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PHASE IV FINAL REPORT
PROGRAM FOR THE IMPROVEMENT OF
DOWNHOLE DRILLING MOTOR BEARINGS AND SEALS

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Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
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FOREWORD

This report summarizes the work performed for the second 6-month period of Phase IV of the DOE/DGE Contract Number 46-3053 "Program for the Improvement of Downhole Drilling Motor Bearings and Seals."

This reporting period saw the following main accomplishments and developments in the project:

1. Long-duration (53 to 165 hours) and repeatable tests in the Seal Tester,
2. Completion of design to introduce abrasive mud on the low-pressure side of the Seal Test Machine,
3. Expansion of the Bearing-Seal Package Test Facility capacity, and
4. Completion of initial test in the Bearing-Seal Package to establish data for self-generation of heat by the test seals.

This report contains three major sections: Seal Testing and Evaluation, Bearing-Seal Package Testing and Evaluation, and Program Status, Plans and Schedule. There is no Lubricant Testing section of the report since no new lubricant samples have been received during this reporting period. This report will cover progress on the contract through October 31, 1980.

The Maurer Engineering Report "Final Progress Report on Improvement of Downhole Motor Bearings and Seals," Sandia Contract No. 46-3054, by Jeff L. Barnwell has been included as Appendix C of this report.

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INTRODUCTION

This report summarizes the work completed during the second six month period of Phase IV of the DOE/DGE Contract Number 46-3053, "Program for the Improvement of Downhole Drilling Motor Bearings and Seals." The specific objectives of this program are:

1. Develop a lubricated Bearing-Seal Package with a life of over 200 hours;
2. Develop an improved rotary seal which allows bit pressure drops over 1,000 psi; and
3. Develop a Bearing-Seal Package to operate at 250°F circulating bottomhole temperature.

This report presents recent test results from the Seal Test Machine and Bearing-Seal Package. An overall program summary is given in Appendix D, and the major milestones of this phase of the program are shown in the following chart, Table I.

MAJOR MILESTONES

	Nov. 1, 1979			Nov. 1, 1980		
MILESTONES	Feb 1	May 1	Aug 1	Feb 1	May 1	Aug 1
SEAL TESTING						
With:						
New Candidate Seals						
New Shaft Coatings						
High Temperature Lubricant						
Optimization of best Seal-Shaft Coating Combination with High Temperature Lubricant						
FULL SCALE SEAL-BEARING TESTS						
Seal-Bearing Test Stand Modifications						
Seal-Bearing Heat Up Observation Tests						
Major Project Review						
Seal-Bearing Tests						
FULL SCALE MOTOR TESTS						
Test Facility Design						
Complete Test Facility						
Acquire PDM Motors						
Laboratory Verification of Interfacing Members						
Conduct Full Scale Tests						
FIELD TESTING						
Dynamic Full Scale Tests						
Locate and Arrange for Field Site						
Perform Field Tests						

SEAL TESTING AND EVALUATION

SEAL TESTER

Three modifications to the Seal Test Machine were made during this reporting period: the 3/4" cross section Main Vessel Seal Carrier was installed; the vessel seal packs were redesigned; and a mud injection system was designed. Also, the mud properties were established and several test procedure changes were made.

3/4" Seal Carrier

The Main Vessel Seal Carrier for 3/4" cross section seals was made operational. The new Main Vessel Seal Carrier will permit the testing of the 3/4" cross section Canted Seal and mechanical face seals. In addition, a complete set of band heaters has been installed and wired on the Main Vessel Seal Carrier. This will provide for easy change (two to three hours) from the 1/2" cross section Main Vessel Seal Carrier to the 3/4" cross section Main Vessel Seal Carrier.

Vessel Seal Pack

It was observed during the long running seal tests (DMT-040, 045 and 046) that the vessel seal packs had a maximum life of approximately 50 to 60 hours. In order to increase the life of the vessel seal, a new vessel seal pack was designed using the HPCR seal manufactured by Utex Industries. The new vessel seal pack will be used on all seal tests starting with DMT-054.

Mud Injection System

A mud injection system was designed for the Seal Test Machine during this reporting period. The system will inject mud on the low pressure side of the test seal in specified seal tests during the next phase of the program. A schematic of the system is shown in Figure 1.

MUD INJECTION SYSTEM SCHEMATIC

Figure 1

The operation of the mud injection system is as follows. A Cylinder will be used for the mud reservoir. Inside the cylinder will be a piston with mud on one side and hydraulic fluid on the other. A Haskel pump pressurizes the hydraulic fluid which in turn pressurizes the mud and injects it into the Seal Test Machine. A valve downstream of the Seal Test Machine is used to create a back-pressure on the mud and pressurize the system.

Mud Properties

The following drilling mud properties will be maintained in the seal tests:

- a. Mud weight will be 9.0 lb/gal water base mud.
- b. #3 blasting sand will be used for abrasives. The percent solids will be 2%, with a 3% maximum.
- c. The pH of the mud will range from 7-9.
- d. The mud will be checked periodically to maintain the proper rheological properties and proper percent solids.
- e. This mud will also be used in the Bearing-Seal Package Tests.

Test Procedure Changes

Starting with DMT-054, the following changes will be made in the test procedure:

- a. All tests will be run with Pacer PLX-014 lubricant, and specified tests will be run with mud on the low pressure side.
- b. The differential pressure across the seals will remain at 1500 psi (2500 psi - high pressure/1000 psi - low pressure) when testing with Pacer PLX-014 lubricant. The differential pressure

will be reduced to 1000 psi (1500 psi - high pressure/500 psi - low pressure) when testing with mud on the low pressure side. This change is being made because in the seal tests with mud, the pressure ports will be switched; i.e. the high pressure will be at each vessel seal.

