	391	0044	000000
00:41	05203.3	000	00.1	102.6	000.0	150	130	146	000	1447	1815	370	0044	000000
00:41	05203.3	000	00.0	078.1	000.0	150	130	146	000	1447	1809	370	0046	000000
00:42	05203.3	000	00.3	276.8	000.0	149	130	147	000	1454	1809	402	0046	000000
00:42	05203.3	000	00.4	220.9	000.0	149	130	146	000	1447	1804	434	0044	000000
00:42	05203.3	000	00.2	032.5	000.0	149	130	146	000	1437	1813	436	0044	000000
00:42	05203.3	000	00.9	360.0	000.0	149	130	146	000	1437	1804	402	0041	000000

TABLE 2

SILENT 700 PRINTOUT OF McCOOK DATA

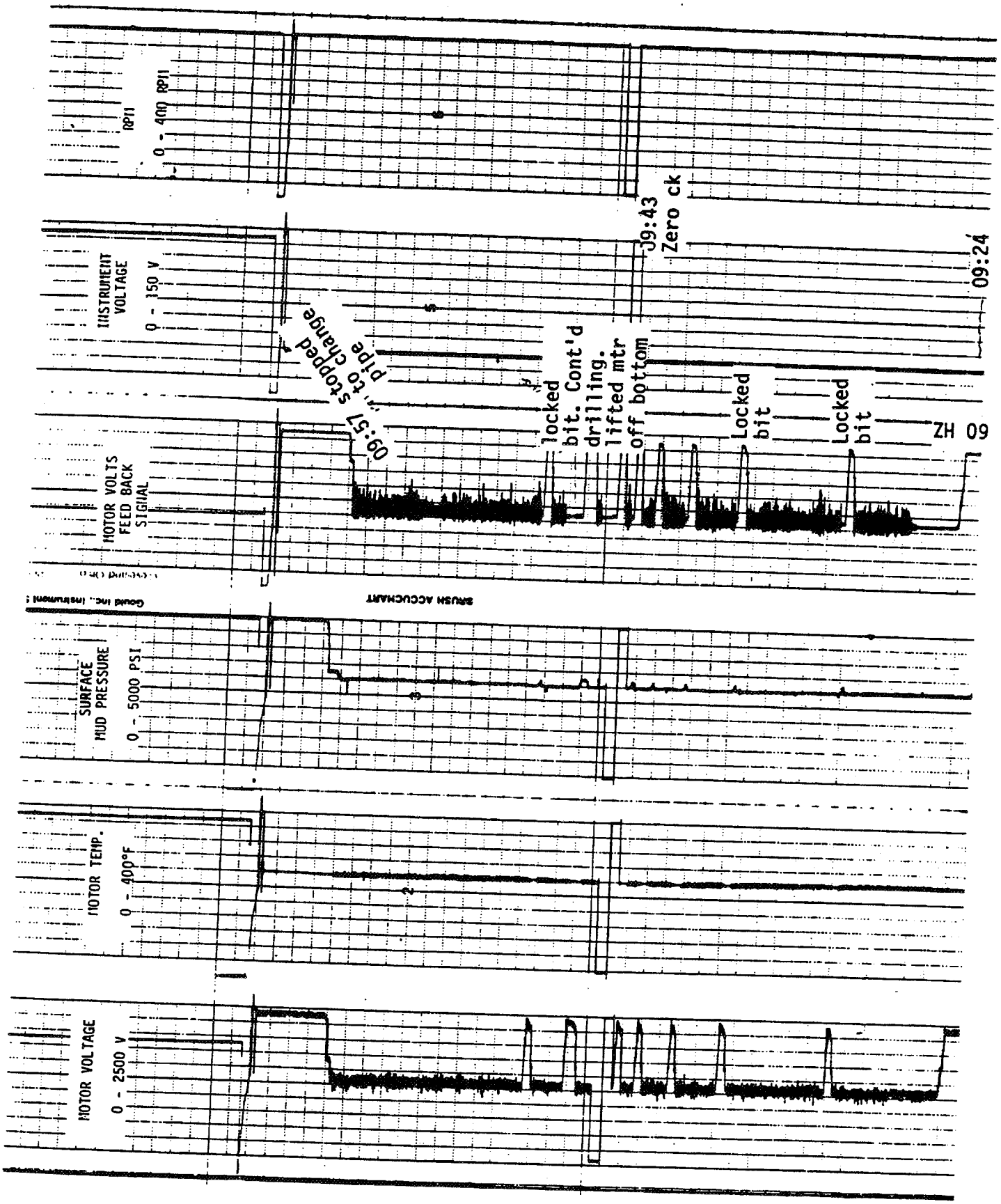

FIGURE 24

EXAMPLES OF McCOOK BRUSH RECORDER DATA

Upon completion of drilling down the kelly, the use of a prewired 30 foot joint of drill pipe was required to drill ahead as detailed in Section 6 of this report. The first 30-foot prewired joint of pipe was made up and an electrical problem in the connectors of this prewired pipe was encountered. Three 30-foot prewired joints were subsequently rejected (one being damaged by the rig hands). At this point, it was decided to conventionally drill an additional 60 feet. This would permit drilling with Electrodril to continue by using a 90 foot prewired stand of pipe and the electrified kelly.

The process of drilling ahead 60 feet utilizing the Electrodril string and rotary power was successfully completed and a 90-foot stand of prewired pipe was added and a part of the kelly was drilled down using Electrodril when a short developed. The short was traced to the 90-foot stand which was then replaced. The Electrodril System was again used to complete the drill down of the kelly. Real time data from the downhole instrumentation subsystem was again received, displayed and recorded in the instrument trailer.

During this drilling ahead period, the connectors on the prewired 30 foot joints were replaced and made ready for reuse. However, none of these reworked prewired joints were successfully mated electrically in the drill string. The decision was subsequently made to again drill ahead 60 feet using conventional rotary power and the Electrodril. This process was accomplished without incident.

A second 90-foot stand of prewired pipe was then added to the string. This process was not successful, however, due to indications of electrical leakage

to ground. A replacement 90 foot prewired stand was also unsuccessfully introduced and after a third unsuccessful attempt to obtain electrical continuity, the Electrodril demonstration was discontinued. Although a major cause for this decision was the inability to make up the 90-foot prewired stands, the primary cause was the identification of increasing electrical leakage (<500K Ω to ground) in the downhole electrical string. This electrical leakage represented an equipment failure potential and was located somewhere in the 5000-foot cable string or in the Electrodril downhole assembly. Subsequent analyses indicate that the female connectors downhole were the probable cause of this failure. A more detailed failure analysis is presented in Appendix D.

Despite the power cable/connector failures and the resulting demonstration shutdown, a number of significant accomplishments were achieved.

- The motor voltage feedback loop successfully controlled the motor voltage during some 20 motor stops and starts, under varying loads and frequencies.

- The operation of the motor while drilling ahead approximately 60 feet at rates up to 120 feet per hour was a major accomplishment.

- All channels of the instrumentation system functioned before, during, and after drilling with Electrodril. Real time downhole position data, gamma log data, mud temperature inside and outside the drill string, motor temperature, differential mud pressure (inside drill pipe pressure minus annulus pressure), vibration spectrum, motor voltage and instrument voltage were ceived and recorded on the surface. In addition, several surface parameters were monitored, processed and recorded. Included was depth, penetration rate, mud flow rate, mud pressure, motor current, and motor voltage.

- Demonstrated the ability of the Electrodril motor assembly to compensate for Electrodril System failures by drilling ahead while rotating the drill string conventionally. A total of 160 feet was drilled in this manner.

- Downhole pressure zones indicated pressure drop across bit nozzles was close to surface test reading. While pulling up to make connection, pressure reading decreased showing suction effect of bit.

- Downhole temperature readings showed effect of circulating mud on motor temperature.

- The static inverter allowed the driller to control the bit speed. The motor was run at 60 rpm, 120 rpm and 200 rpm.

The failure to successfully complete this drilling demonstration was particularly disappointing as the probable cause still appears to be centered around the malfunctioning of the connectors. Knowing that the connector assemblies are key to the functional success of the Electrodril concept, much testing had been conducted to assure their functional compatibility. It is apparent that more work is needed in this area before additional system demonstrations are attempted.

9.0 CONCLUSIONS

An objective review of both Electrodril demonstrations leads to the conclusion that accomplishments made at the well sites fall far short of program expectations. The fact that very little footage was actually drilled sharply limits the ability to form judgements regarding the economic viability of the system.

Electrodril was, however, deployed at two operational drilling sites and successfully retrieved. At no time was there any hint of an unsafe situation. Any apprehension exhibited by rig crews and their supervisory staff regarding the power levels being used was quickly allayed. The fact that the system was demonstrated to be compatible with a conventional drilling operation (rig and crews) validates one of the most important design goals and is of great significance.

From a technical viewpoint, the fundamental concept of Electrodril remains valid. The method of cable deployment through the use of multiple length cable assemblies also appears technically viable, given that the connector problems can be resolved. The post-test analyses from both drill sites indicates that the problems are limited to the connectors and are centered around their manufacturing process. No basic connector design flaw has been identified. The selection of a parallel connector mating member, in lieu of the tapered design evaluated in 1976, appears to be valid for the 30-foot and 90-foot prewired cable assemblies. This technical approach is particularly important in supporting the drive to minimize the number of "special" subsystem designs.

The Electrodril "measurement-while-drilling" system has worked extremely well throughout the demonstration program. The motor voltage control loop with the surface static inverter, after initial calibration, has worked steadily and without problems. The bit shaft and motor assembly has functioned well. The gearbox and lube compensation system has performed extremely well, although the bit shaft seals need adjustment to reduce the leakage. A summary of the system development status is shown in Table 3.

The need now exists to implement the necessary manufacturing process changes for the connectors. A limited number of "new" connectors should then be manufactured and exhaustively tested to demonstrate the functional readiness of these connectors to be once again deployed in an operational well to support the evaluation of Electrodril's economic viability.

TABLE 3

DEVELOPMENT STATUS OF SYSTEM

POWER GENERATION	OPERATIONAL
REELS AND DRIVES	OPERATIONAL
CABLE & CONNECTORS	CABLES OPERATIONAL CONNECTOR PROBLEMS UNDER INVESTIGATION
INSTRUMENTATION	OPERATIONAL
MOTOR BIT SHAFT	OPERATIONAL SEAL PROBLEMS - REQUIRE ADJUSTMENT
INTEGRATED SYSTEM OPERATION	COMPATIBILITY WITH RIG AND CREW DEMONSTRATED

APPENDIX A

ELECTRODRIL

DEEP DRILLING SYSTEM

FIELD TEST PROGRAM

PHASE II TASK C

SITE SELECTION CRITERIA

GENERAL ELECTRIC

Thermal Systems

Houston Texas

INTRODUCTION

This report documents the site selection criteria used to identify drill site areas in support of the Phase II, Task C Electrodril demonstration program. The drilling demonstration program is designed to qualify the Electrodril Deep Drilling System for use by the oil industry in deep tough drilling conditions. This demonstration/qualification program has two major thrusts:

- Demonstrate the operational capability of the Electrodril Deep Drilling System by drilling below 10,000 feet in at least two operational wells.

- Demonstrate the economic viability of the Deep Drilling System through analysis of operational data and comparison of results obtained during demonstration drilling operations with established economic models.

The specific objectives of the demonstration program are:

1. Demonstrate the capability of the 285-HP Electrodril System, with its associated power cable deployment and retrieval system, in tough formations deeper than 10,000 ft. Penetration rates and drill bit life are expected to exceed current rotary system performances by virtue of the Electrodril System's ability to provide high torques at the bit with a variable speed range from 40 to 400 rpm.

THE SA UNIVERSITY

2. Demonstrate the capability of the 285-HP Electrodril System, with its downhole sensor and telemetry system, to drill in tough formations while transmitting to the surface downhole data on borehole environment and drill bit parameters.

3. Demonstrate the capability of the 285 HP-Electrodril System with its downhole sensor and telemetry system and a remotely controllable deviation sub, to drill effectively in tough formations and compensate for crooked hole situations.

Initial testing of the Phase II Electrodril System was accomplished in a test well at Brown Oil Tools during October 1978. Tests were conducted to insure that system elements were functionally compatible and to identify and resolve any field deployment problem areas prior to operational field deployment.

Selection Criteria

The successful completion of the Systems Verification of Electrodril in a test well has proven that the system is compatible as a modular add-on and operational with conventional drilling rigs. This unique drilling method is now ready to be moved from the test well environment to actual field applications where demonstration drilling is planned for three areas selected to provide successively more challenging conditions.

The well site for the initial operational demonstration will be selected to meet the following criteria:

- Be near the Houston Electrodril base, to ease logistics and support considerations.
- In a proven field where correlation, with previously drilled wells, is available.
- In medium hard, ductile formations, which would, with conventional rotary drilling, reduce the penetration rate significantly. Formations where gas-cut mud and lost circulation allow tests of the downhole sensors without unduly exposing the drilling operation to hazardous conditions.
- On a land-based drilling rig with a well-trained crew.
- Drilling parameters:

  Hole size - 9½" to 12¼".

  Hole depth - starting below 6,000' drilling to 8,000' or more.

  Hole drift not to be more than 3^{o}.

  Hole temperature not to exceed $250^{o}F$.

The field test program will be initiated at a well drilling site in the middle Gulf Coast region, the Victoria-Bay City area, where wells are drilled to the Frio in the Oligocene or deeper wells are drilled to the Wilcox in the Eocene.

The well site for the second Electrodril test will be selected from an active drilling area in the lower Gulf Coast region which meets the following criteria.

- o Proven field where the formations are well defined and correlation with previously drilled wells is available.
- o The formations due to overburden and hydrostatic pressure reduces conventional penetration rates.

  In the deeper zones abnormal pressures cause intermittent gas flow into the hole necessitating mud weights of 13-16 lbs.
- o Land-based rig with a well-trained crew.
- o Drilling parameters:

  Hole size - 9½" to 12¼".

  Hole depth - starting below 8,000' drilling to 12,000' or more.

  Hole drift not to be more than 3^{o}.

  Hole temperature not to exceed 250^{o}F.

  Mud weight not to exceed 16 lbs.

In the Corpus Christi-Laredo-Brownsville area, wells are drilled to the Vicksburg in the Oligocene to 14,500 feet. Deep wells in the same area are drilled to the Edwards in the Cretaceous to 18,000 feet. The second Electrodril test in the deeper zones may encounter unconformities, anticlinal and fault traps in a continually changing strata which will show the advantages of this system.

