Development and Manufacture of Cost Effective Composite Drill Pipe

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1.0 DISCLAIMER

2.0 ABSTRACT

This technical report presents the engineering research, process development and data accomplishments that have transpired to date in support of the development of Cost Effective Composite Drill Pipe (CDP). The report presents progress made from October 1, 2004 through September 30, 2005 and contains the following discussions:

- Qualification Testing
- Prototype Development and Testing of "Smart Design" Configuration
- Field Test Demonstration
- Commercial order for SR-CDP from Torch International

3.0 TABLE OF CONTENTS

4.0 LIST OF GRAPHICAL MATERIALS

5.0 INTRODUCTION

This writing assumes the reader has prior knowledge of this contract and the progress, development issues and technical hurdles within this program. To learn more of the history and detail of prior work and efforts it is recommended that reader refer to prior year annual reports (40262R5, 40262R10, 40262R15, 40262R20, 4026R25).

The objective of this contract is to develop and demonstrate "cost effective" Composite Drill Pipe. It is projected that this drill pipe will weigh less than half of its steel counter part. The resultant weight reduction will provide enabling technology that will increase the lateral distance that can be reached from an offshore drilling platform and the depth of water in which drilling and production operations can be carried out. Further, composite drill pipe has the capability to carry real time signal and power transmission within the pipe walls. CDP can also accommodate much shorter drilling radius than is possible with metal drill pipe. As secondary benefits, the lighter weight drill pipe can increase the storage capability of floating off shore drilling platforms and provide substantial operational cost savings.

This co-operative agreement was awarded September 30, 1999 and has been amended thirteen times. Amendment M013 has an end date of July 30, 2006. The original contract consisted of ten major tasks of which eight have been substantially completed. Two additional tasks were added to include the development and field demonstration of Short Radius CDP because of early development successes and at the request of industry. The SR-CDP development is completed and the product was made commercially available in 2004. Amendment A008 was awarded September 30, 2003 to include the development of a "Smart" feature and to complete developmental qualification testing of the ER/DW CDP. Work is ongoing to characterize the mechanical properties if the pipe and reduce to practice the Smart feature (direct electrical connection through the pipe wall and across the tool joints).

6.0 EXECUTIVE SUMMARY

Design and analysis remains a continuous effort throughout this DOE contract and is an integral part of all ongoing CDP manufacturing operations. Initial work concentrated on specifying the requirements for a "typical" drill pipe which when converted to the capabilities of composites would enable extended reach and deeper water drilling. These requirements have continually been refined during this program and are updated as experience with the use and manufacture of CDP is obtained. The goal remains to further extend the reach for horizontal drilling and enable drilling into even deeper water.

The original design of the ER/DW-CDP was based on Toray T700 carbon fiber and Shell 9470/9405 epoxy resin. Shell sold its resin division to Resolution Performance Products who in turn discontinued manufacturing this particular resin system. This resin system became unavailable early in 2004. ACPT investigated alternative systems and settled on a high-temperature epoxy system manufactured by Bakelite.

During this same period, the Toray T700 carbon fiber became increasingly more difficult to acquire as the market demand for all carbon fibers exceeded the capacity to produce it. The carbon fiber market is currently experiencing shortages and the carbon fiber manufacturers are forecasting the shortage to last for two years before increased capacity comes on-line. ACPT has substituted fibers from Zoltek (Panex 35) to continue research and development of the CDP. However, the Panes 35 properties vary from the T700 properties. More specifically, the tensile strength of Panex 35 is approximately 10% less than T700. This translates to 10% less tension load capability in the CDP.

Tests were planned and conducted to characterize the mechanical and fatigue properties of the CDP.