- c. Both seal packs will be established as test seals, and the test will be terminated when one of the seals has leaked one gallon of lubricant. This change is being made in order to eliminate the problem of disturbing the test seal if the dummy seal fails first and has to be replaced. The only exception will be the tests with the Face Seals. In these tests, a dummy seal pack of HTCR seals will be used because of the high costs of the face seals.

SEAL TEST RESULTS

Sixteen seal tests were completed during this reporting period. These tests included the following seal types: HTCR SF Design, Variseal^R, Hybrid Assembly, Mesh Matrix, Canted HTCR and Grafoil^R - Phosphor Bronze (Horizontal Laminates). The test results are shown in Table II and Appendix A. Following is a description of these tests.

HTCR SF Design

This seal type was tested for the first time during this reporting period. Two tests were run with this seal, DMT-040 and DMT-046. HTCR is manufactured by Utex Industries, Inc. and uses an Aflas^R base. Aflas^R is a copolymer of tetrafluroethylene and propylene. The seal is reinforced with alternating plys of synthetic arimid and glass fabric. A diagram of this seal is shown in Figure 2. Each test seal pack consisted of three pressure rings and SAE 660 Bronze top and bottom adapters.

Figure 2

HTCR SF Design Seal Diagram

TABLE II

COMPLETED SEAL TESTS

Test ID	Ending Date	Seal Type	No. of Pressure Rings	Back Up Rings	ΔP (psi)	RPM	Duration (Hours)	Chrome Shaft Coating Finish (rms)	Diametrical Clearance: Shaft to Back Up Rings (inches)
038	6-04-80	Hybrid Assembly SF Design	3	SAE 660 Bronze	1500	412	8.0	8-12 μ	0.016
039	5-29-80	Hybrid Assembly V Design	3	Back Up III w/4 ea. 1/64" Leaves	1500	412	3.8	4-8 μ	Flexing Leaves: 0.001 Back Up Ring: 0.170
040	6-08-80	HTCR SF Design	3	SAE 660 Bronze	1500	412	53.3	8-12 μ	0.016
041	6-16-80	Variseal ^R (Double Spring)	1	SAE 660 Bronze	1500	412	5.3 (Aborted)	8-12 μ	0.063
042	6-17-80	Variseal ^R (Single Spring)	1	SAE 660 Bronze	1500	412	4.3 (Aborted)	8-12 μ	0.063
043	6-24-80	Mesh Matrix Copper Wire	3	Sintered Graphite	1500	412	0.8	4-8 μ	0.008
044	6-25-80	Mesh Matrix Glass Fiber	3	Sintered Graphite	1500	412	-0-	4-8 μ	0.008
045	7-23-80	Variseal ^R (Double Spring)	1	SAE 660 Bronze	1500	412	164.8	8-12 μ	0.005
046	8-21-80	HTCR SF Design	3	SAE 660 Bronze	1500	412	71.8	8-12 μ	0.016
047	9-12-80	Variseal ^R (Double Seal)	1	SAE 660 Bronze	1500	412	10.3	8-12	0.005
048	9-18-80	Hybrid Assembly SF Design	2	SAE 660 Bronze	1500	412	6.7	8-12	0.016
049	9-30-80	Mesh Matrix Copper Wire	3	SAE 660 Bronze	1500	412	-0-	4-8	0.016
050	10-08-80	Mesh Matrix Glass Fiber	3	SAE 660 Bronze	1500	412	2.0	4-8	0.016
051	10-09-80	Canted HTCR	2	SAE 660 Bronze	1500	412	-0-	8-12	0.008
052	10-14-80	Grafoil ^R Phosphor Bronze (Horizontal Laminates)	3	Back Up III w/4 ea. 1/64" Leaves	1500	412	3.7	4-8	Flexing Leaves: 0.001 Back Up Ring: 0.170
053	10-20-80	Variseal ^R (Double Spring)	1	SAE 660 Bronze	1500	412	0.9	8-12	0.005

The duration of DMT-040 was 53.3 hours. The lubricant leakage past the test seal was very gradual throughout the test, and the test was terminated when one gallon of lubricant had leaked past the test seal. Inspection of the shaft sleeve after the test showed excessive wear of the chrome surface. The dummy seal had worn a groove 13.5 mils deep and the test seal had worn a groove 7.7 mils deep. The seals showed very little degradation in post test inspection and it appears the shaft surface wore to the point that the seal could no longer compensate for the wear, and failure occurred. Figure 3 shows the test sleeve, Figure 4 shows the dummy seal pack and Figure 5 shows the test seal pack after the test.

An important observation can be made from inspection of the test data in Appendix A. In the plot of the Lower (Test) Seal Temperature vs. Time, the thermocouple indicated temperatures above 450°F for a large part of the test and as high as 565°F for short periods. From the one-dimensional heat transfer model developed for the Seal Test Machine by Don Dareing of Maurer Engineering, these temperatures correspond to predicted temperatures at the shaft/seal interface above 700°F. This is the only elastomeric seal we are aware of that will not degrade at these high temperatures.

We consider DMT-040 a landmark in the seal test program. Prior to this test, it was believed that the seal alone was the only component of the sealing problem that needed a solution. However, the excessive wear observed on the shaft sleeve leads to the conclusion that both the seal and the shaft need to be considered together in solving the sealing problem.

The duration of DMT-046 was 71.8 hours. This test duplicated the long test run of DMT-040. This test lasted longer than DMT-040, and we conclude that the test results from the HTCR seal are repeatable. Post test inspection of the test sleeve showed excessive wear of the chrome surface by the test seal

Figure 3
DMT-040 Test Sleeve

Figure 4
DMT-040 Dummy
Seal Pack

Figure 5
DMT-040 Test
Seal Pack

pack, as in DMT-040. The test seal pack showed slightly more material degradation than the test seal pack in DMT-040. The plot of the Lower (Test) Seal Temperature vs. Time (Appendix A) showed that the DMT-046 test seal pack ran cooler than the DMT-040 test seal pack. Figure 6 shows a photograph of the test seal pack from DMT-046 after the test.