The well site for the third Electrodril test will be selected for a change of drilling conditions in the West Texas region which meets the following criteria:

- o Proven field, where drilling conditions are well defined and where correlation with previously drilled wells is available.
- o Formations are hard and abrasive, which will provide a significant challenge to the drilling system. Also, the intrusion of gas and salt water and a continual change in formation characteristics will thoroughly test the downhole sensors.
- o Well-designed drilling rig with a well-trained crew.
- o Drilling parameters:

  Hole size - 9½" to 12¼".

  Hole depth - starting below 11,000', drilling to 16,000 to 21,000'

  Hole drift not to be more than 3^{o}.

  Hole temperature not to exceed 250°F.

In the Ft. Stockton area of the Delaware Basin, wells are drilled to the Fusselman in the Silurian to 14,000 feet. Deep wells in the same area are drilled to the Ellenberger in Ordivician to 21,000 feet. The third Electrodril test will penetrate the Mississippian Limes, Devonian Cherts, Silurian Shales and Simpson Sands, showing the superiority of this system.

CONCLUSION

In summary then, the field test of the Phase II Electrodril System will be accomplished in operating wells selected to provide increasingly more challenging drilling conditions. Demonstrations will be established in operating wells in the following areas:

- In the Gulf Coast, in the Victoria-Bay City, Texas Area where medium hard formations are encountered at 10,000-15,000 feet with a minimum potential for hazardous conditions.

- In the South Texas Area near Laredo and Brownsville where formations are somewhat harder and higher temperatures and pressures are encountered. Drilling is planned at depths of 12,000-17,000 feet.

- In the West Texas - Fort Stockton Area where varied formations are expected with potential for hazardous conditions. Drilling at depths of 11,000-18,000 feet is planned.

APPENDIX B

OPERATIONAL DEMONSTRATION OF THE ELECTRODRIL DEEP DRILLING SYSTEM

TEST PLAN

For

SITE I - January, 1979

SITE II - June, 1979

Note: Since the test at Site I was aborted with no actual drilled footage, the test plan for Site II was exactly the same, except for names and location. To reduce repetition, the specific data for Site II has been inserted in parenthesis.

GENERAL ELECTRIC

Thermal Systems
Houston Texas

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1.0 INTRODUCTION

This report documents the test plan for the performance evaluation of the Electrodril Deep Drilling System at the first operational drilling site in support of the Phase II, Task C activity. This drill site, tentatively selected, is the Exxon I.C.H. Matthews Well No. 1 near Beaumont, Texas. (Site II is Shell Oil Company's Martinez Well No. 4, La Copita Field near McCook, Texas.)

2.0 OBJECTIVE

The objective of the Task C drilling demonstration of the Electrodril Deep Drilling System is to evaluate both the technical and economic viability of the Electrodril System. The operational readiness of the system will also be demonstrated by drilling in test sites in the Texas Gulf Coast Area. The economic viability of the system will be demonstrated through analysis of operational data and comparison of results obtained during drilling operations with established economic models.

3.0 TEST REQUIREMENTS

3.1 GENERAL

It is anticipated that the Electrodril Deep Drilling System will be deployed initially after the surface casing has been set. For this first well site, this will be at approximately 7000' (Site II at 5180') which is typical for wells along the Texas Gulf Coast. Test drilling will be conducted for about two weeks.

3.2 SCHEDULE

A typical schedule for a test site is shown in Table 1 and is centered around two 100-hour drilling demonstrations. It should be noted that the exact timing for big changes is not known, and thus, scheduling is an approximation.

3.3 TECHNICAL APPROACH

The plan for this drilling demonstration is to verify that the Electrodril penetration rate is the same or better than previous drilling operations when using a similar bit and rotating at the same rate. Subsequently, an optimum rotational speed will be selected, still using the same bit, to verify the technical contention that higher drilling rates can be obtained using a "constant power" approach to drilling. Subsequent to this initial comparative evaluation of drilling rates, a series of exploratory combinations of bit speed and weight on bit will be made to determine the drilling characteristics and operating regime of Electrodril when using this particular bit.

Upon the completion of this series of drilling tests, the drill string will be removed and a single-shot well survey made to establish well alignment. A second Electrodril motor and bit shaft will then be run in the hole for drilling evaluation. The bit used for this second drilling demonstration will maximize the high-speed, high-torque potential of Electrodril. The bit selection will, of course, be made commensurate with the formation to be drilled.

The second drilling demonstration at the well site will maximize penetration rate. Rotational speeds and weights on bit will be varied to identify the

TEST TIME IN DAYS

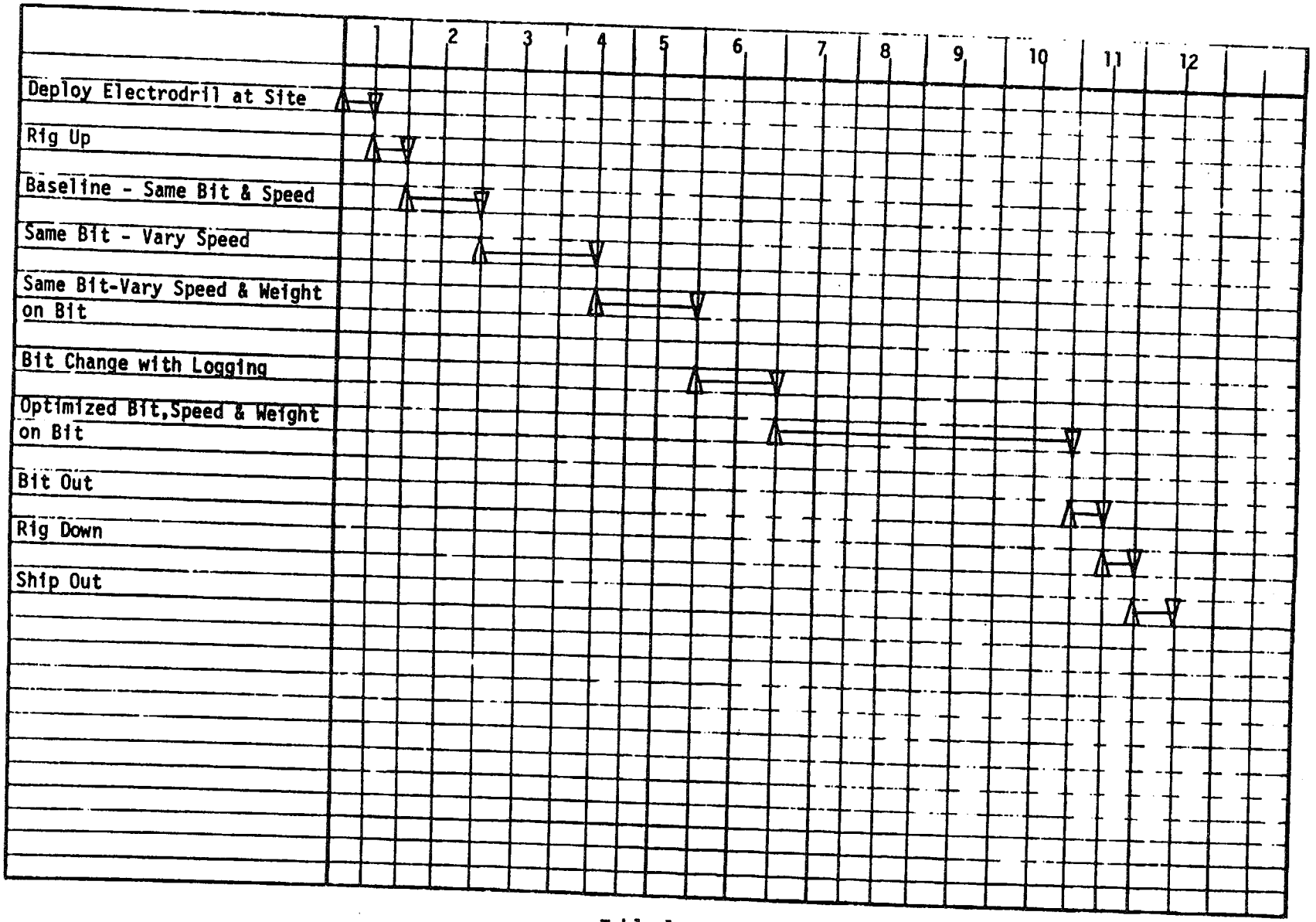


Table 1

TYPICAL WELL SITE SCHEDULE

drilling characteristics of the new bit with Electrodril. In addition, close observation will be made of the rig floor operations to identify and measure the drilling "dead time" (viz.pipe-changing and cable-rigging time which extends normal drilling dead time). Post-test analyses will assess the economic viability of the total drilling system.

3.4 DATA

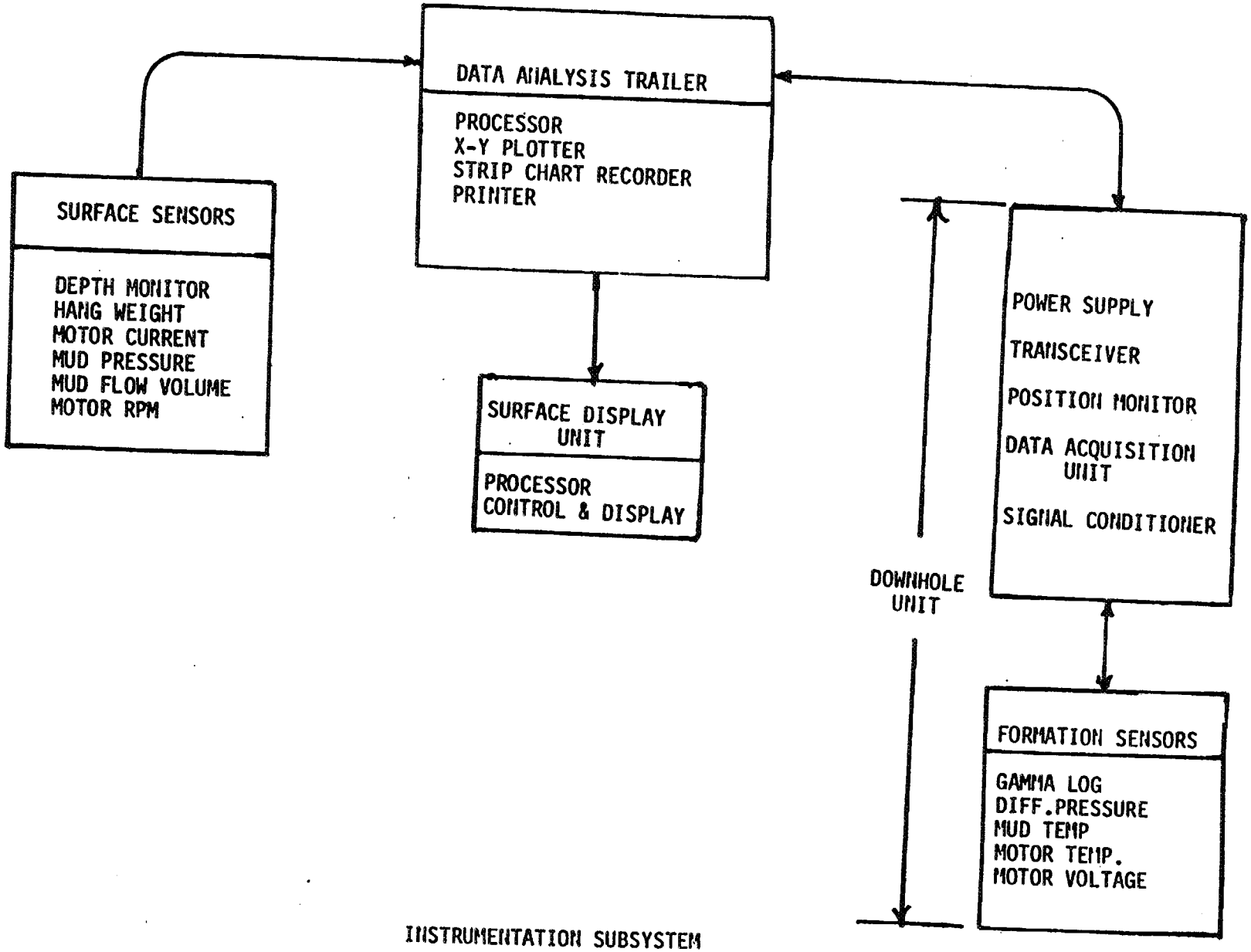
The Electrodril Instrumentation Subsystem shown schematically in Figure 1, provides the ability to sense the surface and downhole parameters (Table 2) in real time and thus aids significantly in contolling the drilling operation. For the two-site drilling demonstration, the downhole instrument package of Electrodril will perform the following functions:

1. Receives from the surface 120 VAC 1000 Hz electric power and converts and distributes same to support the downhole instrumentation.

2. Monitors the analog and digital downhole parameters and processes (multiplex) this data.

3. Sends the processed data in pre-established digital formats to the surface.

4. Receives heat sub and vibration sensor control commands from surface equipment for execution by the downhole units.



INSTRUMENTATION SUBSYSTEM

Figure 1

Table 2

SUMMARY

ELECTRODRIL DATA AVAILABILITY

	Driller's Console	Driller Control/ Display Unit	Data Analysis Trailer	Remarks
Time, Hours/Minutes	no	no	yes	
Depth, Feet	no	no	yes	
Pen. Rate F/H	no	no	yes	
*Drift. Deg.	no	yes	yes	
*Azimth Deg	no	yes	yes	
*Tool Face Deg	no	yes	yes	
*Mtr Temp °F	no	yes	yes	
*Instr Temp °F	no	yes	yes	
*Annulus Temp °F	no	yes	yes	
Motor Amps	yes	no	yes	
*Motor volts	no	yes	yes	
*Delta Press PSI	no	yes	yes	
Surf Press PSI	no	no	yes	
Mud Vol GPM	lo	no	yes	
*Gamma Count	no	yes (1)	yes	(1) Digital format, not gamma count directly
*Instrument Voltage	no	yes	yes	
Motor RPM	yes (2)	no	yes	(2) Setting device only.
*Vibration	no	yes	yes	
Hang Weight	no	no	yes	

* Sensed Downhole

The surface equipment, consisting of the driller's Control and Display Unit and the Data Analysis Trailer, receives the downhole data, establishes bit and frame synchronization, checks parity, decides on the data acceptability, performs data transformation, routes and displays the data. It also monitors, processes and displays data from the surface sensors.

