BERC/TPR-77/11

**ELECTRODRIL SYSTEM FIELD TEST PROGRAM
INTERIM PHASE—FINAL REPORT, JANUARY—APRIL 1977**

By

General Electric Company, Space Division
Prepared for DOE Under Contract No. EY-76-C-02-4033

Date Published—February 1978

MASTER

Bartlesville Energy Research Center
U.S. Department of Energy
Bartlesville, Oklahoma

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been produced directly from the best available copy.

Available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$4.00
Microfiche \$3.00

**ELECTRODRIL SYSTEM FIELD TEST PROGRAM
INTERIM PHASE—FINAL REPORT, JANUARY—APRIL 1977**

By
General Electric Company
Space Division
P.O. Box 58408
Houston, Texas 77058
August 1, 1977

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared for the Department of Energy
Under Contract No. EY-76-C-02-4033

B. V. Traynor, Jr., *Contract Manager*
Peter D. Taylor, *Program Manager*
Troy L. Belver, *Project Engineer*
General Electric Company

C. Ray Williams, *Technical Project Officer*
Bartlesville Energy Research Center
U.S. Department of Energy
P.O. Box 1398
Bartlesville, Oklahoma 74003

Date Published—February 1978

U.S. DEPARTMENT OF ENERGY
TECHNICAL INFORMATION CENTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FOREWORD

The Electrodril System Field Test Program—Interim Phase, as described herein, is a cooperative, cost-sharing venture between the Department of Energy (DOE), formerly 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.A002. 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 contract was approved by the Division of Oil, Gas and Shale Technology, Mr. Hugh D. Guthrie, Director, and was funded by the Branch of Drilling, Exploration and Offshore Technology, Mr. Don Guier, Branch Chief. The work was supervised by the Bartlesville Energy Research Center, Mr. John Ball, Director. The foresight of these men should be commended because many researchers believe that a successful Electrodril system will be the greatest achievement in drilling technology in many years.

The work performed during Phase I uncovered some problems which required improvements before proceeding with Phase II; therefore, the Interim Phase was conceived and performed. This report describes the problems and their solutions. Work has now started on Phase II which will field test the Deep Drilling System.

The final report, as submitted by G.E., contained Appendices A, B, C, D, E, and F. These appendices are not being published and copies can only be obtained from the library at Bartlesville Energy Research Center.

C. Ray Williams
Technical Project Officer
Bartlesville Energy Research Center

ELECTRODRIL SYSTEM FIELD TEST PROGRAM
INTERIM PHASE
FINAL REPORT
ABSTRACT

The Interim Phase of the Electrodril System Field Test was set up to provide the transition between Phase 1 Testing and the Phase 2 Major Drilling System Test. Specifically, it included more detailed analyses, some redesign, and additional field testing required to rectify three problems that surfaced during Phase 1 Testing. These problems were:

1. Motor Lower Seal Failures
2. Excessive Wear of Bit Shaft Seal
3. Cable/Connector Failures

The Phase 1 Motor Lower Seal Failures were found to have been caused by failure to rigidly fix the Face Seal Stator and by having the Face Seal inversely designed into the motor system. Downhole testing with the seal inversely installed but with the stator rigidly fixed demonstrated that the seal performed satisfactorily. In all subsequent use of the motor, the seal should be configured as recommended by the manufacturer.

Interim Phase Downhole Testing demonstrated that a properly refurbished bit shaft is capable of functioning satisfactorily in a drilling environment. Seal wear experienced during test indicates that these seals should be replaced periodically.

The Interim Phase was used to provide extensive analysis into Phase 1 Cable/Connector Failures, evaluation of potential cable conductor insulation material, evaluation of stronger, more rigid material for fabricating the male connector body, and evaluation of "Bondability" of materials used in connector fabrication and cable insulation. These

analyses and evaluations were used as inputs in the design, fabrication, and procurement cycle to yield a new replaceable Electrodril connector pair and armored cable with water blocked MS type connectors capable of accepting the replaceable Electrodril connectors. Repeated downhole matings were made during test. The cable and the replaceable male connector performed flawlessly. The internal conductor rings in the replaceable female connector gradually became oversize as the test progressed. Subsequent female connector rings will be fabricated using a harder, springier material to assure successful downhole mating even after extensive use.