Figure 6
DMT-046 Test
Seal Pack

Variseal^R

This seal type was tested for the first time during this reporting period. Five tests were run with the Variseal^R: DMT-041, DMT-042, DMT-045, DMT-047, and DMT-053. The Variseal^R consists of a carbon-filled TFE body loaded by a single or double alloy spring. Each test seal pack consists of one pressure ring with an SAE 660 bronze housing and back up ring. Figure 7 shows a diagram of the Variseal^R.

Figure 7
Variseal^R Diagram

The duration of DMT-041 was 5.3 hours, and the duration of DMT-042 was 4.3 hours. Both tests were terminated after catastrophic failure of the dummy seal. The failure mode of both tests was the same: the seal material had extruded between the shaft sleeve and back up ring. After the tests, it was learned that the back up ring supplied for testing had a diametrical clearance of 0.062" to 0.069", which is much larger than the manufacturer's recommended clearance of 0.004" to 0.008". New back up rings were manufactured to the tighter tolerance and these new rings were used for DMT-045, 047 and 053.

The duration of DMT-045 was 164.8 hours, the longest test to date. Following is a brief description of the test.

a. 0 to 84 hours

Test ran smoothly during this period and there was very little leakage in both test and dummy seals. At 84 hours there was a catastrophic failure of the dummy seal. The dummy seal was replaced with a new seal and the test was resumed.

b. 84 to 156 hours

Test ran smoothly during this period, and there was very little leakage in both test and dummy seals. At 156 hours there was a catastrophic failure of the dummy seal. The dummy seal was replaced with a new seal and the test was resumed.

c. 156 to 164.75 hours

At 164.75 hours there was a catastrophic leak failure of the test seal, and the test was terminated.

Post test inspection of the seals and shaft sleeve showed excessive wear of the chrome surface of the sleeve and material loss of the seal. The test seal had worn a groove 7.2 mils deep and dummy seal had worn a groove 9.6 mils deep in the chrome sleeve. Figure 8 shows a photograph of the test sleeve and Figure 9 shows a photograph of the test seal from DMT-045.

Figure 8

DMT-045 Test Sleeve

Figure 9

DMT-045 Test

Seal

Two attempts were made to duplicate the results of DMT-045. The duration of DMT-047 was 10.3 hours and the duration of DMT-053 was 0.9 hours. In both tests the failure of the Variseal^R was due to material cracking in the heel of the seal. Figure 10 shows a photograph of the test seal from DMT-047.

Figure 10

DMT-047 Test

Seal

Hybrid Assembly

Hybrid Assembly seal packs were tested for the first time during this reporting period. Two different types of hybrid assemblies were tested: (1) The Hybrid Assembly V Design consisting of Grafoil^R and HTCR seals with Zero Clearance Back Up System III (DMT-039) and (2) The Hybrid Assembly

SF Design consisting of a combination of HPCR Fabric and HPCR Homogeneous Seals (DMT-038 and 048).

The duration of DMT-038 was 8.0 hours. This test seal pack was a Hybrid Assembly-SF Design arrangement which contained three pressure rings. The high pressure seal ring was an HPCR-Fabric Seal, the middle seal ring was a Graphite-Homogeneous and the low pressure seal ring was an HPCR-Homogeneous. (After the test it was discovered that the correct arrangement of these seals reversed the position of the two HPCR seals; the HPCR-Fabric Seal should have been the low pressure seal and the HPCR-Homogeneous should have been the high pressure seal.) Post test inspection of the seals showed a considerable material loss from the Graphite-Homogeneous and HPCR-Homogeneous Seal rings. Figure 11 shows a photograph of the test seal pack after the test.

Figure 11
DMT-038 Test
Seal Pack

The duration of DMT-039 was 3.8 hours. This test seal pack was a Hybrid Assembly-V Design which consisted of three pressure rings: The top and bottom rings were Grafoil^R-Phosphor Bronze seals and the middle ring was an HPCR-Homogeneous Seal. Zero Clearance Back Up System III with four 1/64" thick

leaves was used. Inspection of the seals after the test showed a considerable loss of Grafoil^R material from the top and bottom seal rings, possibly indicating that the Zero Clearance System did not flex properly. Figure 12 shows a photograph of the test seal pack after the test.

Figure 12
DMT-039 Test
Seal Pack

The duration of DMT-048 was 6.7 hours. The test seal pack was a modified Hybrid Assembly-SF Design. The seal pack consisted of two pressure rings: an HTCR-Homogeneous ring on the high pressure side and an HTCR-Fabric ring on the low pressure side. In this test, it was decided to delete the Graphite-Homogeneous ring based on the results of DMT-038; in DMT-038, the Graphite-Homogeneous ring did not appear to contribute anything to the seal pack. Inspection of the seals after the test showed wear of the two HTCR seals. Figure 13 shows a photograph of the test seal pack after the test.

Figure 13

DMT-048 Test

Seal Pack

Mesh Matrix

New generation mesh matrix seals were tested during this reporting period. Two types of mesh matrix seals were tested: the Mesh Matrix-Copper Wire seals consisted of a high temperature binder with copper wire reinforcement ; and the Mesh Matrix-Glass Fiber seals consisted of a high temperature binder with glass fiber reinforcement. These two seal types are considerably stiffer and more brittle than any other mesh matrix seal that has been tested. Four tests were completed with these seals during this reporting period.