A surface equipment power supply provides the 1000 Hz power for the downhole instruments. The surface support equipment includes two data display stations:

1. The Display and Control Unit (Figure 2) located on the rig floor in the driller's mud house, displays the three-axis hole direction data and has one other display window for any other selectable downhole data.

2. Electronics in the Data Analysis Trailer (Figure 3) permit system diagnostics to be performed and enhance the analysis capabilities for supporting Electrodril System performance evaluation. In addition, raw downhole data can be decoded, converted, and displayed independently from the rig floor Display and Control Unit. Two types of hard copy output are provided. A printer periodically prints downhole and surface parameter values as a function of time while two strip chart recorders record parameters as a function of time and as a function of depth. A typical printer output is shown in Table 3, while typical strip chart recorder traces are shown in Table 4.

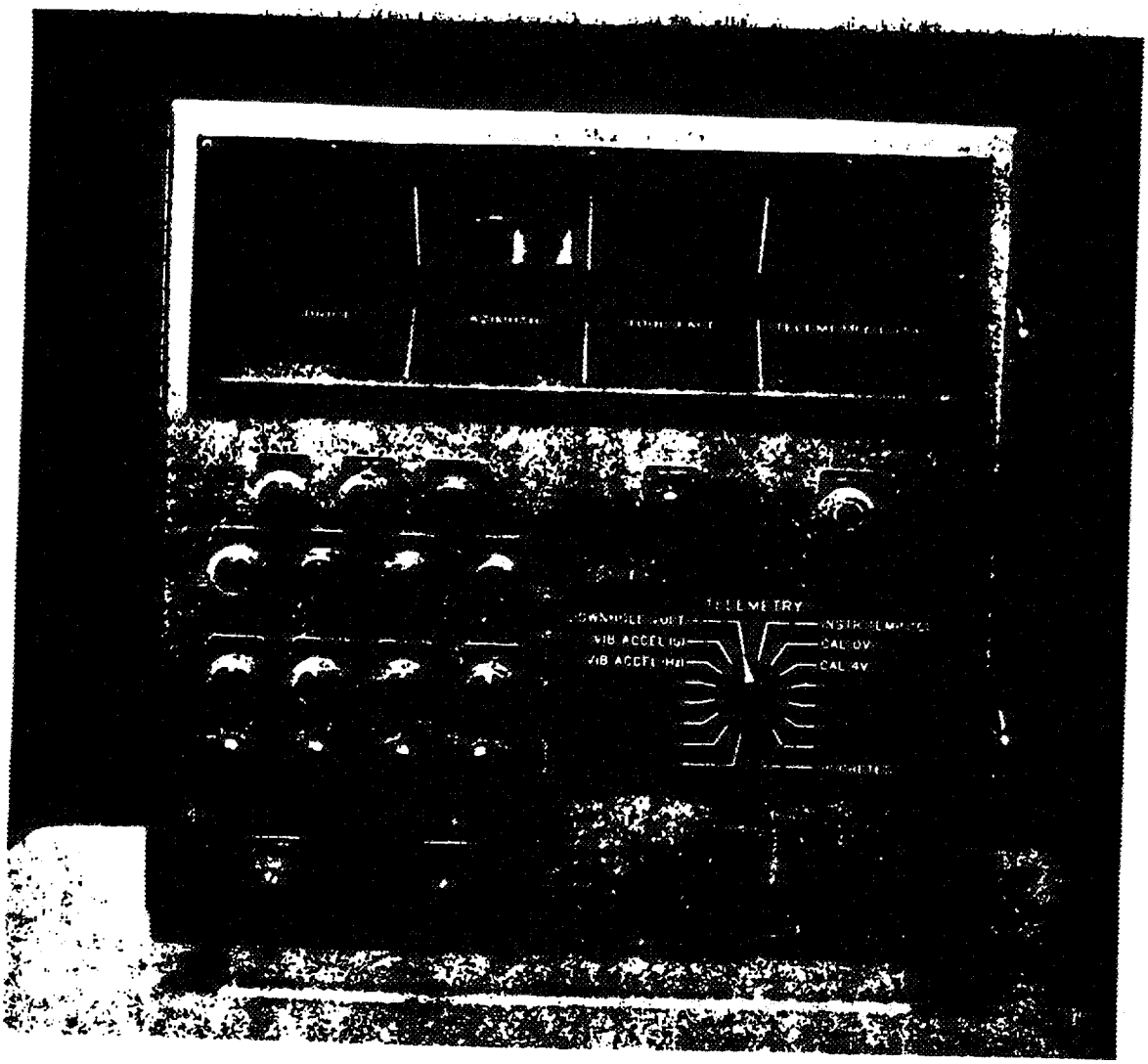


Figure 2

DISPLAY AND CONTROL UNIT

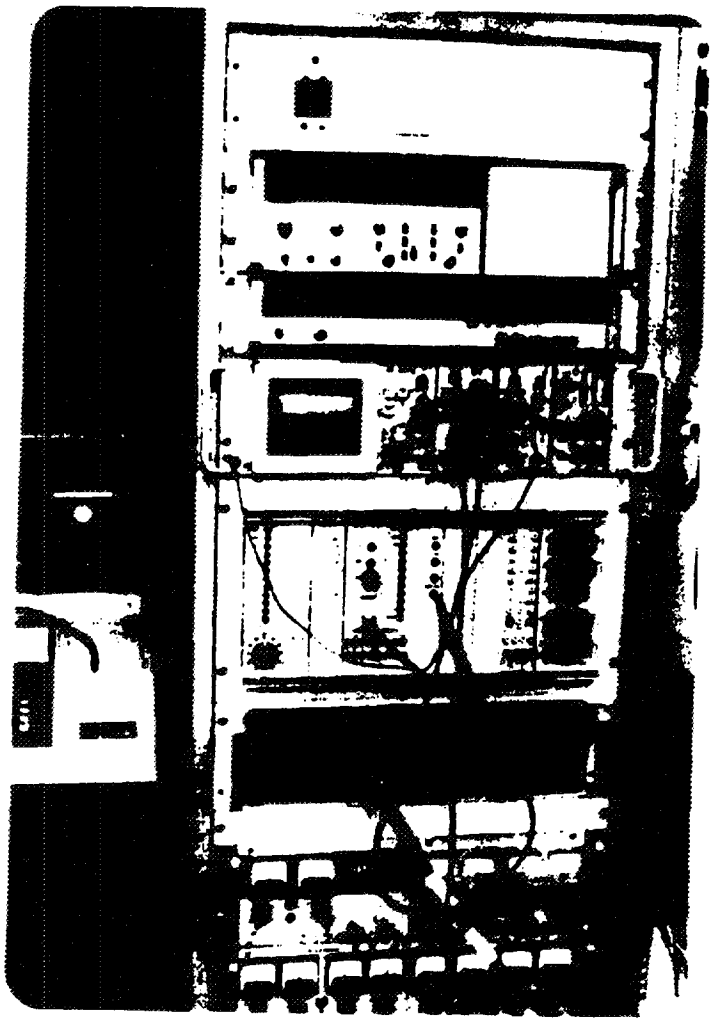


Figure 3

INTERIOR OF DATA ANALYSIS TRAILER
SHOWING PRINTOUT DEVICES

TYPICAL ELECTRODRIL RECORDER OUTPUT

```
DATE?  -  MM DD-YY-HH:MM  -  11/07/78 18:53
COMPANY?  -  GENERAL ELECTRIC
FIELD?  -  BROWN OIL TOOL
LEASE?  -  BOT
WELL NO.?  -  TEST
COUNTY?  -  HARRIS
STATE?  -  TEXAS
MAGNETIC DIP ANGLE?  -  55.7
TRUE NORTH CORRECTION?  -  1
CURRENT DEPTH?  -  1015.9
GAMMA MULTIPLIER?  -  1
GAMMA CORRECTION RATIO?  -  1
MUD PUMP DIAMETER?  -  7
MUD PUMP STROKE LENGTH?  -  6
NO. MUD PUMP CYLS?  -  2
```

COMPANY: GENERAL ELECTRIC FIELD: BROWN OIL TOOL LEASE: BOT
WELL NO: TEST COUNTY: HARRIS STATE: TEXAS DATE: 11/07/78

TIME HR:MN	DEPTH FEET	PEN F/H	DRFT DEG	AZMTH DEG	TFACE DEG	MTR DGF	INS DGF	ANN DGF	MTR AMP	DPRS PSI	SURF PSI	VOL GPM	GAMA CNT	HKNGWT POUNDS	SPD RPM
P.15															
18:55	01015.9	000	00.2	180.5	000.0-401	059	084	000	0032	0508	443	0000	000000	000	
18:55	01015.9	000	00.2	180.5	000.0-401	059	084	000	0032	0520	472	0000	000000	000	
18:55	01015.9	000	00.1	180.5	000.0-400	059	084	000	0035	0571	520	0000	000000	000	
18:55	01015.9	000	00.1	180.5	000.0-400	059	084	000	0035	0537	504	0000	000000	000	
18:56	01015.9	000	00.0	180.5	000.0-401	059	084	000	0032	0513	328	0000	000000	000	
18:56	01015.9	000	00.1	180.5	000.0-400	059	084	029	0032	0518	472	0000	000000	002	
18:56	01015.9	000	00.2	180.5	000.0-401	059	084	022	0035	0518	472	0000	000000	065	
18:56	01015.9	000	00.1	180.5	000.0-400	059	084	021	0038	0518	496	0000	000000	088	
18:57	01015.9	000	00.3	180.5	000.0-401	059	084	022	0035	0569	456	0000	000000	095	
18:57	01015.9	000	00.2	180.5	000.0-401	059	084	022	0035	0544	464	0000	000000	097	
18:57	01015.9	000	00.2	180.5	000.0-401	059	084	022	0029	0527	448	0000	000000	097	
18:57	01015.9	000	00.2	180.5	000.0-401	059	084	022	0032	0571	536	0000	000000	097	
18:58	01015.9	000	00.0	180.5	000.0-400	059	084	021	0035	0542	472	0000	000000	097	
18:58	01015.9	000	00.0	180.5	000.0-401	059	084	022	0029	0530	416	0000	000000	099	
18:58	01015.9	000	00.1	180.5	000.0-401	059	084	023	0029	0537	504	0000	000000	129	
18:59	01015.9	000	00.2	180.5	000.0-401	059	084	024	0035	0552	512	0000	000000	173	
18:59	01015.9	000	00.2	180.5	000.0-401	059	084	024	0035	0513	528	0000	000000	197	
18:59	01015.9	000	00.0	180.5	000.0-400	059	084	024	0041	0564	560	0000	000000	203	
18:59	01015.9	000	00.1	180.5	000.0-400	059	084	024	0041	0540	528	0000	000000	203	
18:59	01015.9	000	00.2	180.5	000.0-401	059	084	024	0032	0520	456	0000	000000	205	
19:00	01015.9	000	00.1	180.5	000.0-400	059	084	024	0035	0520	512	0000	000000	205	
19:00	01015.9	000	00.0	180.5	000.0-400	059	084	024	0035	0505	480	0000	000000	205	
19:00	01015.9	000	00.2	180.5	000.0-401	059	084	024	0039	0522	448	0000	000000	205	
19:00	01015.9	000	00.0	180.5	000.0-400	059	084	022	0035	0515	488	0000	000000	166	
19:01	01015.9	000	00.1	180.5	000.0-400	059	084	021	0041	0508	472	0000	000000	121	
19:01	01015.9	000	00.1	180.5	000.0-400	059	084	022	0041	0515	392	0000	000000	105	
19:01	01015.9	000	00.0	180.5	000.0-400	059	084	021	0035	0554	456	0000	000000	101	
19:01	01015.9	000	00.2	180.5	000.0-401	059	084	022	0032	0530	488	0000	000000	099	
19:02	01015.9	000	00.1	180.5	000.0-400	059	084	022	0041	0510	416	0000	000000	099	
19:02	01015.9	000	00.2	180.5	000.0-401	059	084	020	0035	0557	480	0000	000000	087	
19:02	01015.9	000	00.3	180.5	000.0-401	059	084	020	0032	0500	528	0000	000000	059	
19:02	01015.9	000	00.2	180.5	000.0-401	059	084	020	0035	0520	512	0000	000000	050	
19:03	01015.9	000	00.1	180.5	000.0-400	059	084	000	0035	0549	528	0000	000000	026	
19:03	01015.9	000	00.2	180.5	000.0-401	059	084	000	0032	0554	456	0000	000000	003	
19:03	01015.9	000	00.2	180.5	000.0-401	059	084	000	0032	0518	456	0000	000000	002	
19:03	01015.9	000	00.0	180.5	000.0-400	059	084	000	0035	0515	440	0000	000000	002	
19:04	01015.9	000	00.2	180.5	000.0-401	059	084	000	0032	0562	472	0000	000000	002	
19:04	01015.9	000	00.2	180.5	000.0-401	059	084	000	0032	0515	424	0000	000000	002	
19:04	01015.9	000	00.1	180.5	000.0-400	059	084	000	0035	0515	424	0000	000000	002	