7.0 EXPERIMENTAL

7.1. Task 1 Mechanical Requirements

Task 1 is substantially complete. Defining the mechanical requirements for CDP has been and continues to be an on going effort. The mechanical specifications currently in use for design and manufacture of CDP are as follows:

7.1.1. Extended Reach/Deep Water Product Data

7.1.1.1.Mechanical Specifications

Bending Stiffness	EI	180 $\times 10^6$ lb-in^2
Torsional Stiffness	GJ	115 $\times 10^6$ lb-in^2
Axial Stiffness	EA	33.4 $\times 10^6$ lb
Rated Tension Load	P	450,000 lbs
Rated Torsion Load	T	25,000 ft-lb
Rated Compression Load	P_c	250,000 lbs
Rated Internal Pressure	P_i	9,500 psi
Max Service Temperature	F	350°F

7.1.1.2. Physical Specifications

Tube Inside Diameter	ID	5 in
Tube Outside Diameter	OD	6 in
Length (Pin-to-Box)	L	360 in (30 ft)
Centralizers		5 equally spaced
Weight	LB	375 lbs

7.1.1.3.Connection Specifications

Pin/Box Diameter	OD	7 in
Bore	ID	5 in
Thread	IF	NC 56 or Customer Spec

7.1.2. Short Radius Product Data

7.1.2.1.Mechanical Specifications

Bending Stiffnes	EI	7.22 $\times 10^6$ lb-in^2
Torsional Stiffness	GJ	11.30 $\times 10^6$ lb-in^2
Axial Stiffness	AE	14.30 $\times 10^6$ lb
Rated Tension Load	P	25,000 lbs
Rated Torsion Load	T	2,000 ft-lb
Rated Compression Load	P_c	50,000 lbs
Rated Internal Pressure	P_i	1,000 psi
Max Service Temperature	F	350°F

7.1.2.2.Physical Specifications

Pipe Inside Diameter	ID	1 5/8 in
Pipe Outside Diameter	OD	2 1/2 in
Length (Pin-to-Box)		360 in (30 ft)
Centralizers		5 equally spaced
Weight		92 lbs

7.1.2.3.Connection Specifications

Pin/Box Diameter	OD	3 3/8 in
Bore	ID	1 5/8 in
Thread	IF	NC26 or customer spec

7.1.2.4.Materials of Construction

Pipe body	Filament wound E-glass/Graphite/Epoxy
Std Tool Joints	4140HT steel
Non-magnetic Tool Joints	Stainless steel, Monel or customer spec
Wear Knots	Nitrile

7.1.2.5.Availability

Price and delivery is quoted upon request. Length and diameter can be scaled to customer requirements. Mechanical properties can be customized to suit application.

7.2. Task 2 – Electrical and Magnetic Specifications

Task 2 has been completed.

7.3. Task 3 Physical Requirements

This work is complete and the results are included in Section 7.1. This is also an ongoing effort and the physical requirements will be updated as more actual drilling experience is obtained and as longer reach, deeper water capabilities are defined.

7.4. Task 4 Progress Report

Task 4 is completed. A first year report was presented at NETL in Morgantown on 8/31/01.

7.5. Task 5 Laboratory Testing

Laboratory testing is essentially complete. Task 5 included:

1. Screening and verification of mechanical properties of resins, fibers, and adhesives for design and fabrication of CDP.
2. Temperature and Environmental Resistance of all material to be used in the CDP.
3. Measurement of Erosion and Mechanical Abrasion characteristics of interior and exterior coatings for CDP.
4. Future work will be conducted in these areas to evaluate possible improvements for the CDP as currently designed.

7.6. Task 6 “Field Testing”

7.6.1. Field Testing of 1-5/8” CDP

This task has been completed.

7.6.2. Field Testing of 5” CDP

The planned field testing of ER/DW CDP is now an optional add-on to the program depending on the outcome of Task 12 Qualification Testing of Smart ER/DW CDP.

7.7. Task 7 Second Year Technical Reporting

An oral presentation of the accomplishments of this program was made at the NETL/DOE facilities in Morgantown, WV on 8/20/01. The report has been filed with DOE/NETL AAD Document Control. Task 7 is complete.

7.8. Task 8 Test Samples and Preliminary Drill Pipe Sections

This is ongoing as test specimens are continuing to be produced in support of tasks 10, 11 and 12.

7.9. Task 9: Pilot Plant Production

All Pilot Plant production will be performed at ACPT. The existing facilities have modified to accommodate Task 9.