The duration of DMT-043 was 0.8 hours. The test seal pack consisted of a set of three Mesh Matrix-Copper Wire pressure rings with Sintered Graphite top and bottom adapters. Inspection of the seal packs after the test showed that the female Sintered Graphite adapter had fractured under the differential pressure loading. DMT-044 was set up, with a seal pack consisting of a set of three Mesh Matrix-Glass Fiber pressure rings with Sintered Graphite top and bottom adapters. Several attempts were made to establish a differential pressure across the seals without success. Inspection of the test seal pack showed that the female Sintered Graphite adapter had fractured again under the differential pressure loading. The seal packs from the two tests, however,

showed no wear; and it was decided to run the two sets of seal packs again with new SAE 660 Bronze adapters. Figure 14 shows the female adapter from the test seal pack of DMT-043.

Figure 14

DMT-043 Test Seal

Female Adapter

DMT-049 tested the Mesh Matrix-Copper Wire seals with SAE 660 Bronze adapters. Several attempts were made to establish a differential pressure without success. DMT-050 tested the Mesh Matrix-Glass Fiber seals with SAE 660 Bronze Adapters, and the duration of the test was 2.0 hours. The seal leaked throughout the test. It was concluded that the new mesh matrix seals are too rigid and will not flex sufficiently to form a seal.

HTCR Canted Seal

One test was completed with the HTCR Canted Seal during this reporting period, DMT-051. The seal would not hold a differential pressure, and

inspection of the seals after the test showed that the seal lips had been damaged by the installation process, which is the same problem that has been experienced before with the 1/2" cross section Buna-N Canted Seal. Further testing of the Canted Seal will be performed with the 3/4" cross section seal. No installation problems are anticipated with the 3/4" cross section seal; and the 3/4" cross section falls within the design constraints of the Bearing-Seal Package.

Grafoil^R (Horizontal Laminates)

The Grafoil^R (Horizontal Laminates) seals were tested for the first time during this reporting period. One test was completed with these seals, DMT-052, and the test duration was 3.7 hours. Zero Clearance Back Up System III with 4 each 1/64" leaves was used, and each seal pack consisted of three pressure rings. Inspection of the test seal pack after the test showed a large amount of material loss of the seal ring closest to the flexing leaves. Figure 15 shows a photograph of the test seal pack after the test.

Figure 15
DMT-052 Test
Seal Pack

CONCLUSIONS

1. The shaft/seal combination must be considered together in establishing a solution for the sealing problem. The two components of the problem may not be separated.
2. Repeatable tests in the Seal Test Machine have been demonstrated for the HPCR SF Design seal.
3. Sintered Graphite appears to be too brittle to be used as a material for the seal adapters.
4. The 1/2" cross section Canted Seal does not provide enough flexibility to prevent damage during installation. Further testing of the Canted Seal should be performed with the 3/4" cross section seal.
5. The Variseal^R is a viable candidate seal if test repeatability can be established. At the present time, this has not been accomplished.

FUTURE WORK

Fourteen tests on the Seal Test Machine are scheduled during the next phase of the project. These tests are divided into three groups which are described below, and the proposed test matrix is shown in Table III.

I. Tests with Improved Shaft Coatings (DMT-054 through DMT-059)

The long running tests with HTCR and Variseal^R seals during this reporting period have demonstrated that the chrome shaft surface is inadequate for long running seal tests. The purpose of these tests will be to run the best performing candidate seals with improved shaft coatings to increase the life of the seal. The HTCR seal will be tested with an AISI 9310 shaft sleeve carburized to R_C60 hardness, and also with a shaft sleeve coated with a Union Carbide metal coating. DMT-058 and DMT-059 will be determined at a later date.

II. 3/4" Cross Section Seal Tests (DMT-060 through DMT-063)

All seal tests to date have been with 1/2" wide (5" ID x 6" OD) seals. To test cartridge-loaded Canted Seals and mechanical face seals, the seal width must be increased to 3/4" (5" ID x 6 1/2" OD). A new seal carrier has been installed in the Seal Test Machine to accomodate the 3/4" wide seals. The 3/4" wide Canted Seal will be tested with the best shaft coating from DMT-054, 055, and 056; and the Gits Brothers Face Seal and the Stein Seal Company Face Seal will also be tested. DMT-063 will be determined at a later date.

TABLE III

PROPOSED SEAL TESTS

Test ID	Seal Type	Shaft Coating	Shaft Finish (rms)	Diametrical Clearance: Shaft to Back up Rings (inches)	ΔP (psi)	RPM	Abrasives
DMT-054	HTCR-SF Design Two Pressure Rings	AISI 9310 Steel Carburized	8-12 μ	0.005	1,500	412	No
DMT-055	HTCR-SF Design Two Pressure Rings	AISI 9310 Steel Carburized	8-12 μ	0.005	1,500	412	No
DMT-056	HTCR-SF Design Two Pressure Rings	Union Carbide Metal Coating (D-Gun)	8-12 μ	0.005	1,500	412	No
DMT-057	HTCR-SF Design Two Pressure Rings	Best Shaft Coating From DMT-054, 055, and 056	8-12 μ	0.005	1,000	412	Yes
DMT-058							
DMT-059							
DMT-060	HTCR-Canted Seal 3/4" Cross Section	Best Shaft Coating From DMT-054, 055, and 056	8-12 μ	0.025	1,500	412	No
DMT-061	Gits Brothers Face Seal	N/A	N/A	N/A	1,000	412	Yes
DMT-062	Stein Seal Company Face Seal	N/A	N/A	N/A	1,000	412	Yes
DMT-063							
DMT-064	HTCR-SF Design Back-Back	Best Shaft Coating From DMT-054, 055, and 056	8-12 μ	0.005	1,000	412	Yes
DMT-065	HTCR-SF Design Face-Face	Best Shaft Coating From DMT-054, 055, and 056	8-12 μ	0.005	1,000	412	Yes
DMT-066							
DMT-067							

III. Seal Orientation (DMT-064 through DMT-067)

In order to demonstrate the preferred orientation of the seals in the Bearing-Seal Package, the leading candidate seals will be run in the "back-to-back" and "face-to-face" orientations in the Seal Test Machine. The HPCR seal with the best shaft coating from DMT-054, 055, and 056 will be tested in the "back-to-back" and "face-to-face" orientations. DMT-066 and DMT-067 will be determined at a later date.