ELECTRODRIL - INTERIM PHASE
FINAL REPORT

	<u>TABLE OF CONTENTS</u>	<u>PAGE</u>
1.0	INTRODUCTION	1
2.0	MOTOR LOWER SEAL	1
2.1	BACKGROUND	1
2.2	APPROACH	1
2.3	RESULTS	2
3.0	BIT SHAFT SEAL	9
3.1	BACKGROUND	9
3.2	APPROACH	9
3.3	RESULTS	10
4.0	CABLE/CONNECTOR	11
4.1	BACKGROUND	11
4.2	APPROACH	12
4.3	RESULTS	13
5.0	REFERENCES	17

APPENDICES (Not published. Available from BERC library.)

- A. Progress Report - Motor Lower Seal Investigation
- B. 81 Hour Motor Lower Seal Test Results
- C. Progress Report - Cable/Connector Study
- D. Motor Oil Analysis - 81 Hour Motor Seal Test
- E. Motor Oil Analysis - 100 Hour Motor Seal & Bit Shaft Tests
- F. 100 Hour Motor Lower Seal Test Data Sheets

LIST OF ILLUSTRATIONS

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
1	81 HOUR MOTOR LOWER SEAL TEST CONFIGURATION	4
2	100 HOUR MOTOR LOWER SEAL TEST	5
3	REPLACEABLE MALE CONNECTOR ON TOP OF MOTOR	14
4	REPLACEABLE FEMALE CONNECTOR AT END OF 2500 FOOT CABLE	14

ELECTRODRIL - INTERIM PHASE FINAL REPORT

1.0 Electrodril Interim Phase was implemented to provide the more detailed analyses, possible redesign, and field testing required to rectify three specific problems that surfaced during Phase 1 Testing. These problems were:

1. Motor Lower Seal Failures
2. Excessive wear of Bit Shaft Seal
3. Cable/Connector Failures

The Interim Phase started January 1, 1977, and was completed on April 29, 1977. Field Testing associated with each portion of the Interim Phase was accomplished at the Brown Oil Tool (BOT) Test Site located on the Katy Freeway in Houston, Texas.

2.0 Motor Lower Seal

2.1 Background

Two motor lower seal failures occurred during Phase 1 Field Testing (See Reference 1). In both instances, incorrect procedures were followed when preparing the motor for downhole deployment. This motor oil/mud interface is too important an area to have it remain questionable so it was thoroughly studied, modified and tested during the Interim Phase.

2.2 Approach

The seal in question is a commercially available face seal with a Stellite Face on the Rotor and a Ni Resist Face on the Stator. The first step in the Interim Phase was to analyze the seal operation to

verify that the seal does indeed function as required. Next, the seal integrity was checked by operating a 60 HP motor continuously, downhole with drilling mud circulating, for a period of 100 hours. Motor current, motor voltage, motor temperature, mud pressure, and mud flow rate were monitored throughout the test to detect any abnormalities that might develop.

2.3 Results

2.3.1 Study

An investigation, including a review of the design and mathematical analysis, was made to establish the cause of the seal failures experienced during Phase 1 testing. A copy of the report documenting the results of that study is included as Appendix A. Three significant conclusions can be drawn from the report.

1. The face seal was inversely designed into the Electrodrill Motor System. (See Figure 3 of Appendix A). This problem was further complicated by the failure to rigidly fix the stator. The overall results were to allow the stator to push against the rotor, causing the entire seal to move against the spring force of the rotor. This resulted in excessive pressure on the face which in turn led to excessive wear during Phase 1 testing.
2. Simply fixing the stator, without inverting the entire seal, should yield a seal suitable for most non-severe applications. (See Figure 4 of Appendix A). Excessive loss of motor oil should be expected.
3. In all subsequent use of the motor, the seal should be configured as recommended by the manufacturer (See Figure 6 of Appendix A). This will yield a seal with good sealing properties, long life, and little loss of oil.

2.3.2 Tests

Two separate tests were run in the Brown Oil Tool 200 foot cased hole. The configurations in each case are illustrated in Figures 1 & 2. Both tests were planned to continuously operate the 60 HP motor downhole with mud circulating for a period of 100 hours. The first attempt was terminated after 81 hours by a connector failure. The second attempt operated successfully for 100 hours.

2.3.2.1 First Test

The first lower motor seal test was run during the period March 8, 1977, through March 12, 1977. This test was run prior to completing the theoretical analysis of the seal performance. The seal was used as shown in Figure 3 of Appendix A, i.e., it was installed inversely to the method recommended by the vendor and its stator was not fixed in place.