7.10. Task 10: Design and Develop Wire through Wall of ER/DW CDP

This task is essentially complete. The process of embedding a twisted pair or other conductor in the wall of the pipe body has been demonstrated and reduced to practice. There is a maximum conductor size that will work with the composite laminate and the tool joint size. This becomes a variable for the different geometric configurations of pipe size and tool joint selection. Pipe design will vary depending on conductor size required for the application.

7.11. Task 11: Design Direct Electrical Connection Field Prototype for ER/DW CDP

Development engineering for the contact ring design continued until a bench test failed during the make up torque of the tool joint assembly. Failure was attributed to the inner seal during make up. Posttest analysis concludes that the redesign of the inner seal will correct this deficiency. Bench testing of the bayonet design was successfully concluded utilizing two modified tool joints and performing multiple make-break tests. Results included consistent and repeatable pressure actuation and making direct electrical connection.

Previous testing of the bayonet and circular ring direct electrical connection conducted using the pipe break out machine identified several areas in need of improvement. These improvements were made in May and June 2005 and the modified design was subsequently re-tested in a flow loop using 3 segments of composite drill pipe. The specific improvements made to the design were as follows:

- Changed spring spacer retainer from a cross pin dowel to a press fit in order to eliminate a potential fluid leak path
- Added an anchor pattern to the ring contactor groove on the pin connection to achieve better adhesion of the elastomer used to electrically insulate the contact ring from the drilling fluid
- Added a spacer to the bayonet shoulder and increased shoulder thickness be relocating the o-ring gland to prevent bayonet damage at full stroke

In addition, flow and exit subs were designed and manufactured to support flow testing of the smart composite drill pipe segments. A complete list of the drawings, including the revision history over the course of the project has been included in the attached zip files.

Flow Loop Testing

Three segments of composite drill pipe were connected together and plumbed into Maurer Technology's instrumented flow loop as shown in Figures 1 - 5. The power/data signal side wire and the ground return line from one end of the piping were connected to a DC power supply while the other lead ends were connected to an electrical load. The electrical load consisted of a small light bulb, which provides an obvious indication as to whether the electrical circuit has been made when a certain pressure inside the drill pipe has been achieved and when electrical continuity is lost.

In addition to the light bulb and multi-meter the leads were also periodically connected to an oscilloscope which showed the power to be clean free of jitter that would be caused if their was lift off between the bayonet and the contact ring.

