Development and Manufacture of Cost Effective Composite Drill Pipe

2004 Annual Technical Progress Report

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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, 2003 through September 30, 2004 and contains the following discussions:

- Direct Electrical Connection for Rotary Shoulder Tool Joints
- Conductors for inclusion in the pipe wall (ER/DW-CDP)
- Qualify fibers from Zoltek
- Qualify resin from Bakelite
- First commercial order for SR-CDP from Integrated Directional Resources (SR-CDP)
- Preparation of papers for publication and conference presentations.

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5.0 INTRODCUTION

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).

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 drastically increasing 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 nine times. The current amendment A009 has an end date of January 30, 2005. The original contract consisted of ten major tasks of which eight have been substantially completed. Three additional tasks were added to include the development and field demonstration of Short Radius CDP as a result of early development successes and at the request of the industry. The SR CDP is intended for land based well re-entry and directional drilling activities. The SR CDP development is completed and was made commercially available in 2004. Amendment A008 was awarded September 30, 2003 to include the development of a "Smart" feature demonstrated earlier in the project and to complete developmental qualification testing and field demonstrations of the ER/DW CDP.

6.0 EXECUTIVE SUMMARY

Design and Analysis remains a continuous effort throughout the 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.

Specifications have been prepared, reviewed and finalized for a 127mm (5") inside diameter Composite Drill Pipe. This increase in diameter from the original specifications came about for two primary reasons: 1) Industry partners (Omsco and Chevron/Texaco) had expressed concerns about hydraulic losses in the 114.3mm (4.5") design, but the design of that pipe was limited by the MCI geometry and process of manufacturing. The inside diameter of the pipe body was at its maximum in the current design; 2) The wind in place tool joint process proved to be extremely difficult to control and produced a wide variance in test results. It was concluded that if ACPT had trouble with the manufacturing processes it would never be commercialized on a large scale. The maximum tension test results only reached 2,224,111 Newtons (500,000 pounds) ultimate load, while the goal has remained at about 2,668,933 Newtons (600,000 pounds). In order to reach that goal the MCI had to be modified to accommodate an additional 20% tensile load. The redesign of the MCI set out to accomplish making the CDP "manufacturing friendly", capable of increased tensile loads and increase the inside diameter of the pipe. These goals have been met with the new MCI design.

The new MCI design was first developed and tested on the SR CDP. Results were 160% of goal. Based on these results, the MCI for ER/DW CDP was developed and tested. Initial results were 106% of goal. Full-scale tests of both 3m (10') and 9m (30') sections of the 127mm (5") CDP have been planned and scheduled. Based on the tension test results, which is considered the controlling parameter, this design iteration is expected to exceed all specification requirements (tension, torque, pressure and compression).

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.

During this 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 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.

7.0 EXPERIMENTAL

7.1. Task 1 Mechanical Requirements

Task I 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 x10^6 lb-in^2
Torsional Stiffness	GJ	115 x10^6 lb-in^2
Axial Stiffness	EA	33.4 x10^6 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 x10^6 lb-in^2
Torsional Stiffness	GJ	11.30 x10^6 lb-in^2
Axial Stiffness	AE	14.30 x10^6 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. CDP can carry power and/or real time communications through lines embedded in the composite walls. This program was empowered to investigate the feasibility of accomplishing these ends. Initial discussions with industry experts combined with in house knowledge of composites provide a different view of providing LWD/MWD capabilities in the CDP. In summary: 1.) Signal and power can be transmitted through the composite walls. 2.) The problem to be solved is reliably

transmitting signal or power through the metal joints connecting the individual CDP sections.

A direct connect prototype was demonstrated to the DOE-NETL in Morgantown in August of 2002. Maurer and ACPT prepared and submitted a proposal to demonstrate practicality and reduce this concept to practice. This has now become Task 10 and Task 11 in Amendment A008 of the contract.