The drill motor, cable connector, one joint of $4\frac{1}{2}$ " X-hole drill pipe, King swivel, and wireline packoff were assembled with the motor/drill pipe joint at the surface. The assembly was then lowered into the hole, circulation started, and then the motor turned on. (See Figure 1 for configuration details). At test initiation and then once each hour for the duration of the test, the following parameters were recorded:

- Applied Motor Voltage (Voltmeter on Display/Control Panel)
- Motor Current (Ammeter with Overcurrent Alarm)
- Mud Pressure (Standard Standpipe Gage)
- Mud Flow Rate (Count of Strokes/Min)
- Temperature (Thermocouple)

FIGURE 1
81 HR MOTOR LOWER SEAL TEST CONFIGURATION

FIGURE 2
100 HR MOTOR LOWER SEAL TEST

Three thermocouples were used to measure and record temperature. One measured mud temperature in the return sump. The second one was taped to the upper motor housing. The third was taped to the lower motor housing near the lower bearings.

After the test was started, the mud apparently caked on the pump swabs and liners. This in turn caused the mud temperature to elevate to $\approx 95^{\circ}\text{C}$. Mud was exchanged periodically between the sump and a 55 barrel mud tank to effectively cool the mud being circulated by the motor.

Appendix B is a report written to document the first motor seal test. Motor voltage and current were stable during the test. During the 81st hour of the test, the current alarm went off. A current of > 30 amps was noted. The motor and mud pump were turned off. The motor was immediately removed from the mud. Subsequent investigation revealed three important points.

- The high motor current indication resulted when the male connection on the top of the motor failed and shorted out to the mud.
- A small amount of drilling mud was found in the motor oil (See Appendix D).
- A temperature indication rod located in the motor oil indicated that the motor temperature had exceeded 150°C .

When the motor was disassembled, it was found that the rubber compensation bag had ruptured, allowing mud to enter the motor oil. The lower seal was slightly worn. It is believed that the mud entered primarily through the ruptured compensation bag. The compensation bag rupture was precipitated by the excessively high temperatures (hence high oil expansion). The problem

was compounded by the fact that, while filling the motor, the compensation chamber fill plugs were loosened before they should have been. This prevented providing a precisely known compensation volume. Measurement of the oil volume obtained when the plugs were removed indicated that $\sim 1/2$ (20 to 25 OZ) the specified expansion capability existed during test. The resulting high pressure and reduced expansion capability forced the bag to rupture.

2.3.2.2 Second Test

The second Lower Motor Seal Test was run during the period March 29, 1977, through April 3, 1977. This test was run after the theoretical analysis of the seal performance. The seal was used as shown in Figure 4 of Appendix A, i.e., it was installed inversely to the method recommended by the vendor, but the stator was securely fixed in place.

Several steps were taken to assure that the problems that appeared during the first test did not recur. 1) The mud flow configuration was altered to circulate all mud through an Aerator/Filter and the 55 Barrel Mud Tank to assure cooler mud, 2) water softener (Hexameta Phosphate) was added to the mud to reduce its viscosity to decrease the possibility of mud caking up in the mud pump, 3) A different mud pump was used, 4) an exact 44 ounces of fluid was put into the outer compensation cavity to assure proper pressure compensation, 5) a thermocouple was installed inside the motor in the oil with the wires brought out and to the Data Analysis Trailer for continuous recording. Also recorded on the recorder were ambient air and return mud temperatures.

The Second Lower Motor Seal Test progressed exactly as planned. The motor oil temperature reached a maximum of approximately 46°C. An interesting observation is that the difference between the return mud temperature and motor oil temperature was between 3 and 4°C throughout the test.

Appendix F is a copy of the actual Data Sheets filled out during the test.

The test was terminated after 100 hours of continuous running. Subsequent investigation revealed that no mud had entered the motor; the pressure compensation bag was intact, and the lower motor seal showed no unusual wear. The motor oil level was noticeably reduced, indicating that oil had probably been lost through the lower motor seal. This test confirmed the analysis (Appendix A) that indicated that the lower seal, with fixed stator, but inversely installed should function but with more than normal oil loss.

3.0 Bit Shaft Seal

3.1 Background

Post test inspection of the Bit Shaft used during Phase 1 Testing revealed that the oil/mud seals in the bit shaft had worn more than anticipated. During Phase 1 Testing, the bit shaft was not cleaned or refurbished even after repeated trips downhole. Thus, drilling mud may have caked up in the outer pressure compensation chamber to an extent to prevent proper pressure compensation.