Table 3

TYPICAL ELECTRODRIL STRIP RECORDER TRACES

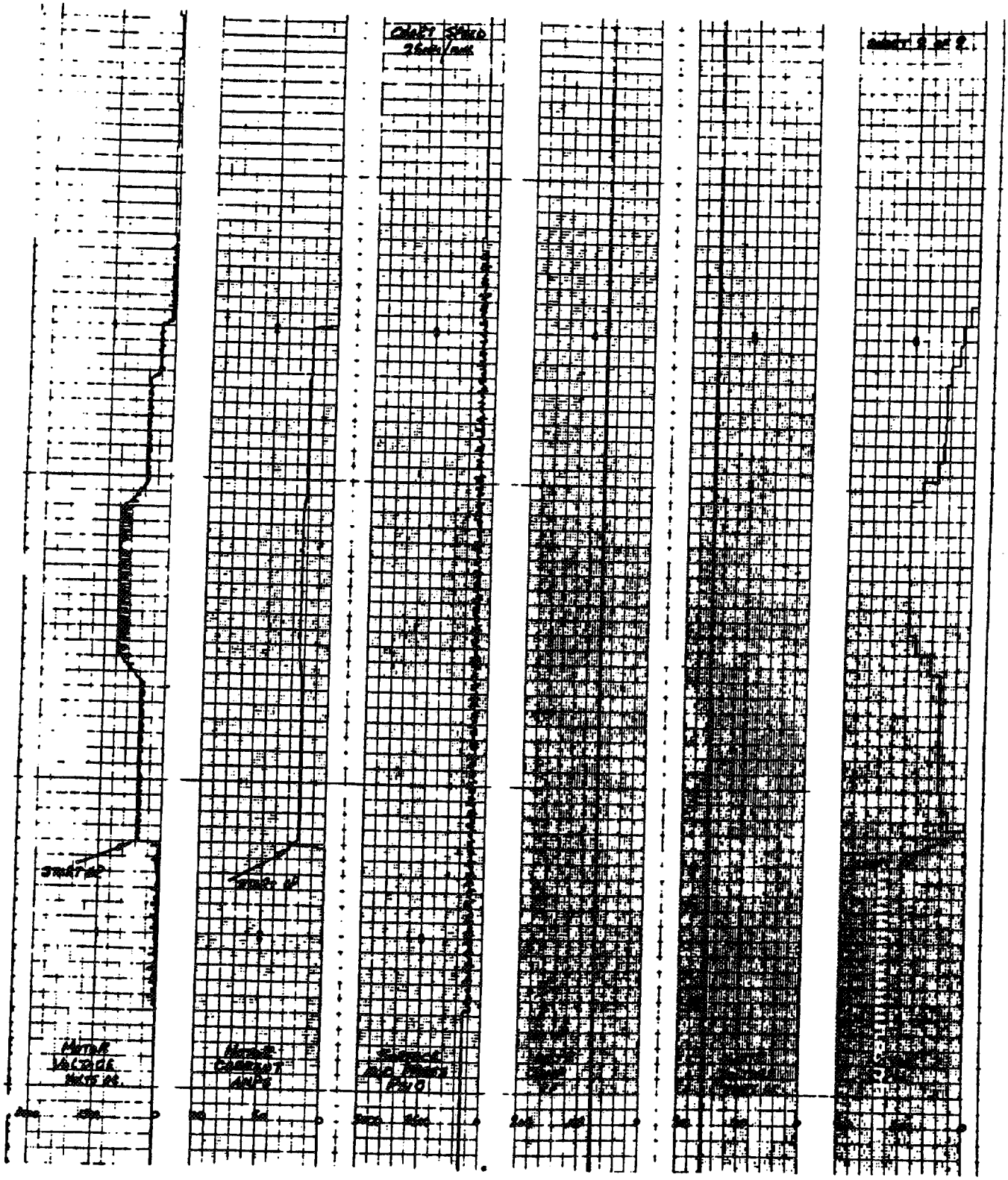


Table 4

4.0 MEASURES OF EFFECTIVENESS

Several means of obtaining data have been implemented in the Electrodril Instrumentation Subsystem design to assure that the information obtained during the test program will permit meaningful performance evaluation of the Electrodril System. The measures of system effectiveness have been grouped into three categories: Economic, Functional and Safety.

The most important economic yardstick will be cost per foot drilled. The cost aspect is made up of the cost of amortizing the Electrodril System, cost of operations at site and cost of maintenance. There are other direct measures of functional effectiveness which include penetration rate, hole quality (straight, smooth hole), percent time spent drilling, rig up and rig down time, deployment time, and trip time.

In addition, there are less tangible measures that are still important factors in considering drilling system performance.

- Reduction or elimination of blowouts by downhole sensing while drilling.
- Demonstration of the drilling systems' ability to adapt to changing conditions such as different type bits, variations in formations, mud type/density/flow rate.
- Reduction of tripping frequency by optimizing bit life through carefully controlling mud flow, mud type, RPM, and bit torque as downhole condition changes are noted via the telemetry system, and by eliminating the need for position and formation logging.

- Demonstration that the Electrodril System is safe.
- Reduction of damage to hole wall casing and drill pipe by slower rotation of pipe, resulting in longer drill pipe life.
- Reduction of need for fishing jobs by monitoring changes in downhole vibration characteristics to predict bit failure.
- Reduction in likelihood of sticking and twistoff.

The less tangible measures will be evaluated through a comparison of historical data on drilling performance with conventional methods in each drill site area.

Data sheets and detailed instructions for obtaining the directly measured data have been generated and will be used during each drilling demonstration.

APPENDIX C

SITE I TEST

REPORT ON

ELECTRODRIL DEEP DRILLING SYSTEM

DEMONSTRATION

AT

EXXON I.C.H. MATTHEWS WELL NO. 1 FIELD SITE

BEAUMONT, TEXAS

April 1979

GENERAL ELECTRIC

Houston, Texas

1.0 INTRODUCTION

This report documents the major events of the Electrodril Deep Drilling System deployment at the Exxon I.C.H. Matthews Well No. 1 drill site south of Beaumont, Texas, April 4-15, 1979. The report includes a chronology of the deployment/ demonstration effort, an analysis of the anomalies encountered and a summary of the lessons learned in this initial operational demonstration.

2.0 DEPLOYMENT/DEMONSTRATION CHRONOLOGY

April 4

Electrodril equipment loaded on transporters to be held overnight at freight yard prior to delivery at well site. Exxon drilling at 40 ft/hr and at a total depth of 2553 ft.

April 5

Electrodril surface equipment delivered and deployed at well site, cabled up and exercised using diesel APU. Instrument trailer, power inverter and control unit check OK. Exxon is continuing drilling and projecting reaching Electrodril deployment target depth (5876 ft) by some time 4/8/79.

April 6

Electrodril drill pipe, motors and instrument assembly delivered to drill site. Prepared to exercise both motors and instrument assembly to assure their functional readiness. Remeasured length of kelly and saver sub to assure total length is correct length for cable. No modifications necessary. Exxon projecting coming out of hole for bit change and hole logging some time 4/7/79.

April 7

With the string inside the casing, Electrodril kelly crossover sub installed on top of rig kelly, preparatory to laying it down and installing cable. Crossover sub experienced pin end twist-off during torque-up. Post-failure analysis indicated thread root relief incorrectly machined at shoulder. Crossover sub returned to Drilco at Houston for rework.

Exxon uses open hole time to survey and to check BOP. BOP ram failure discovered (4:30 pm). Trip out of hole and await parts for BOP. BOP repaired (3:30 am), trip pipe in hole to test BOP.

April 8

Electrodril kelly crossover sub returned to well site (9:00 am) after over-night rework by Drilco. Test of Electrodril motor, instrument and power subsystem over 2000' of cable proved unsuccessful. Technical support requested from Houston to help diagnose problem.

Exxon continues drilling (8:00 am). Drilling progress slow due to problems with plugged flow lines and standpipe problems.

April 9

Electrodril voltage control system problem isolated in instrument sub, necessitating assembly return to Houston for repairs. Exxon requested to drill ahead without Electrodril to new target depth of 6973 ft.

Exxon proceeds with drilling program, pulls out of hole (4:00 am) lays down kelly and installs kelly cable. Crossover sub and cable removed until Electrodri motor is deployed. Successfully makes up Electrodril crossover sub (6:00 am).

April 10

Electrodril instrument assembly returned from Houston after successful repair. Assembly successfully exercised over 7000' of cable with motor and power generator.

Exxon pulling out of hole after reaching 6973 ft., drill string hits BOP rams and three drill collars with drill bit are dropped to the bottom (10:30 am). BOP pipe ram connecting rod broken. BOP changeout begun.

April 11

Electrodril instrument assembly successfully exercised over 5000' of cable with motor and power generator.

Exxon effects repairs on BOP and proceeds with fishing for downhole drill collars. First attempt succeeds in latching collars but drop out on trip out of hole (7:00 pm). Trip back in hole (11:30 pm) with overshot and second fishing attempt succeeds (6:00 am 4/12/79). Kelly saver sub threads damaged - sub replaced.

April 12

Primary activity of the day was to recondition the hole and to test BOP

and casing string. Final trip in the hole for reconditioning (6:00 pm) the GE dedicated 90' stands are made up so that they can be stood back in the rig when the drill string is tripped out to receive Electrodril.

April 13

Trip into hole with Electrodril began 6:00 am. Bottom hole assembly lowered to bottom of surface casing (1984') and circulated (11:00 am). Crossover sub added and kelly laid down and wired for Electrodril (4:00 pm). Drill string lowered into hole to 4700' (11:00 pm). First 5000' Electrodril cable lowered into hole - successful mate but unacceptable electrical parameters. Cable removal from hole (3:30 am) started. Cable reel problems experienced, fixed by 5:30 am. Cable clear of hole at 6:00 am.

April 14

Drill pipe added to a total depth of 5125'.	(7:00 am)
Second 5000' Electrodril cable deployed to 5027'	(8:00 am)
Drill pipe added to total depth of 6183'	(8:30 am)
Deploy 1000' Electrodril cable	(9:30 am)
Complete drill string with 8 dedicated 90' stands	(11:00 am)
Slip Ring added to top of crossover sub and power cable added	(1:00 pm)
Circulate and test motor through slip ring, kelly with 6870' of dedicated pipe and cables. Five successful motor starts were made (no drilling).	(2:30 pm)
Failure to start motor realized (failure isolated at approx 7000' level).	(3:00 pm)
Decision to pull out of hole	(3:30 pm)
Lay down dedicated pipe	(7:00 pm)

Pulled out 1000' and 5000' cables	(9:00 pm)
Pulled drill string in surface casing	(11:00 pm)
Lay down kelly and remove subs and cable	(2:00 am)
Complete removal of Electrodril string	(5:30 am)

April 15

Electrodril equipment prepared for loading and return to Houston. No trucks available, decision to remove equipment from drill site early April 16.

Exxon makes up drill string and goes to hole bottom (6:00 am) continues own drilling program.

3.0 FAILURE ANALYSIS

Early in the afternoon on April 14, 1979, the Electrodril system was fully deployed to approximately 7000 feet, all subsystems were functional and drilling operations were about to be initiated. After five consecutive motor starts for system calibration purposes, an electrical short was experienced and the drilling demonstration was aborted. This prime failure is discussed below.

During the process of removing the Electrodril equipment from the hole, a series of tests were made to isolate the power conductor failure and to identify its location. Immediately upon recognition of a "no start" situation with the motor, the power cable from the output transformer to the top of the kelly slip ring assembly was disconnected and a Time Domain Reflectometer was used, which indicated the failure cause was located approximately 6800 feet downhole. This information indicated the failure location was close to the instrument sub.

Upon completing the withdrawal of the 5000-foot and 1000-foot cables, together with the associated drill pipe, tests were again made at the top of the instrument sub, which indicated that the instrument was functioning correctly but the power leads had been shorted to ground. The instrument sub was then removed from the string, separated from the motor and laid down, and for the first time the failure was determined to be somewhere in the instrument sub rather than in the motor.

The instrument sub was disassembled in the Houston shop, and the failure cause was isolated in the lower power connector assembly (Figures 1 and 2). The

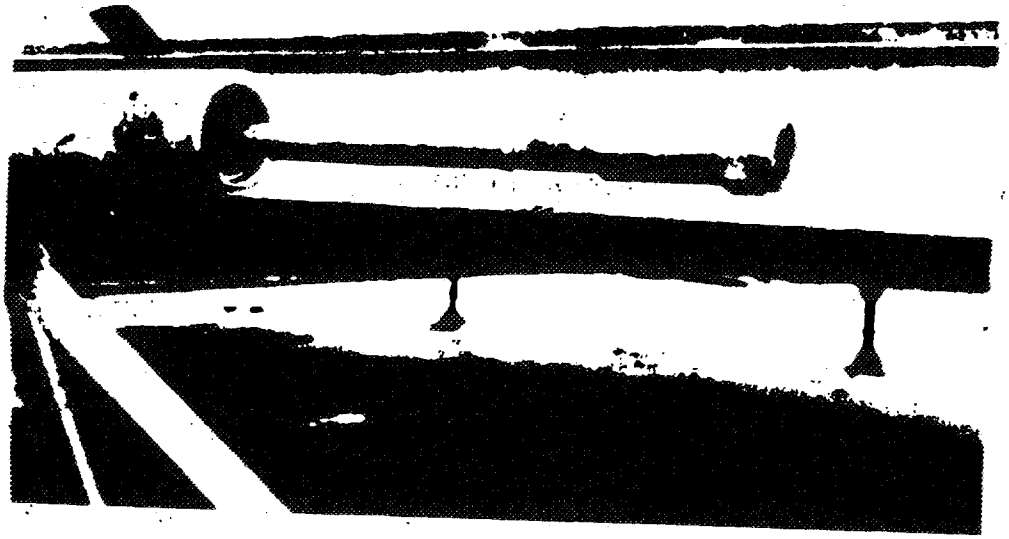


Figure 1
LOWER INSTRUMENT SUB POWER CONNECTOR

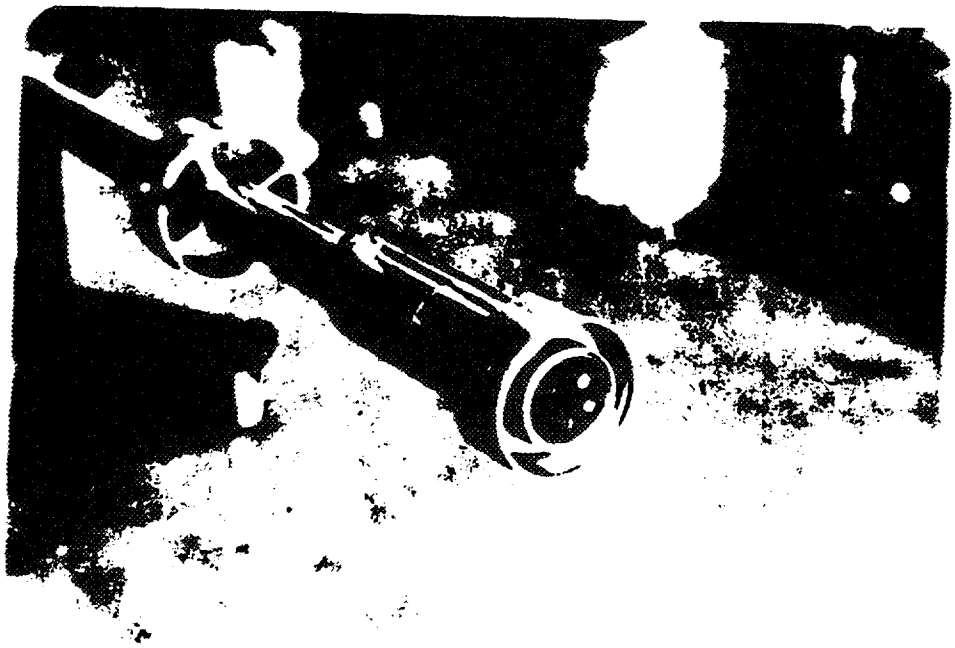


Figure 2
POWER CONNECTOR SHOWING FAILURE MODE

female connector was not damaged but its adaptor had been shorted to ground and the power conductors had failed. The absolute cause is not discernible as there is little left for failure analysis. The most probable cause, however, appears to be a mechanical malfunction in the mating of the connector adaptor, which caused shorting of the power conductors.