Figure 1 Composite Pipe Segment

Figure 2 CDP Box Connection with Bayonet Retracted

Figure 3 CDP Pin Connection

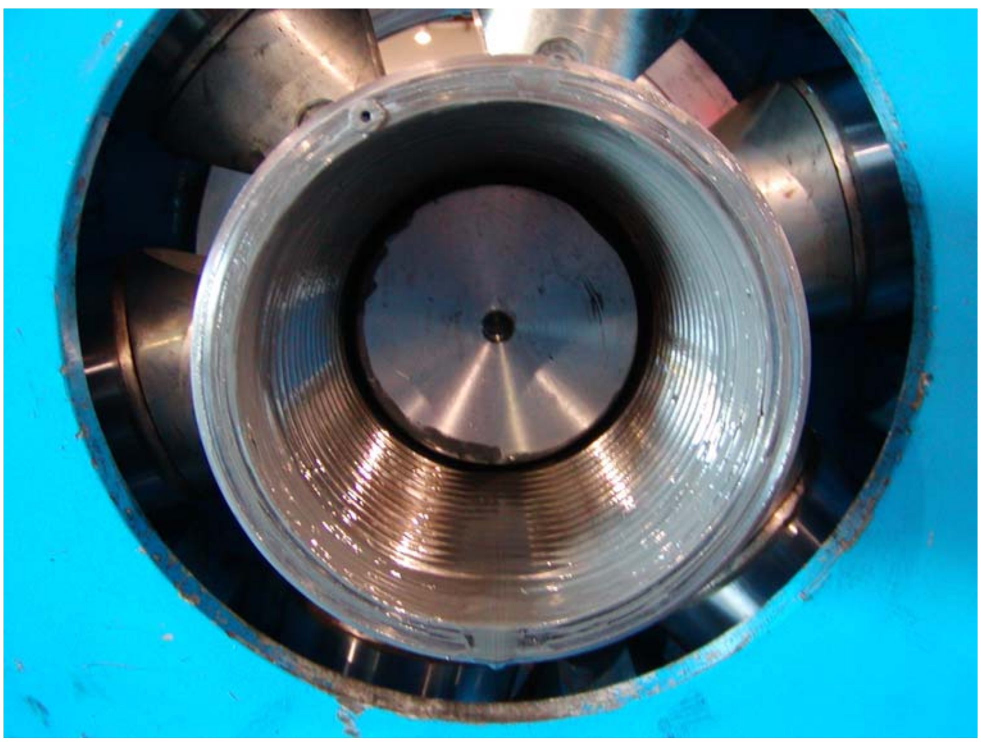

Figure 4 Female Tool Joint in Breakout Unit

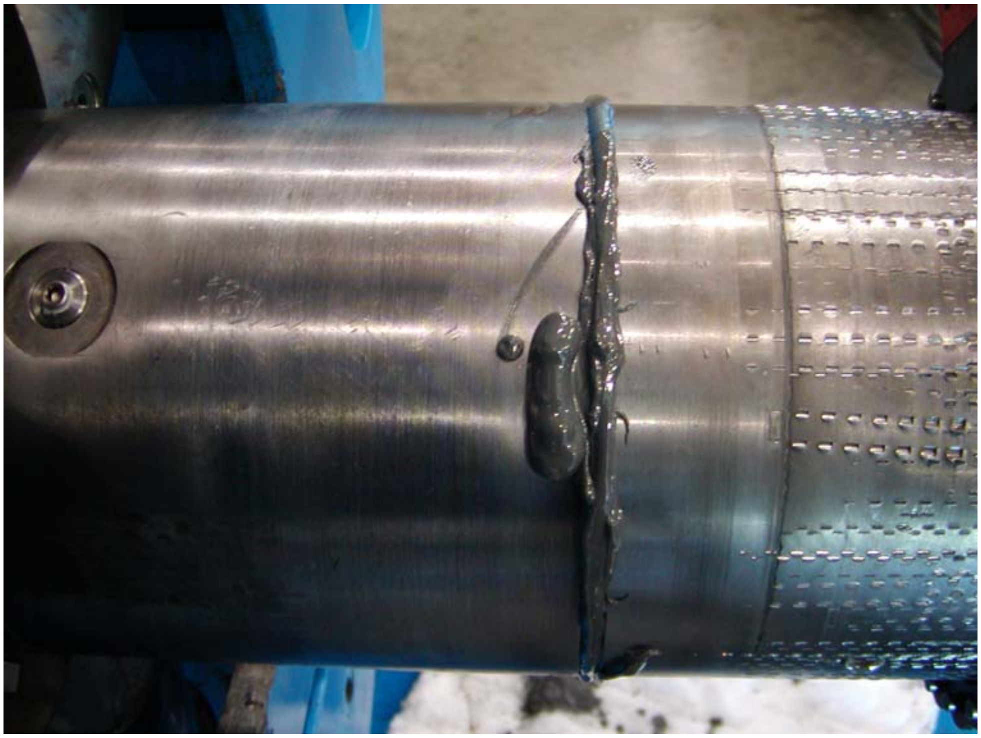

Figure 5 Torqued CDP Tool Joints

Figure 6 Composite Drill Pipes Placed Into Flow Loop

Figure 7 Flow Control Console, Flow Meter and Pressure Readout

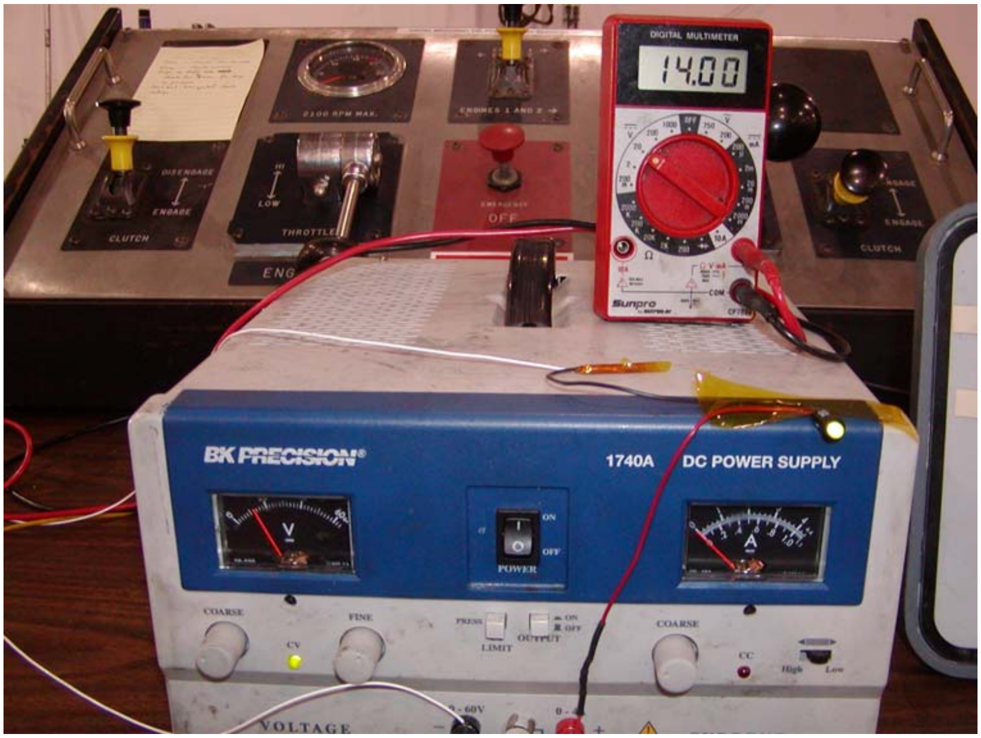

Figure 8 Monitoring of Electrical Signal

A total of 30 electrical cycles were made. These cycles consisted of turning power on with flow, holding the flow and pressure at which electrical contact is made for a period of 5 minutes followed by shutting electrical power off by either completely stopping fluid flow or reducing the flow rate to a level where the standpipe pressure falls below 200 psig. All tests were successful with no signs of leaks or any damage evident to the electrical contacts (bayonet and circular ring elements). During the break in cycle the standpipe pressure required to make electrical contact ranged from 200 to 262 psig. Break in was accomplished in 15 cycles after which it consistently required from 200 to 204 psig to make electrical connection between the bayonets and the contact rings. It is believed that the pressure differences before and after break in were due to seating in of the sealing elements. Table 1 summarizes these test cycles.