3.2 Approach

The Interim Phase Plan was to verify that a properly refurbished bit shaft is capable of functioning downhole in a drilling mud environment. Upon completion of the 100 hour lower motor seal test, the motor was refilled with oil and then a bit shaft attached to the motor assembly to begin the Bit Shaft Test. A 9/16" hole was drilled in the center of a pipe joint plug. The hole was used to create a pressure differential (simulated bit) between the oil in the bit shaft and the exterior mud. The deployed configuration was identical to that for the 100 hour motor seal test (See Figure 2) except for the addition of the bit shaft, removal of the thermocouple in the motor oil, and changing the bit simulator nozzle from 7/8" to 9/16". The lower motor seal was not changed before starting the bit shaft test.

3.3

Results

The motor was used to turn the bit shaft continuously for 24 hours with a 450 to 500 PSI pressure differential across the seals. The test proceeded normally for 24 hours. Subsequent inspection revealed that 1) no mud had entered the motor and 2) mud had entered the bit shaft (See Appendix E). The bearings in the bit shaft were slightly worn by the mud but can be reused. Thus the bit shaft was still functional after the test. The bit shaft seals were worn and must be replaced during refurbishment.

4.0 Cable/Connector

4.1 Background

Several cable/connector failures were experienced during Phase 1 Testing (See Reference 1). These failures have been attributed to a variety of causes. Included in the list of causes of cable/connector failures are:

- * The EPDM used in insulating the individual conductors in the Phase 1 cable contained a foreign "waxlike" material that prevented a good bond to the Neoprene used in the Electrodril connectors. The poor bond in turn led to mud leakage into the cable/connector interface.
- * The Neoprene body of the male connector did not bond well to the copper conductor rings. As a result, the male connector was physically weak. This led to male conductor failures when the connector was mechanically stressed.
- * The Dielectric grease used to pack the female prior to deployment downhole in the drilling mud was too viscous to exit properly through the small vent holes. This caused "Blowouts (Ruptures in connector body to allow grease to escape)" and "Blowby (Grease forced back over the wiping ring and between the male and female copper rings)" in the female connector when attempting to make up downhole.

Thus, it was decided that any subsequent cable/connectors must be made using strong material with good bonding characteristics, the exit holes in the female must be enlarged, and the entire connector/cable interface must be water-tight even when under 15,000 PSI pressure. An additional requirement of making the connectors "Field Replaceable" was also imposed on any new development.

4.2

Approach

The plan to develop a more reliable downhole connector configuration included the following major subtasks:

1. Evaluate several potential cable conductor insulation and connector body materials to determine their bondability. Actually try to bond the various materials and test the bonds under high pressure.
2. Consider using materials with more rigidity and strength to fabricate the male connector body.
3. Survey multiple cable vendors to determine the optimum cable insulation material.
4. Evaluate techniques to make the connectors "Field Replaceable".
5. Design and fabricate "Field Replaceable" male and female connectors. Evaluate and test them in the lab.
6. Procure 2500 feet of armored cable.
7. Deploy a 60 HP motor with replaceable male connector downhole in mud to 2000 feet in the Brown Oil Tool 3600 foot well. Then deploy the new Electrodril cable with the new replaceable female connector downhole to achieve a mechanical mate. Check the electrical mate. Turn on motor to verify good mate, pull cable, then repeat this procedure for 5 - 8 hour days.

4.3 Results

4.3.1 Insulation Material Evaluation

A survey of several cable vendors was made to obtain technical data on different types of cable insulation and to obtain samples of insulated wire to perform bondability tests. Four types of insulating materials were tested; Hypalon, E.P.D.M., Exane and E.P.C. All four passed the bondability test. Details of the vendor survey and bondability tests are documented in Appendix C.

4.3.2 Replaceable Connector Concept

The concept that was developed to provide for field replacement of Electrodril connectors was to have the selected cable vendor attach a MS Series Connector to both ends of their armored cable. The connector was to be totally water blocked for pressures up to 15,000 PSI. The replaceable connector would then be attached to the MS Series Connector via a threaded knurled sleeve.