This particular failure was most disappointing as the instrument harness assembly had been exhaustively tested at the manufacturer and during our own assembly process (Figures 3 and 4). In addition, the complete assembly was hydrostatically and electrically tested prior to closeout for shipment to the well site (Figures 5 and 6). A reassessment of the design approach taken at this connector interface is in progress now. Particular attention is being paid to methods of motor servo loop isolation to permit drilling with Electrodril to continue in the event of instrumentation sub failure.

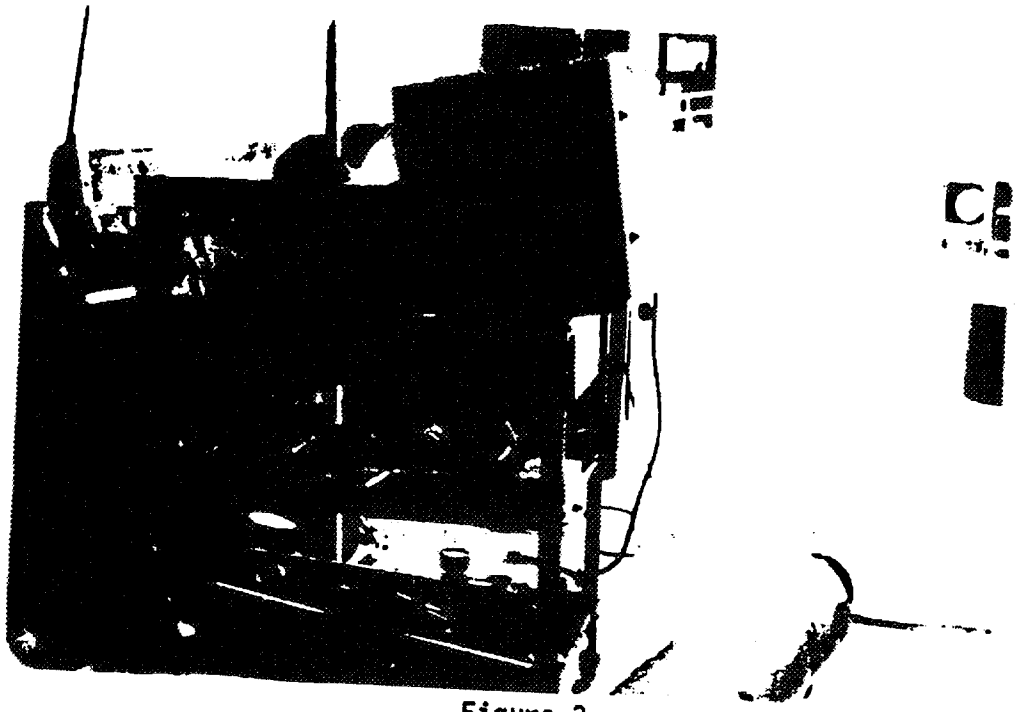


Figure 3
USING REMOTE DISPLAY UNIT TO MONITOR
ASSEMBLY PROGRESS OF INSTRUMENT UNIT

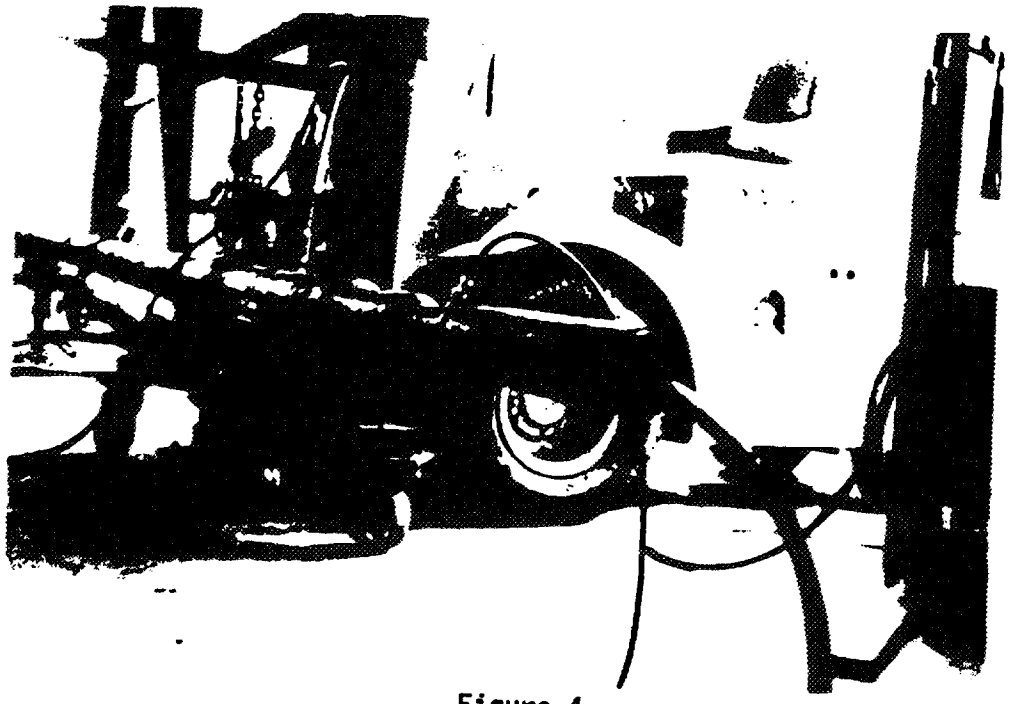


Figure 4
FINAL ASSEMBLY AND TEST OF INSTRUMENT SUB

Figure 5
HYDROSTATIC TESTING OF ASSEMBLED INSTRUMENT SUB

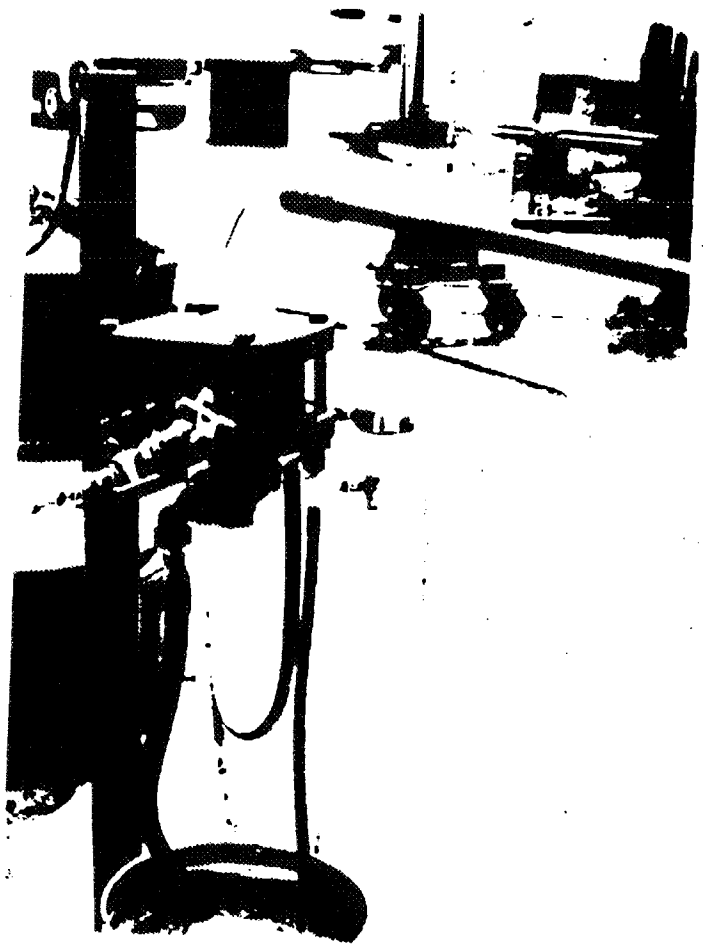


Figure 6
HYDROSTATIC TESTING OF ASSEMBLED INSTRUMENT SUB

4.0 OTHER PROBLEMS

Other equipment failures were experienced during the deployment period at the well site. These malfunctions, however, did not contribute to the primary cause for removing the Electrodril system from the hole. These anomalies are discussed below.

Kelly Cross Over Sub

During preparations for the first "test assembly" of the electrified kelly (April 7) the pin end of the kelly crossover sub was twisted off (Figures 7 and 8). Investigation of the failed parts by Drilco (Houston) revealed the twist off occurred at the thread root near the pin shoulder. A crack had propagated from a tool mark (in the thread relief groove) and caused the failure.

Drilco faced the end off the crossover sub and made a female thread in the end. A pin-by-pin saver sub was then used to make up the assembly. Prior to delivery, the reworked sub was magnafluxed to assure no additional failure/corrosion cracks existed and the sub was also tested for correct metallurgy and heat treatment.

Motor Servo Loop

Prior to going into the hole with Electrodril, the motor voltage servo loop was being exercised on the surface when it exhibited a failure which was isolated in the instrument sub at the formation sensor sub assembly. This failure required the instrument sub to be returned to Houston for rework. This rework was completed overnight and returned to the well site. The

Figure 7
TWIST-OFF OF KELLY CROSSOVER PIN END

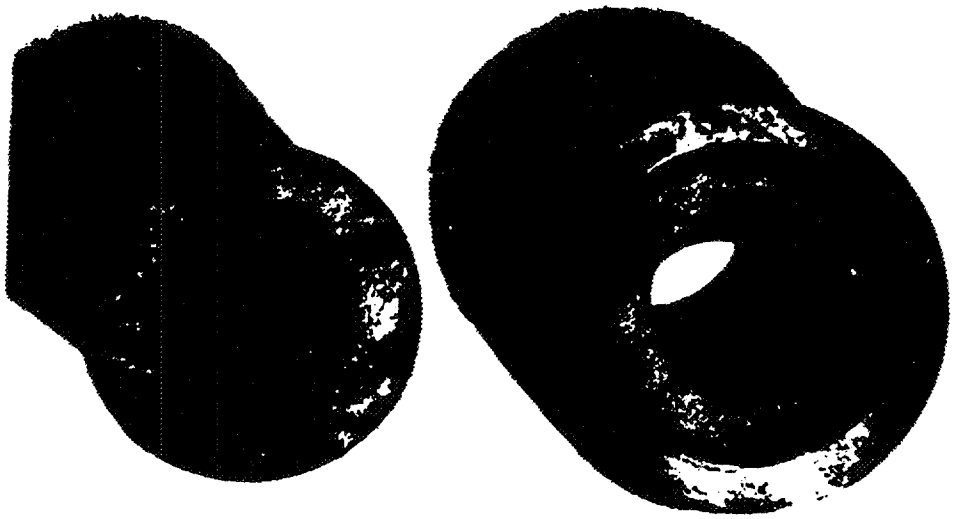


Figure 8
TWIST-OFF OF KELLY CROSSOVER PIN END

failure was caused by an integrated circuit which had come loose from its mother board but had caused no subsequent electrical failure. Reinsertion of the I.C. chip into its mother board and soldering the pins to assure good mechanical attachment, was the solution. This servo loop failure, which occurred April 8, caused Exxon to continue drilling ahead. A new deployment target depth (6973 feet) was established.

5000-foot Cable

At the completion of the first 5000-foot cable deployment in the drill pipe, the cable length did not coincide with the preplanned pipe tally (i.e., cable too long by 30 feet). At the same time it was noticed that the core of the cable connector had receded from its housing by approximately 3/8 inch. This cable was retrieved from the drill string and a second 5000-foot cable was successfully deployed.

It appears that the core of the cable connector was "milked down" by the hanging weight of the cable (10,000 lbs.). A more positive retainer was installed to correct this problem.

Cable Reel Skid

During the second deployment of a 5000 foot-cable into the hole, the cable reel skid began to make clanking and squealing noises in the drive bearing located near the operator console. The reeling-in process was temporarily terminated and upon investigation, it was found that six of eight bushing re-

tainer bolts had come loose and dropped between the rotating and non-rotating members. These bolts were wedged in this area and had to be driven free using a cold chisel. Upon clearing the bolts, the reeling process was begun and successfully concluded without further event. It appears that these bushing drive bolts had worked loose under stress. No mechanical means of retention had been provided. New bolts were installed and lock wired to prevent recurrence.

Sinker Bars

There appears to be a tolerance stackup problem with male to female sinker bar connections. Not all male adaptors will mate with all female adaptors even though the gages provided by the vendor do mate on any sinker bars. A reassessment of the worst case tolerance stackup has been made (by the vendor) and appropriate rework has been accomplished.

During the process of going in the hole with the second 5000 foot cable, the decision was made to use two sinker bars. The sinker bar mating process was difficult because of the tolerance stackup problem previously identified. The sinker bars were laid down and mated on the drill pipe ramp. In the process of picking up the mated pair, the two sinker bars were picked up by their ends and they folded in the middle (total weight 750 lbs.). Clearly the sinker bar connector nuts were not intended to withstand a bending moment of 21,000

lb-ft. The use of a second sinker bar as a means to compensate for errors in cable deployment is to be discouraged. The need for two sinker bars to facilitate cable deployment (i.e., to overcome mud bouyancy effect) does not exist, even for mud weights up to 17-lb.

Connectors

Aside from the lower instrument harness connector adaptor failure, one other connector-related failure was experienced. The male connector located at the top of the 5000-foot cable lost its tip during the process of mating. At the time the first 5000-ft. cable was deployed, a manual mate of a female connector was made with the male connector at the top of the 5000-foot cable to check its electrical characteristics. This process was physically awkward, and in mating the female, very severe bending loads were inadvertently forced on the male. Normal downhole mating would never result in such loading. The male was simply not designed to withstand these bending forces and the tip broke away from the connector.

Sprague Clutch

At the time motor start failure was established, Exxon was advised to proceed drilling in the conventional way using the kelly and rotary table but drilling ahead with Electrodril. This process was designed into the Electrodril System by means of an overrunning clutch.