Table 1. Cycle Summary

Voltage	Pressure	Flow	Means of Breaking Electrical Continuity	Voltage	Pressure	Flow	Means of Breaking Electrical Continuity
14 Vdc	240 psig	226 gpm	Throttle	5 Vdc		212	Throttle
14 Vdc	203 psig	216 gpm	Throttle	5 Vdc		202	Throttle
14 Vdc	202 psig	212 gpm	Throttle	5 Vdc		202	Throttle
14 Vdc	201 psig	212 gpm	Throttle	5 Vdc		212	Throttle
14 Vdc	203 pisg	212 gpm	Throttle	5 Vdc		212	Throttle
14 Vdc	205 psig	230 gpm	Throttle	5 Vdc	200 psig	203	DV
14 Vdc	250 psig	230 gpm	Throttle	5 Vdc	200 psig	210	DV
14 Vdc	250 psig	230 gpm	Throttle	14 Vdc	200 psig	212	DV
14 Vdc	250 psig	230 gpm	Throttle	14 Vdc	204 psig	212	Throttle
14 Vdc	202 psig	211 gpm	Throttle	14 Vdc	202 psig	200	Throttle
14 Vdc	264 psig	235 gpm	Throttle	14 Vdc	200 psig	212	Throttle
5 Vdc	241 psig	228 gpm	Throttle	14 Vdc	200 pisg	212	Throttle
5 Vdc	220 psig	220 gpm	Throttle	14 Vdc	200 psig	212	DV
5 Vdc	202 psig	212 gpm	Throttle	14 Vdc	200 pisg	202	DV
5 Vdc		202 gpm	Throttle	14 Vdc	199 psig	210	DV

DV = Dump Valve

The bayonet/circular contact rings has been successfully implemented and tested in 3 segments of composite drill pipe. The electrical connections showed unbroken electrical continuity and clean signals when energized with standpipe pressures slightly above 200 psig. The design modifications will now be finalized as they proved to be successful. The next activity is to pursue the ring/ring direct electrical connection.