The final choice was to purchase a 2500 foot, 4 conductor (3 - #10 AWG Stranded and 1 #18 AWG Stranded) cable from Vector Cable Company. The 4 conductors are insulated with an Ethylene/Propylene base EPC. Two layers of improved plow steel armor protects the cable and gives it the high tensile strength necessary to support 5,000 feet of its own weight. A 4-Pin MS Series female connector is attached to each end of the cable. The General Electric Company then molded a strong rigid male Electrodril connector using castable epoxy. This field replaceable connector has a MS Series male on the opposite end to mate with the cable connector. Figure 3 is a photograph of the male Electrodril connector as it is about to be attached to the female MS connector located on top of the 60 HP motor. The corresponding female Electrodril connector was made with Beryllium copper contact rings and a molded Neoprene body. Figure 4 is a photograph of the female connector as it is about to be attached to the end of the 2500 foot Electrodril cable.

FIGURE 3 REPLACEABLE MALE CONNECTOR ON TOP OF MOTOR

FIGURE 4 REPLACEABLE FEMALE CONNECTOR AT END OF 2500 FOOT CABLE

4.3.3 Field Test

4.3.3.1 Test Results

The field test of the Electrodril Cable/Connectors was performed in the Brown Oil Tool 3600 Foot Test Well. The motor was lowered to a depth of 128.5 feet on 3 joints of 5" X-Hole Pipe plus one 4 1/2" X-Hole Pipe on April 18, 1977.

Baroid Petroleum Services mounted a new prototype depth measuring device on the upper sheave to monitor the length of cable deployed into the hole each time a mating attempt was made.

Four completely successful matings were achieved on the 18th and 19th. After the four matings time was taken to lower the motor assembly to a depth of 2116.5 feet by adding another 64 joints of 5" X-Hole Drill Pipe. After deploying the motor, circulation was established for approximately two hours to remove any debris that might have fallen on the male connector. After circulation, four more completely successful matings were achieved. The fifth try resulted in no measurable continuity being established. After pulling the cable from the hole, it was discovered that a significant quantity of rubber shavings (cable armor filler) and rust (from drill pipe) was present inside the female connector. This debris is assumed to have prevented the good mate. Circulation was established again to clean the motor connector area. After the circulation, two more successful matings were achieved. Next, three partial mates were achieved, i.e., two of the three connector rings were mated but the top ring on the male connector was not mated. The motor was then tripped out of the well. Inspection of the male connector showed it to be o.k. The motor was again lowered to 2116.5 feet and circulation established. After circulation was complete, three successful matings were achieved; followed by two partial mate

(two leads o.k, the upper ring connection was open). Thus 13 successes and 6 partial mates were achieved using the first female connector (Berylco 10CR rings).

Next, a new female connector (Amcoloy 815 Rings) was attached to the Electrodril cable. Two mating attempts resulted in no rings making contact.

The test was terminated on April 25, 1977, due to a schedule conflict concerning use of the Brown Oil Tool Test Well.

The average time to deploy the 2116 feet of cable was 12 minutes. The average time to remove the cable was 15 minutes.

The Baroid cable length measuring device performed without failure. It was extremely repeatable and proved extremely valuable in assuring a low speed mate by allowing us to know when the cable was almost fully deployed to the motor connector.

4.3.3.2

Post Test Analyses

The Vector Cable/Connector performed as required. There was no excessive wear on the armor. The cable/connector interface showed no signs of leakage. A loose pair of set screws allowed the connector to rotate slightly with respect to the connector body. This movement did not cause a failure and was easily fixed after the test.

The replaceable male connector showed some slight signs of wear but nothing to affect its functioning.

The replaceable female connectors appeared ok to a visual examination. Measuring the I.D. of the internal rings indicated that they were slightly oversize after the test.

A laboratory test was run after the field test. The test consisted of mating a male and female connector by hand. A successful attempt was made with clean dielectric grease in the female. Next, oil well debris was purposefully put into the dielectric grease. The mating attempt resulted in a partial mate with two rings mating with the third open. It appears that debris can plug the vent hole in the female. When this happens, the dielectric grease "Blows By" the male Neoprene wiper ring and forces the upper female ring to expand. The result is dielectric grease between the male and female ring. This problem can be alleviated by expanding the size of the vent hole, hardening the female rings to increase their spring modulus and decrease their ability to take a permanent set, and by using a dielectric fluid (held in by a diaphragm) instead of grease to decrease the tendency of debris to accumulate around the male connector.

5.0

REFERENCES

1. Final Report - Electrodril System Field Test Program, Phase 1