There appears to have been a drilling anomaly during the period when Electrodril was used as part of the conventional drill string. The penetration rate immediately prior to the deployment of Electrodril was in the order of 20 ft./hr. While drilling with Electrodril in the conventional string, however, the penetration rate had dropped to 10 ft./hr. Upon removal of Electrodril and resumption of conventional drilling, and penetration rate was approximately 35 ft./hr.

The inference given by this data alone is that the Electrodril string had a negative influence on the drilling rate. Checks made on the overrunning clutch indicated that it was in operational condition. Discussions with the driller indicate a significantly lower weight on bit was used with Electrodril during this drilling process. An appropriate reduction in penetration would normally be expected, but the magnitude of reduction is not completely supported by the reduction in weight on bit. This drilling anomaly remains a mystery.

APPENDIX D

SITE II TEST

REPORT ON

ELECTRODRIL DEEP DRILLING SYSTEM

DEMONSTRATION

AT

SHELL, MARTINEZ STATE NO.4 FIELD SITE

McCOOK, TEXAS

June 1979

GENERAL ELECTRIC

Houston, Texas

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SUMMARY

Transport of the Deep Drilling System to the McCook site begain June 25, 1979. Initial plans called for deployment of Electrodril at 5180 feet. A thorough surface checkout of the system was successfully conducted after delivery and assembly of the system was completed. At this time, June 27, the driller's prognosis for Electrodril deployment was June 29. Refinement of knowledge of cable lengths caused the target depth for Electrodril deployment to be revised to 5220 feet.

Electrodril was subsequently deployed with 5099 feet of cable to hole bottom at 5220 feet. The drill string with the Electrodril downhole system was checked electrically and found to be operationally ready. The motor was started and shut down twice to calibrate the motor voltage control feedback loop. The motor subsequently was started and 20 feet of hole was drilled to the top of the kelly. All aspects of the downhole instrumentation system functioned properly during the drilling operation with real time data received, displayed, and recorded in the instrumentation trailer. Some examples of the McCook data collected are shown in Figure 1 and Table 1.

In order to drill ahead, a dedicated joint of drill pipe was added but it was laid back down because of poor electrical continuity and leakage. After three dedicated joints were deemed unusable (one was damaged by rig hands), it was decided to conventionally drill an additional 60 feet with the rotary.

At this point, a 90-foot dedicated stand of pipe was added and the system was powered up. Drilling continued until a short developed in the string.

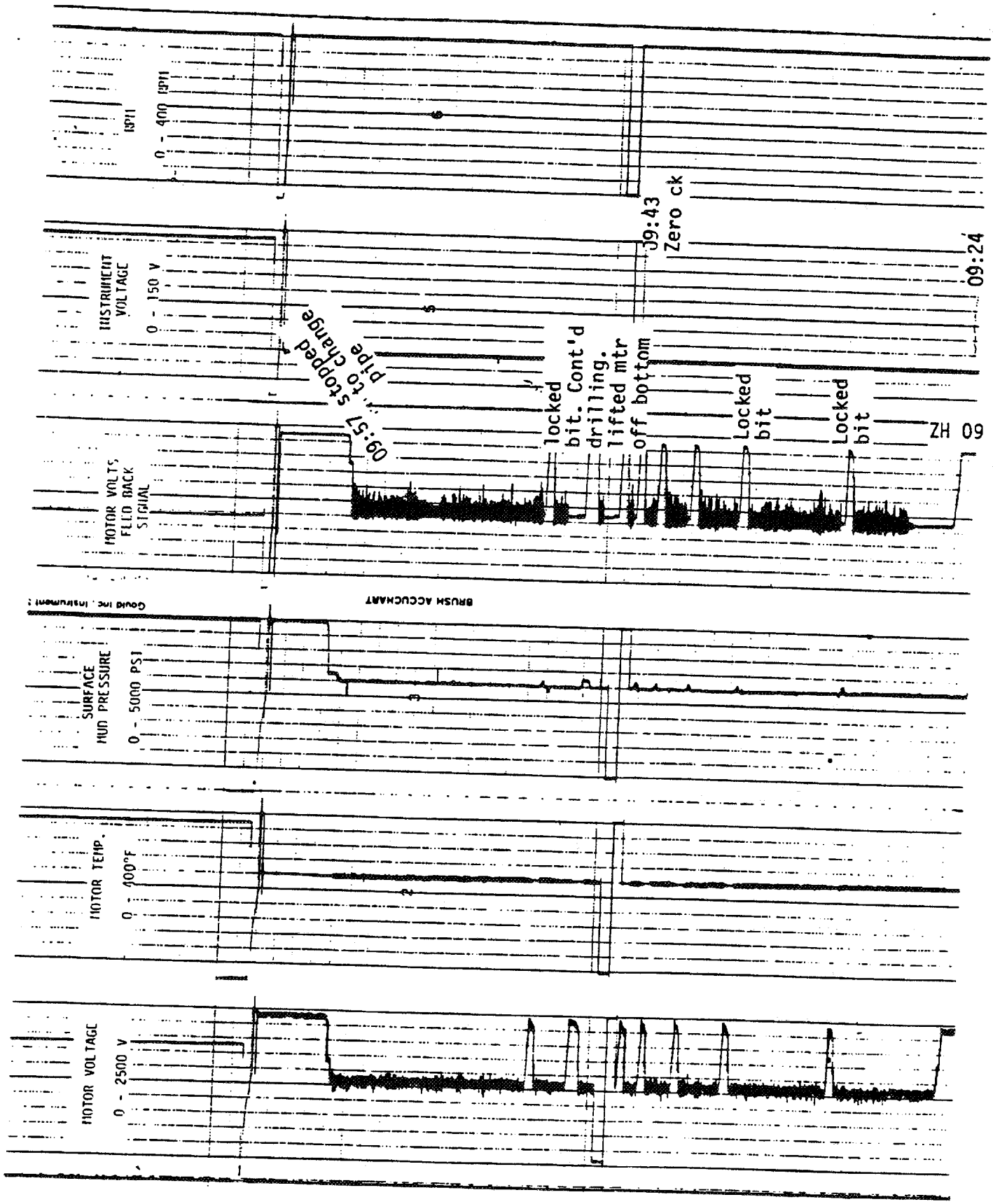

Figure 1

EXAMPLES OF McCOOK BRUSH RECORDER DATA

COMPANY: GE FIELD: LACOPITO LEASE: MARTINEZ1
WELL NO: HARKINS#1TY: STARR STATE: TX DATE: 07/01/79

TIME HR:MN	DEPTH FEET	PEN F/H	DRFT DEG	AZMTH DEG	TFACE DEG	MTR DGF	INC DGF	ANN DGF	MTR AMP	DPRS PSI	SURF PSI	VOL GPM	SMMA CNT	HANGWT POUNDS	SPD RPM
00:32	05203.3	000	00.3	219.0	000.0	151	131	147	000	1417	1862	465	0043	000000	000
00:32	05203.3	000	00.0	338.0	000.0	152	130	147	000	1409	1858	465	0042	000000	000
00:32	05203.3	000	00.4	230.6	000.0	152	130	147	000	1259	1683	370	0042	000000	000
00:33	05203.3	000	00.9	078.8	000.0	152	130	147	001	1418	1853	412	0044	000000	000
00:33	05203.3	000	00.9	084.6	331.7	152	130	147	000	1418	1855	423	0043	000000	000
00:33	05203.3	000	00.3	309.5	000.0	152	130	147	001	1418	1841	402	0041	000000	000
00:33	05203.3	000	00.8	308.9	000.0	152	130	147	022	1428	1849	402	0047	000000	000
00:33	05203.3	000	00.7	306.9	000.0	152	131	147	021	1417	1840	455	0045	000000	000
00:34	05203.3	000	01.6	263.4	234.5	151	131	147	021	1407	1836	455	0047	000000	000
00:34	05203.3	000	00.5	104.0	000.0	151	130	147	000	1418	1824	412	0047	000000	000
00:34	05203.3	000	01.0	354.2	349.4	151	130	147	000	1428	1841	423	0048	000000	000
00:34	05203.3	000	00.5	360.0	000.0	151	130	147	000	1428	1818	423	0049	000000	000
00:35	05203.3	000	00.5	124.3	000.0	151	130	147	000	1428	1825	391	0048	000000	000
00:35	05203.3	000	00.4	109.4	000.0	151	130	147	000	1428	1831	370	0043	000000	000
00:35	05203.3	000	01.6	295.2	053.1	151	130	147	000	1428	1814	370	0044	000000	000
00:35	05203.3	000	00.3	360.0	000.0	151	130	147	000	1428	1824	423	0044	000000	000
00:36	05203.3	000	00.2	180.0	000.0	151	131	147	000	1445	1823	412	0043	000000	000
00:36	05203.3	000	01.0	176.2	301.6	150	130	147	000	1428	1816	370	0040	000000	000
00:36	05203.3	000	00.3	360.0	000.0	151	131	147	000	1445	1814	349	0042	000000	000
00:36	05203.3	000	01.0	162.9	142.4	150	130	147	000	1428	1807	402	0046	000000	000
00:37	05203.3	000	00.1	281.3	000.0	150	130	147	000	1437	1812	381	0047	000000	000
00:37	05203.3	000	00.7	102.1	000.0	151	131	147	000	1445	1815	402	0046	000000	000
00:37	05203.3	000	00.3	031.2	000.0	150	130	147	000	1428	1801	381	0046	000000	000
00:37	05203.3	000	00.3	169.3	118.3	150	130	147	000	1447	1797	402	0050	000000	000
00:38	05203.3	000	00.7	273.0	000.0	150	130	147	000	1437	1805	423	0048	000000	000
00:38	05203.3	000	00.4	076.7	000.0	150	131	147	000	1445	1797	434	0044	000000	000
00:38	05203.3	000	00.4	041.3	000.0	150	130	147	000	1437	1779	434	0042	000000	000
00:38	05203.3	000	00.6	237.0	000.0	150	130	147	000	1437	1796	455	0044	000000	000
00:39	05203.3	000	00.0	196.0	000.0	150	130	147	000	1437	1775	465	0046	000000	000
00:39	05203.3	000	00.8	017.1	000.0	150	130	147	000	1437	1788	423	0045	000000	000
00:39	05203.3	000	00.4	360.0	000.0	150	130	147	000	1447	1805	381	0043	000000	000
00:39	05203.3	000	00.6	125.5	000.0	150	130	147	000	1447	1813	370	0045	000000	000
00:40	05203.3	000	00.3	076.3	000.0	150	130	146	000	1456	1808	391	0041	000000	000
00:40	05203.3	000	00.4	082.8	000.0	150	130	146	000	1456	1826	370	0041	000000	000
00:40	05203.3	000	00.3	229.1	000.0	150	130	146	000	1456	1824	444	0045	000000	000
00:40	05203.3	000	00.4	180.0	000.0	150	130	146	000	1456	1818	455	0045	000000	000
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00:41	05203.3	000	00.7	304.4	000.0	150	130	146	000	1447	1816	391	0044	000000	000
00:41	05203.3	000	00.1	102.6	000.0	150	130	146	000	1447	1815	370	0044	000000	000
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00:42	05203.3	000	00.3	276.8	000.0	149	130	147	000	1454	1809	402	0046	000000	000
00:42	05203.3	000	00.4	220.9	000.0	149	130	146	000	1447	1804	434	0044	000000	000
00:42	05203.3	000	00.2	032.5	000.0	149	130	146	000	1437	1813	486	0044	000000	000
00:42	05203.3	000	00.9	360.0	000.0	149	130	146	000	1437	1804	402	0041	000000	000

Table 1

EXAMPLE OF SILENT 700 McCOOK DATA

Analysis showed the problem to be in the 90 foot stand. It was replaced and the remainder of the Kelly was successfully drilled down with the Electrodril complemented by complete real time instrumentation.

An additional 60 feet were drilled ahead conventionally and, while attempting to add another 90-foot prewired pipe, it was determined that the resistance to ground below the top of the 5000-foot cable had degraded to the point where equipment damage could result if power was applied. The Electrodril demonstration was, consequently, discontinued on July 1.

Despite the power cable/connector failures and the resulting demonstration shutdown, a number of significant accomplishments were achieved as shown below:

- The motor voltage feedback loop successfully controlled the motor voltage during some 20 motor stops and starts, under varying loads and frequencies.

- The operation of the motor while drilling ahead approximately 60 feet at rates up to 120 feet per hour was a major accomplishment.

- All channels of the instrumentation system functioned before, during, and after drilling with Electrodril. Real time downhole position data, gamma log data, mud temperature inside and outside the drill string, motor temperature, differential mud pressure (inside drill pipe pressure minus annulus pressure), vibration spectrum, motor voltage and instrument voltage were received and recorded on the surface. In addition, several surface parameters were monitored, processed and recorded. Included was depth, penetration rate, mud flow rate, mud pressure, motor current, and motor voltage.

- Downhole pressure zones indicated that pressure drop across bit nozzles was close to surface test reading. While pulling up to make connection, pressure reading decreased, showing suction effect of bit.

- Downhole temperature readings showed effect of circulating mud on motor temperature.

- The static inverter allowed the driller to control the bit speed. The motor was run at 60 rpm, 120 rpm and 200 rpm.

Subsequent post-test analyses indicated that the primary cause of failure at the McCook site was due to water ingress to the female connectors. In reviewing the manufacturer's product test data, there appears to have been some laxity in the Quality Control process resulting in the receipt and use of connectors that would not have normally passed the acceptance test program. This problem has been identified to the manufacturer, and positive steps have been taken to tighten the production quality control process.

INTRODUCTION

This report documents the major events of the Electrodril Deep Drilling System deployment at the Shell, Martinez State No. 4 drill site west of McCook, Texas, from June 25-July 1, 1979. The report includes a chronology of the deployment/demonstration effort, an analysis of the anomalies encountered and a summary of the lessons learned in this operational demonstration.

DEPLOYMENT/DEMONSTRATION CHRONOLOGY

June 25

The Electrodril equipment was loaded on transporters and held overnight at a freight yard prior to delivery at the McCook well site. Shell set the casing and nippled up.

June 26

The Electrodril surface equipment was delivered and deployed at the well site. It was cabled up and exercised using the diesel auxiliary power unit. The instrument trailer, power inverter and control unit checked OK. Shell was drilling ahead and projected reaching Electrodril deployment target depth (5180 feet) by some time 6/29/79.