BEARING-SEAL PACKAGE TESTING AND EVALUATION

BEARING-SEAL PACKAGE

The Bearing-Seal Package is being modified for the cooling modifications. The cooling modifications will divert a small amount of fluid flowing through the Bearing-Seal Package to an area behind the replaceable shaft sleeve. This fluid will remove some of the heat generated at the shaft/seal interface and keep the operating temperature of the seal cooler, thereby increasing the life of the seal. The cooling modifications are shown schematically in Figure 16.

Figure 16

BEARING-SEAL PACKAGE COOLING MODIFICATIONS

BEARING-SEAL PACKAGE TEST RESULTS

It was explained in the Phase IV Semi-Annual Report (TR80-53) that the hot water system for the Bearing-Seal Package Test Facility was eliminated, and that the testing would continue using the self-generation of heat by the seals.

BSP-03, the initial test of the self-generation of heat by the seal in the Bearing-Seal Package, was completed during this reporting period. The following lists the test conditions:

- Seal Type: Utex Style 701
- Number of Pressure Rings: 3
- Back Up Rings: SAE 660 Bronze
- Differential Pressure: 900 psi
- RPM: 400
- Finish of Chrome Shaft - 8-12 μ

The test duration was 5 hours. The test data are found in Appendix B. Some material degradation of both the upper and lower seal packs was observed, as shown in the photographs in Figure 17 and Figure 18.

Figure 17
BSP-03 Upper Seal Pack

Figure 18
BSP-03 Lower Seal Pack

It should be noted that the thermocouple measuring the temperature of the seal area is located near the seal-outer housing interface. This location is different from the Seal Test Machine where the thermocouple is placed near the seal-shaft sleeve interface. The geometry of the Bearing-Seal Package is such that the thermocouple cannot be placed near the seal-shaft sleeve interface.

Jeff Barnwell of Maurer Engineering, Inc., adapted the one-dimensional heat transfer model (developed by Don Dareing of Maurer Engineering, Inc., for the Seal Test Machine) to the Bearing-Seal Package. Reference to this work will be found in Maurer Engineering Technical Report TR80-28, listed in the Bibliography. The analysis showed it is very difficult to estimate the seal temperature when the thermocouple is located near the seal-outer housing interface because so little heat is transferred outward.

The Drilling Research Laboratory is installing a separate mud system for the operation of the Bearing-Seal Package Test Facility. The reservoir capacity of the system will be approximately 4 barrels, and the mud will be heated by cartridge heaters to a temperature of 170°F. The pump capacity of the new system will be approximately 30 gpm at 3,000 psi. This new system will allow operation of Bearing-Seal Package Test Facility on a 24 hour per day basis independent of any other work in the Drilling Research Laboratory.

FUTURE WORK

Bearing-Seal Package testing will continue during the next phase of the project. Fourteen tests are scheduled. These tests are divided into four groups which are described below, and the proposed test matrix is shown in Table IV.

I. Style 701 Baseline Tests (BSP-04 through BSP-06)

Testing is continuing with the Utex Style 701 seal to establish baseline test data for the Bearing-Seal Package. Three tests will be performed, one each with water, mud, and mud + abrasives. Each of these tests will be run at a constant loading with the dynamic actuator and a constant ΔP .

II. Constant Loading (BSP-07 through BSP-10)

Four tests are scheduled for the Bearing-Seal Package with a constant loading applied by the dynamic actuator and a constant ΔP . These tests will include the HPCR (SF or Canted) Seal with the best shaft coating from DMT-054, 055, and 056; the Gits Brothers Face Seal; and the Stein Seal Company Face Seal.

III. Axial Vibration (BSP-11 through BSP-14)

Four tests are scheduled for the Bearing-Seal Package with a variable loading applied by the dynamic actuator and a constant ΔP . These tests will include the HPCR (SF or Canted) Seal with the best shaft coating from DMT-054, 055, and 056; the Gits Brothers Face Seal; and the Stein Seal Company Face Seal. BSP-14 will be determined at a later date.

TABLE IV

PROPOSED BEARING-SEAL PACKAGE TESTS

Test ID	Seal Type	Shaft Coating	Dynamic Actuator Loading (Pounds)	Circulating Fluid	ΔP (psi)	RPM
BSP-04	Utex-Style 701	Chrome	10,000 Constant	Water	1,000	450
BSP-05	Utex-Style 701	Chrome	10,000 Constant	Mud	1,000	450
BSP-06	Utex-Style 701	Chrome	10,000 Constant	Mud + Abrasives	1,000	450
BSP-07	HTCR (SF or Canted)	Best Shaft Coating from DMT-054, 055, and 056	10,000 Constant	Mud + Abrasives	1,000	450
BSP-08	HTCR (SF or Canted)	Best Shaft Coating from DMT-054, 055, and 056	10,000 Constant	Mud + Abrasives	1,000	450
BSP-09	Gits Brothers Face Seal	N/A	10,000 Constant	Mud + Abrasives	1,000	450
BSP-10	Stein Seal Company Face Seal	N/A	10,000 Constant	Mud + Abrasives	1,000	450
BSP-11	HTCR (SF or Canted)	Best Shaft Coating from DMT-054, 055, and 056	Variable To be Determined	Mud + Abrasives	1,000	450
BSP-12	Gits Brothers Face Seal	N/A	Variable To be Determined	Mud + Abrasives	1,000	450
BSP-13	Stein Seal Company Face Seal	N/A	Variable To be Determined	Mud + Abrasives	1,000	450
BSP-14			Variable To be Determined	Mud + Abrasives	1,000	450
BSP-15	Best Face Seal	N/A	10,000 Constant	Mud + Abrasives	1,000	450
BSP-16	HTCR (SF or Canted)	Best Shaft Coating from DMT-054, 055, and 056	10,000 Constant	Mud + Abrasives	1,000	450
BSP-17			10,000 Constant	Mud + Abrasives	1,000	450