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:

- Screening and verification of mechanical properties of resins, fibers, and adhesives for design and fabrication of CDP.
- Temperature and Environmental Resistance of all material to be used in the CDP.
- Measurement of Erosion and Mechanical Abrasion characteristics of interior and exterior coatings for CDP.
- 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

Grand Resources of Tulsa, OK and JB Drilling of Fort Smith, AR were referred to ACPT by DOE/NETL to negotiate a cooperative arrangement in which ACPT will furnish 8 sections and 9 sections of SR CDP respectively, for use in field testing on mud and air hammer drilling applications. DOE/NETL also requested 3 sections of SR CDP to be delivered to Terra drilling for additional field testing in Oman. Amendment A005 was issued 9/9/02 to include these field tests in this cooperative agreement. This task is essentially complete with the completion of Grand Resources and JB drilling field trials. This product has been commercially released and the first sale was made in June 2004.

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

22 AWG paired conductors were selected for inclusion in the composite pipe wall. Process development has settled on embedding a nylon string on the outside of the carbon fiber structure to form a recessed passageway for the wire. The pipe is wrapped with release tape and cured. After cure, the release tape is removed along with the nylon string. The pipe is then machined to accept the tool joints. The tool joints are machined to accept the face rings and components to form the direct electrical connection. The pipe is bonded to the tool joints, welded and pinned. The wire is then applied to pipe in the wire way and connected to the face rings. Fiberglass is the wound over the outside to complete the process.

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

This task has been sub-contracted to Maurer - Noble Downhole Technology, Ltd. Initial work was done using a face ring on one side and a bayonet connector on the opposite side. When the pipe was pressurized, the bayonet would extend and contact the face ring to complete the circuit. This approach was abandoned because the components would be too difficult to manufacture and there was not enough room in the tool joint design to accommodate the components.

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

This task is ongoing, concurrent with tasks 10, and 11. The following 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		4	Proof Tensile (Hot/Dry) & Tensile Stiffness		Stress Engineering	

4		12	Proof Compression (Hot/Dry) & Compressive Stiffness		Stress Engineering	
4		17	Proof Torsional (Hot/Dry) & Torsional Stiffness		Stress Engineering	
5		5	Proof Tensile (Hot/Dry) & Tensile Stiffness		Stress Engineering	
5		13	Proof Compression (Hot/Dry) & Compressive Stiffness		Stress Engineering	
5		18	Proof Torsional (Hot/Dry) & Torsional Stiffness		Stress Engineering	
6		6	Proof Tensile (Hot/Wet) & Tensile Stiffness		Stress Engineering	
6		19	Proof Torsional (Hot/Wet) & Torsional Stiffness		Stress Engineering	
6		27	Proof Burst (Hot)		Stress Engineering	
7		7	Proof Tensile (Hot/Wet) & Tensile Stiffness		Stress Engineering	
7		20	Proof Torsional (Hot/Wet) & Torsional Stiffness		Stress Engineering	
7		30	Proof Collapse (Ambient)		Stress Engineering	
8		8	Proof Tensile (Hot/Wet) & Tensile Stiffness		Stress Engineering	
8		21	Proof Torsional (Hot/Wet) & Torsional Stiffness		Stress Engineering	
8		32	Proof Collapse (Hot)		Stress Engineering	
9		9	Proof Compression (Ambient) & Compressive Stiffness		Stress Engineering	
9		14	Proof Torsional (Ambient) & Torsional Stiffness		Stress Engineering	
9		24	Proof Burst (Ambient)		Stress Engineering	
10		10	Proof Compression (Ambient) & Compressive Stiffness		Stress Engineering	
10		15	Proof Torsional (Ambient) & Torsional Stiffness		Stress Engineering	
10		25	Proof Burst (Ambient)		Stress Engineering	
11		11	Proof Compression (Ambient) & Compressive Stiffness		Stress Engineering	
11		16	Proof Torsional (Ambient) & Torsional Stiffness		Stress Engineering	
11		29	Proof Collapse (Ambient)		Stress Engineering	
12		22	Destructive Burst (Ambient)		Stress Engineering	
13		23	Destructive Burst (Ambient)		Stress Engineering	
14		26	Destructive Burst (Hot)		Stress Engineering	
15		28	Destructive Collapse (Ambient)		Stress Engineering	
16		31	Destructive Collapse (Hot)		Stress Engineering	
17		33	10^6 Bending Fatigue		Stress Engineering	
18		34	10^6 Bending Fatigue		Stress Engineering	
30' Test Specimens						
19		35	Destructive Bending			
20		36	Destructive Bending			
21		37	Destructive Bending			
22		38	BOP Shear			
23		39	BOP Shear			
24		40	BOP Seal			
25		41	BOP Seal			
26		42	BOP Close Blind Rams			
27		43	Fishing -Overshot Catch			
28		44	Fishing -Milling			
29		45	Fishing -Jarring			

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

ACPT subcontracted Maurer Technology Inc., a wholly-owned subsidiary of Noble Corporation, to design and build field prototypes of a direct electrical connection for rotary shouldered pin and box tool joints capable of providing DC electrical power and AC data communication to downhole MWD/LWD hardware. The prototype **composite drill pipes (CDPs)** are to be field tested by ACPT to evaluate their performance and reliability under typical operating conditions.