7.12. Task 12: Qualification Testing of Smart ER/DW CDP

This task is ongoing, concurrent with tasks 10, and 11. The following test matrix has been updated to current requirements. Tests will be conducted to prove viability and establish ratings for the ER/DW CDP.

ER-CDP TEST MATRIX						
Test Specimen #	S/N	Test #	Test	Result	Test Laboratory	Test Date
1	0604061	1	Destructive Tensile (Ambient) & Tensile Stiffness	518000	Coordinated	9/30/2004
2	1004142	2	Destructive Tensile (Ambient) & Tensile Stiffness	583800	Coordinated	2/2/2005
3	1104003	3	Destructive Tensile (Ambient) & Tensile Stiffness	471500	Coordinated	2/3/2005
4	1050305	4	Destructive Tensile (Ambient) & Tensile Stiffness	390000	Stress Engineering	6/1/05
5		5	Destructive Tensile (Hot/Wet) & Tensile Stiffness		Stress Engineering	
6		6	Proof Tensile (Hot/Wet) & Tensile Stiffness		Stress Engineering	
7		7	Proof Tensile (Hot/Wet) & Tensile Stiffness		Stress Engineering	
14		8	Destructive Compression (Hot/Wet)		Stress Engineering	
9	3051305	9	Destructive Torsional (Ambient) & Torsional Stiffness	33,000	Stress Engineering	7/8/05
8		10	Proof Torsional (Ambient) & Torsional Stiffness		Stress Engineering	
6		11	Destructive Torsional (Hot/Wet) & Torsional Stiffness		Stress Engineering	
7		12	Proof Torsional (Hot/Wet) & Torsional Stiffness		Stress Engineering	
8		13	Destructive Burst (Ambient)		Stress Engineering	
10		14	Destructive Burst (Ambient)		Stress Engineering	
11		15	Proof Burst (Ambient)		Stress Engineering	
7		16	Destructive Burst (Hot/Wet)		Stress Engineering	
13		17	Proof Burst (Hot/Wet)		Stress Engineering	
11		18	Destructive Collapse (Ambient)		Stress Engineering	
12		19	Destructive Collapse (Hot/Wet)		Stress Engineering	
13		20	10^5 Tension Fatigue		Stress Engineering	
30' Test Specimens						
14		21	BOP Shear		Weatherford	
15		22	BOP Shear		Weatherford	
16		23	BOP Seal		Weatherford	
17		24	BOP Seal		Weatherford	
18		25	BOP Close Blind Rams		Weatherford	
19		26	Fishing-Overshot Catch		Weatherford	
20		27	Fishing-Milling		Weatherford	
21		28	Fishing-Jarring		Weatherford	

7.13.Task 13: Final Report

A final report will be prepared in accordance with contract requirements.

8.0 RESULTS AND DISCUSSION

8.1. Direct Electrical Connection for Rotary Shoulder Tool Joints

Following the completed design of the bayonet ring design, ACPT completed the fabrication of three prototype pipe assemblies with the completed bayonet ring design. Maurer Technology successfully completed the laboratory testing of the pipe with providing DC electrical power and AC data communication through the pipe.

8.1.1. Design Direct Electrical Connection for 5½-in. CDP

Two basic designs for the direct electrical connection have been developed during the period and are now being manufactured. These are a 1) dual-ring design and 2) ring/bayonet design. Each is discussed below.

The basic dual-ring design for the electrical connection for CDP is shown in **Figure 9**. The dual-ring design features no moving parts. Each component of the tool joint is modified to accept an insulated contact ring in the face of the tool joint. Each ring is attached to a conductor, which is passed through a portal machined in the wall of the tool joint. This portal terminates where the composite pipe attaches to the metal tool joint components. The insulated contact ring on the pin connection is machined to provide a pilot on the face. Thin O-rings are placed on both the inside and outside diameter of the pilot. The O-rings will mate with the flat face surface of the corresponding contact ring in the box connection of the tool joint. The purpose of the O-rings is to prevent any conductive material, such as copper-filled pipe dope, from contacting the mating surfaces of the contact rings.