IV. Pressure Fluctuations (BSP-15 through BSP-17)

In tripping into a well, the Bearing-Seal Package seal will experience a fluctuating differential pressure, including cases where the annulus pressure is higher than the Bearing-Seal Package internal pressure. In these tests, the differential pressure across the seals will be varied before rotation, and then will remain constant during rotation. This will simulate the surge and swab pressures. The loading applied by the dynamic actuator will be constant. The seals to be tested will include the HPCR (SF or Canted) Seal with the best shaft coating from DMT-054, 055, and 056; and the best face seal from the seal tests and Bearing-Seal Package tests. BSP-17 will be determined at a later date.

PROGRAM STATUS, PLANS AND SCHEDULE

PROGRAM STATUS, PLANS AND SCHEDULE

Seal Testing and Evaluation

Fifty-three seal tests have been completed in the Seal Test Machine. During this reporting period, the three longest running seal tests were completed: DMT-045 (Variseal^R, 164.8 hours), DMT-046 (HTCR, 71.8 hours) and DMT-040 (HTCR, 53.3 hours). Further testing of the leading candidate seals will be performed with new shaft coatings, Pacer PLX-014 lubricant and abrasive mud. In addition, testing will be performed on the 3/4" cross section Canted Seal, face seals and seal orientation of the leading candidate seals. The schedule for this testing is shown in the detailed milestone chart in Table V.

All of the seals for these tests have been ordered. The new shafts for the HTCR seals are being manufactured. Modifications to the Seal Test Machine for the 3/4" cross section seals and the mud injection system are being completed.

Bearing-Seal Package Testing and Evaluation

The cooling modifications to the Bearing-Seal Package are being completed. Following completion of the modifications, the testing will proceed as outlined in the "Bearing-Seal Package Testing and Evaluation" section of this report. The testing schedule is shown in the detailed milestone chart in Table V.

Lubricant Testing and Evaluation

No new candidate high temperature lubricants have been identified. Additional lubricant tests will be performed only if new candidate high temperature lubricants are identified.

[illegible]

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November 11-12, 1976

Geothermal Projects Review Meeting
Terra Tek, Salt Lake City.

July 19-20, 1977

Geothermal Well Technology Program
Review Meeting, Albuquerque,
New Mexico.

September 7, 1977

Geothermal Drill Bit Program and
Downhole Motor Program Review
Meeting, Terra Tek, Salt Lake
City.

February 7, 1978

Sandia/Terra Tek/Maurer Engineering
DOE/DGE Project Review Meeting,
Terra Tek, Salt Lake City.

June 11, 1978

Seal Test Review Meeting, Terra
Tek, Salt Lake City.

June 20-22, 1978

Geothermal Drilling and Completion
Contractor Review Meeting, Washington,
D. C.

March 22, 1979

Sandia/Terra Tek/Maurer Engineering
Downhole Motor Project Review
Meeting, Terra Tek, Salt Lake City.

December 11-13, 1979

Geothermal Drilling and Completion
Contractor Review Meeting, Washington,
D. C.

January 28, 1980

Sandia/Terra Tek/Maurer Engineering
Downhole Motor Project Review Meeting,
Terra Tek, Salt Lake City.

June 19-20, 1980

Geothermal Drilling and Completion
Technology Advisory Panel Meeting,
Lubbock, Texas.

July 17, 1980

Sandia/Terra Tek/Maurer Engineering
Downhole Motor Project Review Meeting,
Terra Tek, Salt Lake City.

APPENDIX A
Seal Test Results

Signal From Thermocouple
No. 6 Was Lost During
The Test.

Signal From Thermocouple
No. 2 Was Lost During
The Test.

Signal From Thermocouple
No. 4 Was Lost During
The Test

Signal From Thermocouple
No. 7 Was Lost During
The Test

APPENDIX B

Bearing-Seal Package Test Results

APPENDIX C
Summary of Work Performed

Summary of Work Performed
for

IMPROVEMENT OF DOWNHOLE DRILLING MOTOR
BEARINGS AND SEALS
Sandia Contract No. 46-3054

by

Jeff L. Barnwell

submitted to

SANDIA LABORATORIES
Geothermal Drilling and Completion
Technology Development Program
Albuquerque, New Mexico 87185

Attention: Mr. John Finger

November 1980
TR80-35

CONTRACT WORK STATEMENT

Maurer Engineering contracted to participate in the rotary seal and bearing-package development program. The following tasks were laid out in the work statement:

Task I - Manufacture Motor Interface Parts

The parts required to adapt the Bearing-Seal Package to commercial downhole motors will be manufactured by Maurer Engineering. The manufacturing will include materials selection, construction, and heat treatment of parts to make the Bearing-Seal Package fit these motors.

Task II - Design and Manufacture an Improved Floating Piston

The Bearing-Seal Package uses a floating piston, exposed on one side to mud pressure and on the other side to the bearing lubricant, to maintain pressure on the bearing lubricant. To do this more reliably, a new floating piston will be designed and manufactured.