8.1.1. Technical Approach/Work Plan

The approach selected for producing a direct electrical connection for rotary shouldered tool joints is shown in **Figures 1–4**. A circular groove is machined into the shoulder of the pin connection. A highly conductive contact ring backed by an insulating member made of PEEK is installed into this groove. The external surface of the contact ring is to be coated with a flexible electrically insulating polymer. The electrical path is completed by attaching an insulated copper conductor to the back of the circular contact ring, with the conductor embedded into the body of the CDP.

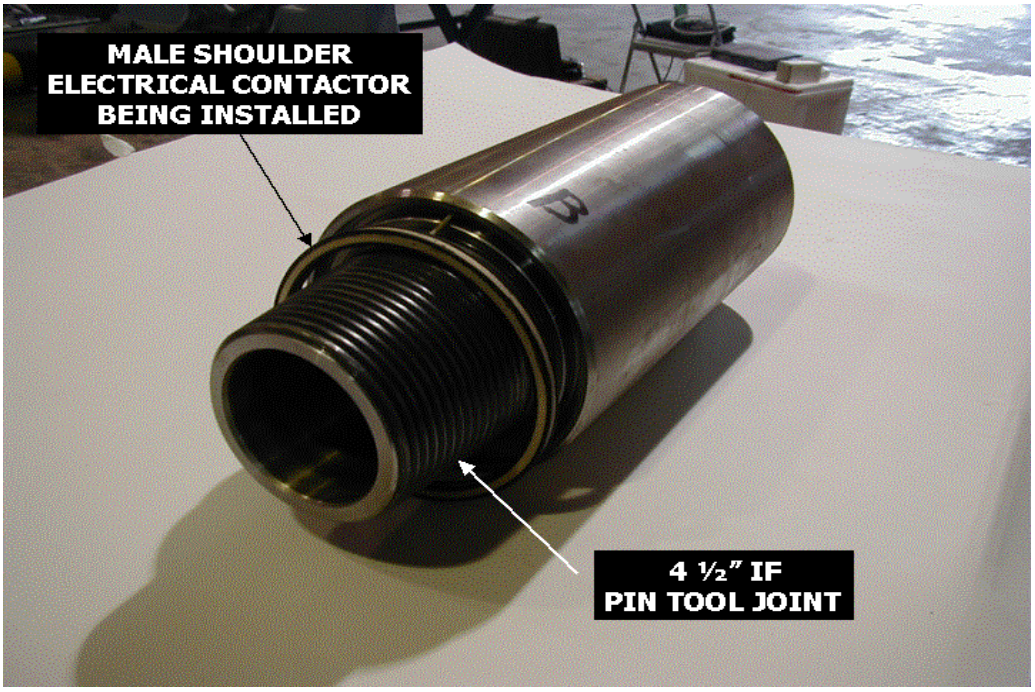

Figure 1 4½-inch IF Pin Connection Components

Figure 2 4½-inch IF Pin Connection Fully Assembled

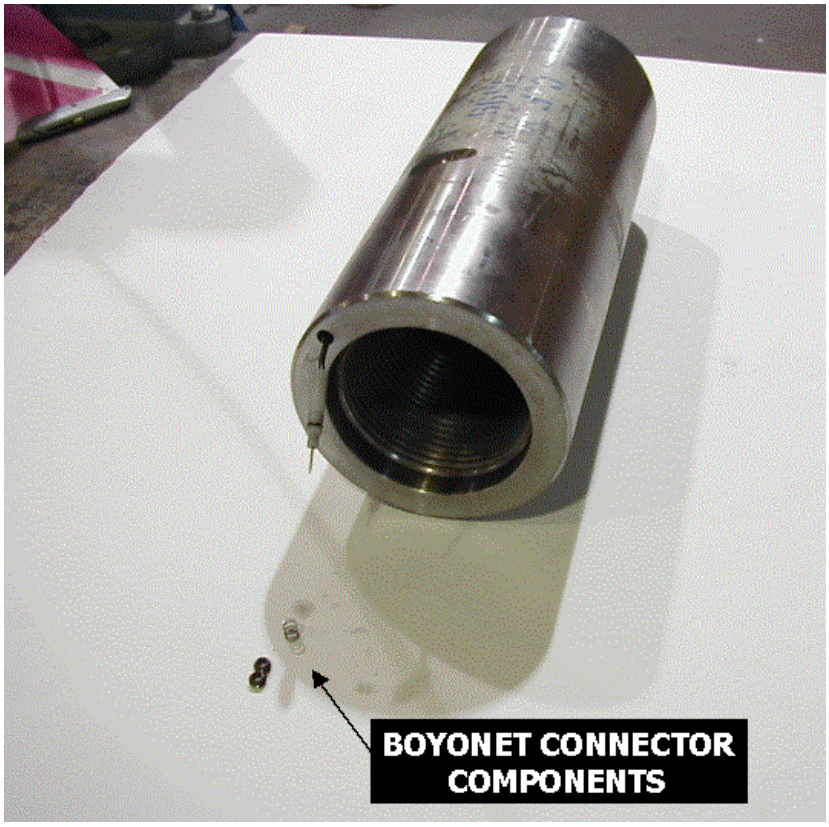

Figure 3 4½-inch IF Box Connection Components

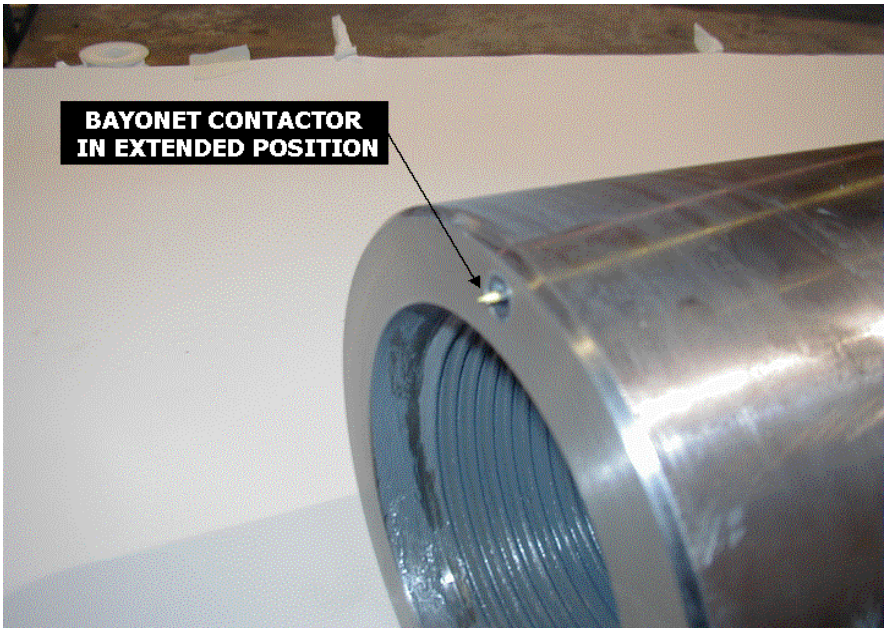

Figure 4 4½-inch IF Box Connection – Bayonet Extended

The box connection of the tool joint will have a hole drilled that houses a circular cartridge held in place by a threaded hollow socket cap screw. The cartridge consists of a metallic bayonet held inside a PEK insulator having thermal and mechanical stability to withstand the rigors of the downhole drilling environment. A spring placed between the bayonet contactor and tool-joint shoulder keeps the bayonet below the surface of the tool joint shoulder during make-up and break-out operations on the rig floor. The spring rate will be chosen to correspond to a minimum drill pipe pressure before the bayonet extends outward, pierces the insulating elastomer coating on the circular contact ring and completes the electrical connection.

Analysis of this design shows that it is not dependent on a specific angular alignment between the pin and box connections, has no active electronic elements and should be relatively inexpensive to install and service once perfected.