June 27

The Electrodril drill pipe, motors and instrument assembly were delivered to the McCook drill site. Both motors and instrument assembly were exercised to assure their functional readiness. The length of the kelly and saver sub were remeasured to assure the length was compatible with that of the cable. No modifications were necessary. Shell decided to come out of the hole for a bit change and survey. While out of the hole, packing of the swivel and cutting of the drill line was accomplished.

June 28

The Baroid logging trailer and depth monitor were moved in and hooked up. Shell drilled ahead, dropped the survey tool, tripped out (laying down 37 joints of pipe) and picked up 33 joints of GE pipe.

June 29

Shell drilled ahead, reached 5180 feet, circulated and dropped the survey tool. Eleven 90-foot stands of GE dedicated pipe were wired during the tripping out process. Shell ran in the Electrodril motor with bit and conducted a motor hydraulic test.

June 30

Laid the kelly down with the crossover and slip ring subs on top, and wired it for Electrodril. Picked up and placed the kelly in the mousehole. Ran surface power cable from the Hoffman Power Skid panel up the standpipe and mud hose to the slip ring assembly. Picked up 43 joints of pipe to replace the GE and Heviwate pipe in the string and continued to the bottom. Reworked the surface power cable as movement of the mud hose tore the rubber clamps loose and broke the cable connector that mates the cable to slip ring assembly. Set the cable sheaves in the rig, made up the sinker bar and went in the hole with a 5000-foot cable. Found the cable to be 37 feet too long. Removed cable and drilled 40 more feet conventionally. Redeployed the cable and made up kelly. Electrical parameters checked out satisfactorily.

July 1

The motor was started and shut down twice to calibrate the motor voltage control feedback loop and other downhole instrumentation. The motor was subsequently started. All instrumentation was displayed on the driller's console located at the driller's stand. Drilling started at 12:30 am; penetrating slowly at first because the motor voltage gain required adjustment while running motor at 60 rpm with 8000 lb weight on bit. Motor stalled each time power demand was too high. To restart, the Tool Pusher pushed the stop button,

pulled off bottom and restarted the motor. Drilled the kelly down a total of 20 feet with the motor current held to less than 40 amperes. A joint of dedicated pipe was then added, but because of a signal lead discontinuity, it was laid down. Picked up a second joint of dedicated pipe and broke the male connector end off while mating with kelly. Picked up a third joint of dedicated pipe but found no continuity on one power phase.

It was decided to drill ahead conventionally 60 feet with the kelly and rotary table combination using conventional pipe. After this was done, the conventional pipe was laid down and a 90-foot stand of dedicated pipe was picked up and mated to the Kelly. Continuity was established and the system was powered up. Drilling was accomplished with the Electrodril motor operating at 200 rpm with 15,000 lb weight on bit. The motor, at this time, was drawing 40 to 45 amperes while drilling ahead at instantaneous rates varying between 80 and 120 feet per hour. Power to the motor was erratic. An electrical short, while drilling, caused the 90-foot stand of dedicated pipe to be replaced. Drilling then continued until the kelly was once again drilled down. Attempted to drill ahead with two different single joints of reworked dedicated pipe but could not establish necessary electrical parameters. An additional 60 feet were drilled ahead conventionally and while attempting to add a 90-foot prewired joint, it was determined that the resistance to ground below the top of the 5000-foot cable had degraded to the point where equipment damage could result if power was applied. The Electrodril demonstration was, consequently, discontinued at 2:00 p.m. Shell tripped out of the hole, laying down the Electrodril tools.

July 2

Electrodril equipment was prepared for loading and return to Houston. No trucks were available, so it was decided to remove the equipment from the drill site on July 3 and 4.

FAILURE ANALYSIS

There were five basic problems identified as a result of the McCook deployment. These were:

1. Shorted 90 foot stand while drilling.
2. Leakage to ground when adding 30-foot and 90-foot stands.
3. Continuing degradation in downhole leakage to ground.
4. Inability to achieve continuity reliably when male and female connectors were mated.
5. Apparent inability of the power generation subsystem to support the drilling process when using the downhole motor.

Each of these problems was investigated in an attempt to arrive at the "most probable cause".

CABLE/CONNECTOR ANALYSIS

Measurements were made at the Longpoint facility after the equipment returned from McCook to provide a baseline for the failure analysis. In general, the 90-foot cables, the 30-foot dedicated pipes, the kelly cable, the slip ring assembly, the 5000-foot cable, the instrument subsystem and the motor subsystem all checked out satisfactorily after disassembly and cleanup. The absence of any electrical anomaly in the cable string, motor and instrument assemblies indicated that the probable cause for the electrical anomalies would be found in the field replaceable connectors.

Subsequent testing of the male and female bayonet connectors indicated that they were the main source of the McCook problems. This baseline testing can be summarized as follows:

- Eight out of 20 female connectors had (electrical) leakage to ground and/or leakage between phases.

- Five out of 20 female connectors had one or more conductors "open" (i.e., no electrical continuity) when mated with a known good male.

- Four out of 25 male connectors were cracked or broken.

- One out of 25 male connectors was electrically shorted.

Prior to these electrical tests, all male and female connectors were inspected for conformity to design dimensions to assure the electrical mating parts were within tolerance. In all instances, the connectors were within tolerance. The results of these tests indicated that the basic design of the connector mating concept was valid and that the probable cause for electrical failure would be found in the manufacturing process and the post-manufacturing test program prior to delivery. The electrical test data sheets are provided for reference purposes in Attachment B of this report. A summary of the male and female connector test results can be found in Tables 2 and 3.

MALE CONNECTOR TEST SUMMARY

	POST MC COOK BASELINE			LOW PRESSURE	HIGH PRESSURE
	VISUAL	DIMENSIONAL ANALYSIS	ELECTRICAL		
PASSED / POPULATION	21 / 25	21 / 21	20 / 21	19 / 20	18 / 19
PHASE TO PHASE & PHASE TO GROUND FALLOUT	4	0	1	1	1

TABLE 2

FEMALE CONNECTOR TEST SUMMARY

	POST MC COOK BASELINE				LOW PRESSURE		HIGH PRESSURE		
	VISUAL	DIMENSIONAL ANALYSIS	ELECTRICAL	ELECTRICAL AFTER DRY OUT	MATED NO LOAD	UNMATED	MATED NO LOAD	UNMATED	MATED VAR. LOAD
PASSED / POPULATION	20/20	20/20	12/20	18/20	17/18	16/17	14/16	12/14	12/12
PHASE TO PHASE AND PHASE TO GROUND FALLOUT				2	1	1	2	2	

TABLE 3

SHORTED 90 FOOT STAND

It was known that the shorted male connector found in the post McCook baseline had been in the drill string atop the 90 foot stand when it shorted. Discoloration of the stainless housing of the connector (Figure 2) indicated that considerable current and heat were generated. The two logical possible causes of the short were water intrusion or a dielectric breakdown under voltage. Temperature was not deemed to be a factor because of the position of the 90 foot stand in the drill string at the time of failure. Removal of the stainless hardware revealed that the four O-rings in the connector body were intact, but a hairline crack was observed at the point that discoloration had occurred as shown in Figure 3. It is possible that a dielectric breakdown caused plastic outgassing which in turn caused the crack. It is much more likely that the crack formed and allowed water in to short out the power conductors.

CONCLUSION:

Most probable cause of the shorted 90-foot stand was a defective male bayonet connector. There is no way of knowing when this defect was caused.

EXCESSIVE LEAKAGE TO GROUND

Excessive electrical leakage to ground was observed all too many times at McCook after making up 30-foot or 90-foot stands. The previously conducted baseline tests suggested that water intrusion into the connectors could be the cause of the problem.

Male and female connectors were subjected to a low-pressure and high-pressure test program using the test equipment shown in Figures 4 and 5, aimed at discovering if and where water was entering the connectors.

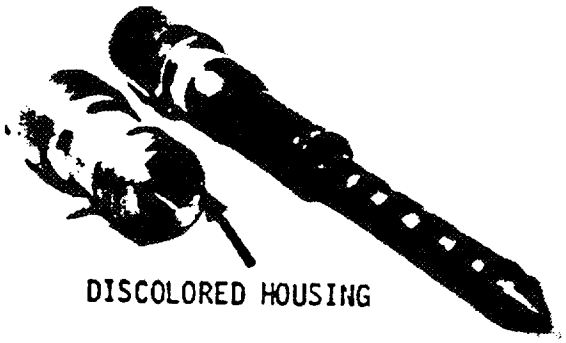

Figure 2

SHORTED MALE CONNECTOR HOUSING

Figure 3

HAIRLINE CRACK IN MALE CONNECTOR

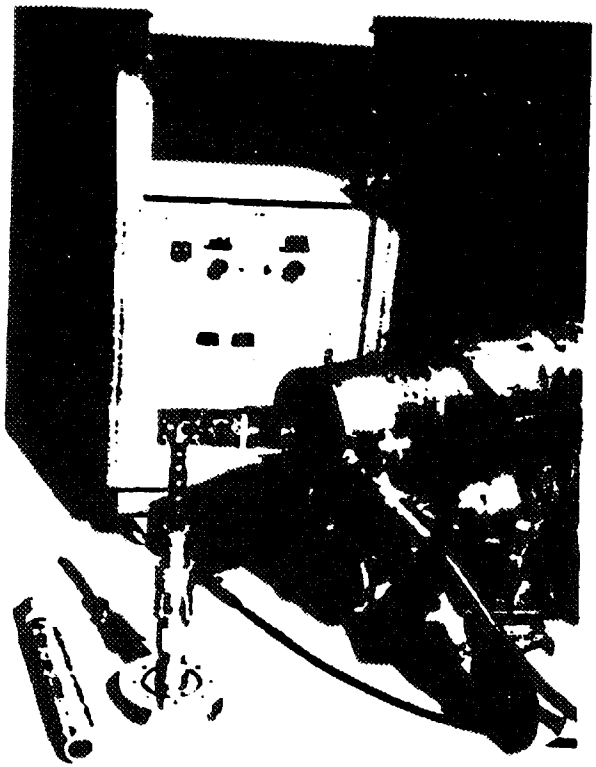

Figure 4

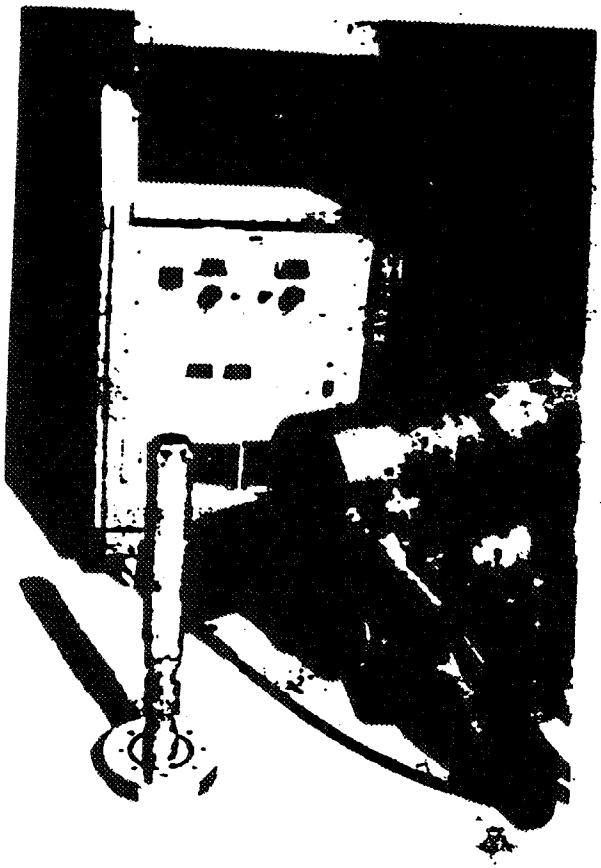

Figure 5

CONNECTOR PRESSURE TEST SETUP

The connectors that showed baseline leakage were put into an oven overnight at 55°C. All but two of the female "leakers" recovered. The remaining 18 female and 20 male connectors were used in the pressure test program. It was decided to test connectors until such time as any leakage was detected, at which time testing of that item would cease.

In an effort to learn more about the water ingress path, the 18 female connectors were subjected to low-pressure water immersion (in a mated condition) and rechecked. One exhibited leakage that was attributed to water intrusion external to the bayonet cavity. The 17 remaining connectors were put back in the water bath without male connectors and rechecking showed one additional "leaker" attributed to water intrusion internal to the bayonet mating cavity.

These tests were repeated for a one-hour @ 2000 psi environment and resulted in a fallout of two additional internal and two more external "leakers".

To determine whether a varying load had any effect on the test results, the 12 female connectors surviving the high-pressure test were put back in the pressure chamber (mated) with currents of 20, 40, 60 and 80 amps being passed for a period of 15 minutes each. Checking for leakage both at elevated and at ambient pressures did not uncover any additional phase leakage anomalies.

Twenty male connectors were subjected to low pressure testing with one fallout. Subsequent high-pressure testing dropped out one additional male leaker.

CONCLUSION:

The most probable cause of excessive leakage to ground is water intrusion into female connectors.

CONTINUING DEGRADATION IN DOWNHOLE LEAKAGE

The cables, motor assembly and instrument assembly had already been eliminated as probable causes for this electrical leakage problem by virtue of the post test analyses conducted at the Longpoint facility. Furthermore, subsequent analyses of the connectors, as previously described, tends to eliminate the male connectors as a probable cause for the electrical leakage problem. It must be understood, however, that there may be a latent problem of electrical leakage that can be related to downhole environment exposure time. The Electrodril system has yet to experience this problem, if it exists.

Inasmuch as the post test-analysis of the connectors identified the female connectors as the probable failure cause, they were further investigated for insight into the leakage degradation problem. All the female connectors used in the water intrusion tests previously described were put in an oven at 55°C for two hours to determine the additional effects of temperature. These connectors were than checked for electrical leakage while they were at temperature. The 12 connectors that had originally shown no leakage still checked satisfactorily. In the case of the originally identified eight "leakers", they showed more leakage (i.e., lower resistance) at elevated temperature than at room temperature. This resistance increased as the connectors were allowed to cool.

This data indicates that the higher temperature probably vaporized the trapped moisture in the connector and increased the leakage path to ground. This is especially so when the leakage data relating to the 12 "good" connectors is considered.