Task III - Design and Manufacture Improved Redundant Seals

Results from the initial tests with redundant seals will be evaluated, and improved redundant seals will be designed and manufactured for use in the seal tester or in the DOE Bearing-Seal Package.

Task IV - Design and Manufacture Improved Rotary Seals

Design and manufacture improved Grafoil rotary seals based on the results of previous seal tests and on the use of the seals in the Maurer geothermal turbodrills in the LASL Hot Dry Rock experiment.

Task V - Bearing-Seal Package Testing Evaluation

Assist Terra Tek personnel in post-mortem examinations of worn parts in Bearing-Seal Package and in redesigning any parts which may fail.

Task VI - Assist Terra Tek in Conducting and Evaluating Full-Scale Motor Tests

Assist Terra Tek in designing and conducting full-scale tests in the Downhole Motor Test Facility.

WORK PERFORMED

Although no formal written report is required, the following summarizes work performed during this contract:

Task I - MEI engineers designed interface parts which would allow the use of both a Dyna-Drill motor section and an Eastman-Whipstock motor section. These parts are:

79-71	Spline Box, Dyna-Drill Adapter
79-72	Housing Adapter, Dyna-Drill Adapter
79-73	Spline Box, Eastman Adapter
79-74	Housing Adapter, Eastman Adapter

These parts were manufactured in Houston. However, two of the parts (Nos. 79-72, 79-74) required machining of proprietary threads by their respective motor manufacturers. These parts were sent to the necessary locations, and all interface parts are now at Terra Tek. These parts, along with a set of assembly drawings (Nos. 79-67, 79-68) provided by Maurer Engineering, can now be used to test these motors with the existing bearing-seal package.

Task II- The fact that the bearing-seal package has a reservoir of lubricant which must be maintained at a pressure higher than surrounding annulus pressure necessitates the use of a floating piston at the oil-drilling fluid interface in the upper portion of the bearing pack. The floating piston which was originally provided with the bearing-seal package used a set of Johns-Mansville Uneepac® seals. However, as the testing program continued, it became obvious that a piston using a more reliable seal would be necessary. After evaluating a number of proposed

piston types, Maurer Engineering designed a new floating piston (No. 80-80) which made use of the Variseal® design seals. This concept was originally intended to be made out of a bronze material. However, the prototype was constructed out of a Ryton material. This provided lower friction and less inertia whipping, which can cause seal-shaft separation. This piston, along with necessary Variseals®, backup rings, and retaining rings, was sent to Terra Tek. During the installation process, the brittle nature of the Ryton caused chips to form at one of the inside ridges and at the retaining ring groove. The piston was then returned to Houston for evaluation. After consultation with the supplier of the Ryton material, it was decided that the piston would be modified. The modifications consisted of developing a threaded ring to hold the seals in place and removing material from the inside ridges. The modifications are complete and the piston will be returned to Terra Tek.

Task III - The benefit of a redundant seal assembly is obvious. Once a successful seal system is developed, the redundant system would multiply the effective life of the seal system by the number of seals involved. Many design concepts were conceived by MEI during an earlier phase of this program (see Terra Tek TR78-58, "Phase III - Part I, Final Report, Program for the Improvement of Downhole Drilling Motors and Seals"). The first redundant seal assembly was manufactured and sent to Terra Tek during this period.

Several second generation concepts were worked with and evaluated. However, at the DHM program review at Terra Tek on July 17, 1980, the general consensus was that further pursuit of a second generation redundant seal system was beyond the scope of this phase. Therefore, Maurer Engineering personnel terminated work on these systems. Any remaining time in this task was to be devoted to the other portions of the contract.

Task IV - Early in this phase, MEI activity was limited to evaluation and analysis of Grafoil® seal systems. Dr. Don W. Dareing was especially helpful here. Dr. Dareing had performed the original cantilever analysis of the back-up systems and his expertise was used in evaluating failed Grafoil® and making recommendations concerning changes in the thickness of the flexing leaves.

Later, using information from LASL and Sandia sponsored motor tests, MEI personnel performed the carrier design necessary to test the Variseals® in the Seal Test machine and supplied the required Variseals®. It became apparent that the original backup system had too much clearance between the shaft and the backup ring, thus allowing the Variseals® to fail by extruding past the rings. After consultation with Variseal® personnel, MEI recommended a new set of dimensions, which greatly reduced the possibility of extrusion.

The repeatability of the Variseal® tests has been very low. After observing the failed seals, MEI personnel, along with Variseal® personnel, have begun to design a new generation of Variseals®. The main features of these will be smaller spring cavities, thicker legs, and a heel which more nearly fills the carrier groove. These are improvements because the majority of Variseal® failures seem to either be fatigue failures along the inside legs or tearing of the material along the heel. Also the possibility of using a Vespel or Teflon backup ring is being investigated.

Task V - MEI personnel assisted in replacing the mesh springs in the Bearing Seal Package with the newer Belleville springs. Other work under this can only be done as the Bearing Package/Motor System becomes operational.

Task VI - The work under this task can only be performed as the Bearing Package/Motor System becomes operational.

In addition to the work outlined above, MEI has been involved with several tasks which do not correspond with any of the tasks as explicitly outlined in the work statement.

Task A - MEI personnel performed a heat transfer analysis of the seals as installed in the Bearing Seal Package. This consisted of adapting a computer model developed by Dr. Dareing for the seal test machine to conditions as exist in the Bearing-Seal Package. Unfortunately, the conclusion of the analysis was that the seal temperature could not be monitored by placing thermo-couples in the Bearing Make-Up Sub, as was originally planned. (For details, please see Maurer Engineering TR80-28, "Bearing-Seal Package Temperature Calculations Using the One-Dimensional Heat Transfer Model").