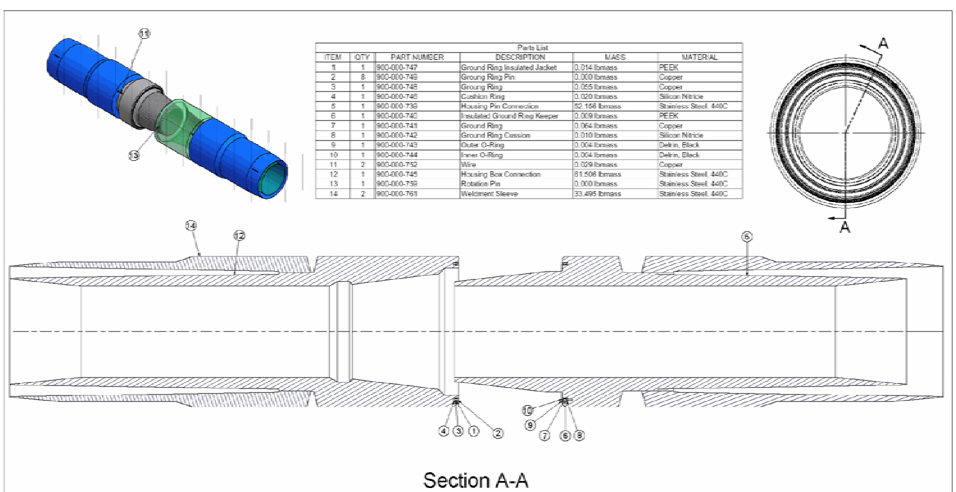

Figure 9 Dual-Ring Electrical Connection for CDP

As the tool joint is made up, the O-rings make contact with the flat face conductor ring in the box connection slightly before the pilot face makes contact with the corresponding flat-faced contact ring. Two aluminum fixture plates are under construction, which will allow testing of this concept without modification to any existing tool joint samples. All components are under construction and are expected to be available in early to mid November.

The bayonet-style design of the electrical connector is shown in **Figure 10**. As described above, a bayonet is used to complete the electrical circuit when fluid pressure is increased after the drill pipe is made up and run in the hole. A spring holds the bayonet retracted until minimum drill pipe pressure is exceeded, after which the bayonet extends outward and pierces the insulating elastomer coating on the circular contact ring and completes the electrical connection.

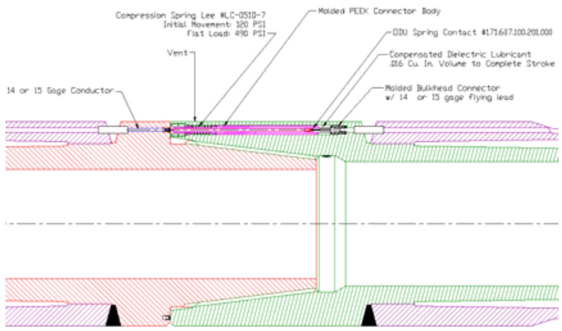

Figure 10 Design of Bayonet-Style Contact Assembly

The bayonet is coated with a high-durometer urethane for insulation from the tool joint body. A spring contactor is used to complete the circuit between the bayonet and the sealed feed through connector that is in turn connected to the 15 AWG conductor wire. The conductor wire passes through a portal machined along the length of the tool joint and terminates in the area where the composite pipe attaches to the tool joint components.

Use of a spring contactor allows axial movement between the bayonet and the feed-through bulkhead connector without full disengagement of the contactor. In this way, continuity is maintained during the stroke and retraction of the bayonet. All moving components are sealed in a pressure-balanced, oil-filled chamber. The oil is nonconductive. Pressure communication to the pipe bore is achieved through a floating piston mounted on a sealed plug and threaded into the tool joint body. As pressure increases in the pipe bore, it acts on the floating piston, which transfers the pressure to the seal bayonet. This causes a differential across the bayonet seal and forces the bayonet forward so that it pierces the insulating elastomer coating on the circular contact ring mounted in the pin joint of the connection.