CONCLUSION:

Degradation of downhole leakage as experienced at McCook, was most probably caused by water intrusion in the female connectors. Temperature effects may become significant with increasing downhole exposure.

INABILITY TO ACHIEVE RELIABLE CONTINUITY

It was first thought that the electrical "opens" (i.e., no continuity) that were experienced at McCook were caused by female connector rings opening wider than the diameter of a mating male connector. The dimensional inspection that was conducted dispelled this theory.

During baseline testing, four female connectors that had an open conductor were identified, along with one other connector with an intermittently open conductor when mated with a known good male connector. All opens cleared up when the male connector was rotated and reinserted.

Pinpointing a "most probable cause" for this problem was extremely difficult because, in approximately 300 matings of various male/female connector combinations, only two opens could be detected and these were not repeatable. This led to the conclusion that repeated matings tend to clean and slightly scour the mating surfaces and thus minimize chances for opens.

Prior to going to McCook, most of the connectors (both male and female) had not been used for several months and during this period had been exposed to heat and humidity by virtue of their storage at the Longpoint facility. These conditions probably allowed oxides to form on the Amcoloy contact surfaces.

Continuity historically has been verified with the ohmmeter portion of a standard multimeter. Instruments of this type use a 1 1/2 volt battery for their operation. Assuming the open problem is related to a thin, non-conductive film between the connector mating surfaces, the 1 1/2 volt level in the multimeter is probably insufficient to break down the non-conducting film. It appears that a higher test voltage could break down the film and establish satisfactory contact. This theory was successfully tested on the two open connections identified after the baseline tests. It took approximately 120 VAC in both cases to establish continuity.

CONCLUSION:

The "most probable cause" of conductor opens is a combination of smooth, oxidized contacts separated by the extremely thin film of dielectric grease used for lubrication and mud exclusion.

POOR POWER GENERATOR SUPPORT

The Emerson prototype AS4590 AC static inverter was able to start and run the drill motor at a depth of 5220 feet. It was soon apparent, however, that the drill motor was not developing maximum horsepower/torque relationships for the frequency/voltage/horsepower selected on the static inverter. The lack of horsepower/torque manifested itself in the fact that the drill motor would stall each time weight was applied to the bit to increase drill motor current from 40 to an optimum of 75 amperes.

Three parameters or anomalies were visually monitored when drilling, which would indicate the prime 480 VAC voltage was unstable and contributing to the inability of the inverter/drill motor to produce proper horsepower.

The parameters were:

- A panel light on the Hoffman control panel is powered directly from the 480 VAC generator. The light output dropped significantly during heavy loading of the drill motor. This indicates a drop in the 480 VAC feeding the inverter.

- Visual observation of the panel volt/ammeter mounted on the 480 VAC, 440 KW diesel generator indicated that, as the current tried to exceed 200 amperes during drilling, the voltage output of the generator would significantly diminish. Since the generator voltmeter was highly damped, the actual decrease in voltage is unknown, but is considerably more than indicated on the meter.

- The static inverter is protected by instantaneous overcurrent trip circuitry which, when sensing an overcurrent condition, causes the inverter to shut down. We experienced arcing and a dead short in one dedicated 90-foot joint at the surface while trying to drill. When this shorting occurred, the inverter did not trip itself off but had to be shut down manually. Strip chart recordings of the inverter output current showed that the inverter could not produce enough current output to trip itself when the 90 foot dedicated pipe/cable shorted. Since the inverter seemed to be functioning properly in every respect, the only answer to this anomaly is that only a drop in input voltage/power could create this condition.

Prior to leaving Houston, the 480 VAC power unit utilized at McCook had refused to output any power whatsoever and had to be serviced by factory representatives. In addition, just before drilling, the power unit became intermittent and required service again. Even though the generator was outputting power, the question arises about its ability to develop enough power to satisfy the static inverter requirements under heavy pulsating loads. It appeared from the parameters monitored during testing that the generator unit was malfunctioning. To further substantiate our conclusions, the generator was returned to Mustang Power Products, Houston, Texas for load testing and evaluation. Subsequent tests at Mustang Power concluded that there was a problem with the generator unit. A complete test of the unit was not conducted due to the inability of the test facility to simulate high dynamic electrical loads such as would be seen when Electrodril was in operation.

the upper seal Tungsten carbide disc which spun in its holder caused mud to enter into the bit shaft oil cavity. This combined with the extrusion of the lower rotating seal O-ring and allowed a short circuit of mud flow through the bit shaft bearing section. This also resulted in rupture of the bladder bag and mud erosion of the upper and lower seal areas. The force that broke the upper seal Tungsten carbide disc is not yet fully understood.

The cause of the Tungsten carbide disc spinning in the holder was the result of a design error by the seal manufacturer. The holder is 316 stainless steel which has a functional upper temperature limit of 280° - 300°F rather than the specified 400°F. The corrective action is to use 17-4 PH material for the disc holder or to eliminate the two-piece design and replace with a solid Tungsten carbide insert.

The most likely cause of the lower seal failure was back pressure on the lower seal assembly, which caused the Tungsten carbide insert to move forward in the insert holder until full compression of the springs bottomed on the compression unit. When the back pressure was relieved, the Tungsten carbide insert cocked in the insert holder rather than moving back into proper position. This would have caused high face loading of the seal, and most likely the heat checking observed on the seal faces. This condition or the removal of the Tungsten carbide insert resulted in the broken Tungsten carbide insert. No mud erosion was noted in this area. The pressure that moved the Tungsten carbide insert forward resulted from over filling the lower cavity with grease, or from running the tool into the well.

APPENDIX A

ELECTRICAL TEST

DATA SHEETS

Female Connectors - Post McCook Baseline

Conn.#	Continuity				Leakage			Leakage to Ground			
	Ø1	Ø2	Ø3	Inst.	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst
1	OK				OK			OK			
2	OK		Open	OK	50M			20M			
3	OK	Int.	Open	OK	100M			50M			
4	OK		Open	OK	inf			100K	inf		
5	OK			Int.	inf			100M			
6	OK				20M			10M	10M	6M	20M
7	OK				20M			20M			
8	OK				20M			12M	10M	7.5M	15M
9	OK				inf			inf			
10	OK			Open	inf			20M	20M	20M	inf
11	OK				inf			inf			
12	OK				inf			inf			
13	OK				inf			inf			
14	OK				inf			inf			
15	OK				inf			inf			
16	OK				inf			inf			
17	OK				inf			inf			
18	OK				inf			inf			
19	OK				inf			inf			
20	OK				inf			inf			

Female Connectors

Test 1 All female connectors put into water tank, unmated for 16 hours - air dried and checked for leakage. Those showing leakage were oven dried @ 55°C for 24 hours, cooled to room temperature and retested.

								After Dryout					
	Leakage			Leakage to Ground				Leakage			Leakage to Ground			
Conn #	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst.	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst.
1	inf			inf										
2	2M			2M				1.5M			1.5M			
3	50M			600K	20M	inf	inf	inf			inf			
4	inf	250K	inf	450K	inf	400K	3.5M	inf			inf			
5	2M			2M			inf	inf			inf			
6	50M			20M	20M	50M	50M	50M			30M	30M	12M	100M
7	inf			1M	inf			inf			inf			
8	3M			2.5M	2.5M	3.5M	4M	inf			inf			
9	50M			50M	20M	inf	inf	inf			inf			
10	3M			2M	5M	20M	50M	inf			inf			
11	inf			inf										
12	inf			inf										
13	10M			1M	10M	inf	inf	inf			inf			
14	inf			inf										
15	2M			1.5M	2.8M	inf	inf	inf			inf			
16	inf			inf										
17	inf			7.5M	inf			inf			inf			
18	inf			inf										
19	inf			inf										
20	inf			inf										

Female Connectors

Test 2 Those which could be dried out in Test 1 were subjected to 16 hour water immersion using DC-3 dielectric and mated with a male.

Conn.#	Leakage			Leakage to Ground				Remarks
	ø1/ø2	ø1/ø3	ø2/ø3	ø1	ø2	ø3	Inst.	
3	inf			inf				
4	inf			inf				
5	inf			inf				
7	inf			inf				
8	20M			20M				External leakage
9	inf			inf				
10	inf			inf				
13	inf			inf				
15	inf			inf				
17	inf			inf				

Female Connectors

Test 3 Those showing no leakage in Test 2 were put back in water bath unmated for 16 hours and retested - DC-3 residue not removed

Conn.#	Leakage			Leakage to Ground				Remarks
	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst	
3	inf			inf				
4	inf			inf				
5	inf			inf				
7	inf			inf				
9	inf			inf				
10	20M			20M				Internal Leakage
13	inf			inf				
15	inf			inf				
17	inf			inf				

Female Connectors

Test 4 All female connectors not culled out from Tests 1, 2 and 3 subjected to 1 hour @ 2000 psi mated - no load and chedked after removal from chamber.

Conn.#	Leakage Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Leakage to Ground Ø1	Ø2	Ø3	Inst.	Remarks
1	inf			inf				
3	100M			50M				External leakage
4	inf	1M	inf	1M	inf	1M	inf	External leakage
5	inf			inf				
7	inf			inf				
9	inf			inf				
11	inf			inf				
12	inf			inf				
13	inf			inf				
14	inf			inf				
15	inf			inf				
16	inf			inf				
17	inf			inf				
18	inf			inf				
19	inf			inf				
20	inf			inf				

Female Connectors

Test 5 All female connectors not culled out in Test 4 subjected to 1 hour @ 2000 psi unmated

Conn.#	Leakage Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Leakage to Ground Ø1	Ø2	Ø3	Inst	Remarks
1	inf			inf				
5	50M			50M				Internal leakage
7	50M			50M				Internal leakage
9	inf			inf				
11	inf			inf				
12	inf			inf				
13	inf			inf				
14	inf			inf				
15	inf			inf				
16	inf			inf				
17	inf			inf				
18	inf			inf				
19	inf			inf				
20	inf			inf				

Female Connectors

Test 6 All 20 females put in oven @ 55°C for 2 hours and checked for leakage before and immediately after removal

Conn.#	Room Temp							55°C						
	Leakage			Leakage to Ground				Leakage			Leakage to Ground			
	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø2	Inst	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Ø1	Ø2	Ø3	Inst
1	inf			inf				inf			inf			
2	1.5M			2M				500K			200K			
3	inf			50M				25M			15M			
4	inf	1M	inf	1M	inf	1M		20CK			100K			
5	50M			50M				20M			10M			
6	1.5M			10M				2M			1M			
7	50M			50M				15M			8M			
8	3M			3M				20M			10M			
9	inf			inf				inf			inf			
10	3M			3M				2M			1M			
11	inf			inf				inf			inf			
12	inf			inf				inf			inf			
13	inf			inf				inf			inf			
14	inf			inf				inf			inf			
15	inf			inf				inf			inf			
16	inf			inf				inf			inf			
17	inf			inf				inf			inf			
18	inf			inf				inf			inf			
19	inf			inf				inf			inf			
20	inf			inf				inf			inf			

Female Connectors

Test 7 All females showing no leakage in Test 6 mated with a male connector having shorted phases. Leakage was checked while the mated pair was in water @ 14.7 psi and 2000 psi prior to passing current. Leakage is checked after 15 minutes of passing 20, 40, 60 and 80 amps through two pair of contacts while at 2000 psi and again at 14.7 psi.

Conn.#	Initial Leakage 14.7 psi	Initial Leakage 2000 psi	Leakage to Gnd after 15 minutes @ 20a.	40a.	60a.	80a.	Final Leakage @ 14.7 psi
1	inf						
9	inf						
11	inf						
12	inf						
13	inf						
14	inf						
15	inf						
16	inf						
17	inf						
18	inf						
19	inf						
20	inf						

Male Connectors - Post McCook Baseline

Conn.	Continuity	Leakage Ø1/Ø2	Leakage Ø1/Ø2	Leakage Ø1/Ø3	Leakage Ø2/Ø3	Leakage to Ground Ø1	Leakage to Ground Ø2	Leakage to Ground Ø2 Inst.	Remarks
M1									Cracked shaft @ rig
M2	OK	inf				inf			
M3									Cracked plastic
M4									Shorted Phases
M5									Cracked shaft
M6	OK	inf				inf			
M7	OK	inf				inf			
M8	OK	inf				inf			
M9	OK	inf				inf			
M10	OK	inf				inf			
M11	OK	inf				inf			
M12	OK	inf				inf			
M13									Broken tip @ rig
M14	OK	inf				inf			
M15	OK	inf				inf			
M16	OK	inf				inf			
X1	OK	inf				inf			
X2	OK	inf				inf			
X3	OK	inf				inf			
X4	OK	inf				inf			
X5	OK	inf				inf			
X6	OK	inf				inf			
X7	OK	inf				inf			
X8	OK	inf				inf			
X9	OK	inf				inf			

Male Connectors

Test 1 All uncracked non leaky male connectors put in water tank for 16 hours and re-checked.

Conn.	Leakage Ø1/Ø2	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Leakage to Ground Ø1	Ø2	Ø2 Inst.	Remarks
M2	inf				inf			
M3	inf				inf			Chipped wafer @ rig
M6	inf				inf			
M7	inf				inf			
M8	inf				inf			
M9	inf				inf			
M10	inf				inf			
M11	inf				inf			
M12	inf				inf			
M14	inf				inf			
M15	inf				inf			
M16	inf				inf			
X1	inf				inf			
X2	inf				inf			
X3	inf				inf			
X4	inf				inf			
X5	inf				inf			
X6	100M				75M			Visual indication of porosity
X7	inf				inf			
X8	inf				inf			
X9	inf				inf			

Male Connectors

Test 2 All male connectors passing Test #1 subjected to 3000 psi for one hour and rechecked.

Conn.#	Leakage Ø1/Ø2	Ø1/Ø2	Ø1/Ø3	Ø2/Ø3	Leakage to Ground Ø1	Ø2	Ø2	Inst.	Remarks
M2	inf				inf				
M6	inf				inf				
M7	inf				inf				
M8	inf				inf				
M9	inf				inf				
M10	inf				inf			50M	Signal leakage only
M11	inf				inf				
M12	inf				inf				
M14	inf				inf				
M15	inf				inf				
M16	inf				inf				
X1	inf				inf				
X2	inf				inf				
X3	inf				inf				
X4	inf				inf				
X5	inf				inf				
X7	inf				inf				
X8	inf				inf				
X9	inf				inf				

★U.S. GOVERNMENT PRINTING OFFICE: 1980-640-258 2296

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