Task B - The possibility of outfitting the Bearing-Seal Package with rotary face-type seals is being considered. MEI personnel have worked with the face-seal manufacturer in several ways. First, MEI personnel were instrumental in adapting the face-seal concept to the available space. This involved conceptual design of new parts for the Bearing-Seal package, as well as recommending changes in the face seal assembly. Secondly, MEI personnel established working pressure limits that the seal assembly would have to withstand. Then, the proposed face-seal assembly was analyzed according to these parameters. The conclusion was that the face-seal assembly could withstand the pressure and should operate without seal-face separation. (For details, please see Maurer Engineering TR80-36, "A Force Analysis of Face Seals for Use in Downhole Motors").

APPENDIX D
Summary of Program Results

SUMMARY OF PROGRAM RESULTS

Phase I Major Accomplishments

- (1) Gathered background information to determine current needs of industry and establish a range of conditions needed to simulate geothermal conditions -
 - A meeting was conducted with downhole motor experts at Rice University.
 - Jeddy Nixon presented his experiences in downhole motor development at a review meeting at Terra Tek, Inc.
 - John Jeter was consulted on the Bearing-Seal Package design and the DHM Seal Test Machine.
 - Industry contacts and correspondence were established.
 - Information from the Geothermal Bit Program such as downhole geothermal temperatures, rock formations, and drilling problems was used to establish design limits of the seal and bearing test equipment.
- (2) Determine the state-of-the-art in motor development and the feasibility of new motor concepts -
 - Maurer Engineering conducted a patent search on downhole motors and reported the results in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
 - Maurer Engineering presented a review of the economic incentives for geothermal downhole motor development.
- (3) Performed the preliminary design of the Bearing-Seal Package -
 - The Bearing-Seal Package design was described in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
- (4) Candidate high temperature seals were identified -
 - A description of the candidate seals was presented in the Semi-Annual (TR76-59) and Final (TR77-29) reports.
 - Bearing application was presented in the Semi-Annual (TR76-59) and Final (TR77-29) reports.

(5) Design and fabrication of the DHM Seal Test Machine was completed -

- Preliminary concepts and evolution of the final design were presented in the Semi-Annual (TR76-59) report.
- John Jeter was consulted on the design of the DHM Seal Test Machine.
- Detailed design and fabrication of the DHM Seal Test Machine was completed.

(6) Conceptual design of the Bearing-Seal Package Test Facility was completed

Phase II Major Accomplishments

(1) Seal Testing and Evaluation -

- Debugging tests on the DHM Seal Test Machine were completed.
- The first evaluation tests on the baseline seals were completed.
- Contacts were established with major seal manufacturers.
- Candidate seals for future testing were obtained.

(2) Bearing-Seal Package Testing and Evaluation -

- Preliminary design of the Bearing-Seal Package Test Facility was completed.
- Fabrication of the Bearing-Seal Package was completed.

(3) Lubricant Testing and Evaluation -

- The Terra Tek High Temperature Lubricant Tester was made operational.

Phase III Part 1 Major Accomplishments

(1) Seal Testing and Evaluation -

- Baseline tests on a standard industry seal were completed.

- Several of the new candidate seal types were tested.
- Additional high temperature candidate seal types were tested.
- The DHM Seal Test Machine underwent several modifications to improve ease of handling and for more reliable operation.

(2) Bearing-Seal Package Testing and Evaluation -

- A design to solve the fluid erosion problem was completed and successfully tested.
- Final design of the Bearing-Seal Package Test Facility was completed. Fabrication of parts was started.
- Machining of the Grayloc connections in the pressure vessel tubes was completed.
- Design and fabrication of the pressure vessel holding fixture was completed.
- The Dynamic Actuator was received and modifications for the Bearing-Seal Package Test Facility were started.
- The 100-HP hydraulic power supply to drive the dynamic actuator and Bearing-Seal Package was designed and purchased.

(3) Lubricant Testing and Evaluation -

- Wear rings and blocks for the Terra Tek High Temperature Lubricant Tester were obtained.
- A survey of downhole motor manufacturers was made to obtain lubricant recommendations. The candidate lubricant matrix was revised.

Phase III Part 2 Major Accomplishments

(1) Seal Testing and Evaluation -

- Second and third generation seals were obtained and some of these seal types tested.
- New seal back up system designs were completed and tested.

(2) Bearing-Seal Package Testing and Evaluation -

- Bearing-Seal Package Test Facility was completely assembled and debugging was started.

- The hot water system was completed and operated. Three tests were performed.
- The electronics from the DHM Seal Test Machine system were interfaced with the Bearing-Seal Package Test Facility.

(3) Lubricant Testing and Evaluation -

- Initial screening of candidate high temperature lubricants was completed in the Terra Tek High Temperature Lubricant Tester.
- The candidate lubricant was selected for testing in the Bearing-Seal Package.

Phase IV Major Accomplishments

(1) Seal Testing and Evaluation

- Landmark tests were run with HPCR SF Design and Variseal^R seals in which excessive shaft wear was observed.
- Flexing leaves back up system was tested.
- HPCR SF Design Seals, new generation Mesh Matrix Seals, Hybrid Assembly Seals and Grafoil^R (Horizontal Laminate) Seals were tested for the first time.
- Design completed to introduce abrasive mud on the low pressure side of the Seal Test Machine.

(2) Bearing-Seal Package Testing and Evaluation

- The dynamometer and mud cooling system were designed and fabricated.
- Tests were run with the Bearing-Seal Package to establish data for the self-generation of heat by the seals.

(3) Lubricant Testing and Evaluation

- Several new lubricant samples were tested in the Terra Tek High Temperature Lubricant Tester.

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