All components of the bayonet-style connector prototype are currently under construction. Parts have been delivered to the urethane coating company for urethane application and finish machining. The same urethane company will help specify and apply the elastomer coating for the circular contact ring on the pin portion of the connection. Machined components and contactor components are expected to be delivered to MTI before mid November.

8.1.2. Work Planned for Next Period

The next goal is to complete the dual ring design and validate it's feasibility by performing bench testing to confirm make up torque and direct electrical connection.

8.2. Qualify fibers from Zoltek and Resin from Bakelite

The original design of the ER/DW-CDP was based on Toray T700 carbon fiber and Shell 9470/9405 epoxy resin. Shell sold its resin division to Resolution Performance Products who in turn discontinued manufacturing this particular system. This resin system became unavailable early this year. ACPT investigated alternative systems and settled on a high-temperature epoxy system manufactured by Bakelite. This effort consumed many engineering hours and manufacturing process development iterations.

The carbon fiber market is currently experiencing shortages and the carbon fiber manufacturers are forecasting the shortage to last for the next two years before increased capacity comes on-line. Earlier this year Toray discontinued their support of the composite drill pipe program as T700 fiber became very scarce and unavailable to ACPT. ACPT began to qualify other fibers from Zoltek and while this effort is on-going, it has consumed many engineering hours and manufacturing process development iterations.

8.3. Commercial Orders for SR-CDP

Following the commercial orders to Integrated Directional Resources, ACPT has received an order from Torch International. Reports from Torch International specify that the CDP will be utilized for ultra-short radius drilling for Petroleum Development of Oman (PDO).

8.4. Papers, Conferences and Presentations

Leslie, Dr. J.C.; Heard, J.T.; Truong, L; Leslie, J.C. II; 2005 Annual Technical Progress Report "Cost Effective Composite Drill Pipe; DOE/NETL Report No. 40262R30; 2/20/2006

9.0 CONCLUSION

ACPT is beginning to market the SR CDP. The press releases over the last year have generated a lot of interest in this product along with some inquiries for price, delivery, etc. We do expect to begin selling more SR-CDP in the near future.

Development and testing, to date, indicate that the ER/DW CDP as currently designed will meet or exceed all mechanical and physical requirements as shown in Section 7.1.1 of this report. This conclusion will be proven through planned laboratory and field testing.

ACPT and Noble Downhole Technology have embarked on a development effort to demonstrate the practicality of a direct electrical contact, data/power, through wall transmission design intended to make the pipe "Smart". Future efforts will be focused on constructing prototypes and testing the connections.

10.0 REFERENCES

1. Leslie, Dr. J.C.; Jean, J ; Truong, L ; Neubert, H ; and Leslie, J.C. II; 2000 Annual Technical Progress Report "Cost Effective Composite Drill Pipe; DOE/NETL Report No. 40262R05; 10/30/2000
2. Leslie, Dr. J.C.; Jean, J ; Truong, L ; Neubert, H ; 2001 Annual Technical Progress Report "Cost Effective Composite Drill Pipe"; DOE/NETL Report No. 40262R10; 10/30/2001
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4. Leslie, Dr. J.C., Composite Drill Pipe an Enabling Technology for Extended Reach and Deep Water Drilling, Gas Technology Institute's First Conference and Exhibition on Natural Gas Technologies, Orlando, Florida, October 2002.
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7. Leslie, Dr. J.C. ; Jean, J ; Truong, L ; Neubert, H ; and Leslie, J. II. ; "Cost Effective Composite Drill Pipe: Increased ERD, Lower Cost Deepwater Drilling and Real Time LWD/MWD Communications" ; SPE Paper No. 67764 ; SPE/IADC Conference ; The Netherlands, 2/27-3/1/01.

11.0 List of Acronyms and Abbreviations

ACPT
  Advanced Composite Products and Technology, Inc., 1
CDP
  Composite Drill Pipe, 3
DOE
  U.S. Department of Energy, 6
ER/DW-CDP
  Extended Reach/Deep Water-Composite Drill Pipe, 3
SR-CDP
  Short Radius-Composite Drill Pipe, 3