This work is being carried out in three sequential tasks:

Task 1 – Select Electrical Conductor

- Define typical MWD/LWD power requirements
- Power loss calculations
- Data telemetry analysis
- Recommended conductor size

Task 2 – Design Direct Electrical Connection for 5½-in. CDP

- Select insulating materials for bayonet body and circular contact insulators
- Select conductor materials for bayonet and circular contact insulators
- Evaluate external insulator coating for circular connector
- Produce detailed designs for bayonet connector and circular contact rings

- Fabricate and test individual components
- Install into CDP tool joints
- Conduct laboratory tests on CDP tool joints
- Revise design to address performance/reliability deficiencies
- Install revised designs into ACPT CDP for field testing

Task 3 – Documentation

- Prepare source control documents
- Prepare monthly reports
- Prepare detailed final report and fabrication/assembly manual

8.1.2. Task 1 – Select Electrical Conductor

Previous work was primarily focused on Task 1. To form a complete pathway for current flow, an electrical conductor consisting of either a coaxial cable or a twisted pair is needed. One wire, such as the outer sheath of a coaxial embodiment, is simply connected to both steel tool joints to provide the current return path or neutral. The center conductor is connected to the bayonet contactor on the box tool joint connection and to the circular ring on the pin tool joint to form the hot side. As these electrical contacts are electrically isolated from the tool joints, a complete current loop is provided.

Analysis of conductor size is based on the maximum voltage rating and maximum current the conductor cable can safely withstand including de-rating due to elevated downhole temperatures. Conductor resistance of copper varies with temperature as

$$R_{T2} = R_{T1} \frac{0.9214 + 0.00393T_2}{0.9214 + 0.00393T_1}$$

where T is in °C and R is the resistance at temperature. Resistance of copper wire decreases as conductor size decreases. It is desirable to use the largest practical conductor size to maximize the voltage and current which can be fed to downhole MWD/LWD while minimizing self-heating due to both resistive and dielectric losses. **Table 1** lists resistance of copper wire as a function of wire size. These distance values are for a round-trip circuit operated at 25°C.

Table 1. Copper Wire Resistance

AWG Wire Size	Ohms/100 ft	Ohms/100 meters	Ampacity
10	0.204	0.669	30
12	0.324	1.06	20
14	0.516	1.69	15
16	0.818	2.68	10
18	1.30	4.27	5
20	2.08	6.82	3.3
22	3.30	10.8	2.1
24	5.24	17.2	1.3
26	8.32	27.3	0.8
28	13.2	43.4	0.5

The most versatile CDP embedded with an electrical wire will be obtained by matching voltage ratings of typical logging cables. This will allow the CDP to be powered from standard wireline electrical power sources and operate the full range of LWD/MWD hardware. A maximum continuous DC voltage rating from 1200 volts can be realized with 18 AWG conductor size while 1500 volts is obtainable from 15 AWG. **Table 2** lists technical specifications for new 1N332 mono-conductor logging cable manufactured by Camesa Inc.

Table 2. 1N32PP Camesa Mono-Conductor

Cable Diameter:	0.322 inches
Inner Armor:	12 wires x 0.0445 inch diameter each
Outer Armor:	18 wires x 0.0445 inch diameter
Maximum Conductor Voltage:	1500 VDC
Conductor AWG Rating:	15
Copper Conductor Construction:	19 wires x 0.0142
Insulation Thickness:	0.022 inches Camtane
Minimum Insulation Resistance:	1500 M-Ohms/1000 ft @ 500 VDC
Armor Electrical Resistance:	2.1 Ohms/1000 ft
Typical Capacitance:	46 pico-Farads/ft
Temperature Rating:	420°F/204°C

It is recommended that ACPT examine the implications of embedding either a twisted pair or coaxial cable having AWG sizing from 16 to 10 with preference to use the largest wire size in this range that does not significantly detract from the CDP strength or present substantial fabrication issues (see more discussion below). MTI is currently in conversation with wire manufacturers to prepare wire/insulation packaging options for ACPT's consideration. Obviously, the outer armor layers used in wireline logging tools can be modified in the CDP application since the armor does not have to support tensile loads.

For AC communications based on common encoding schemes (such as frequency-shift keying (FSK), phase-shift keying (PSK), or pulse-width modulation (PWM)), the controlling characteristic for communication is the signal attenuation versus frequency. **Figure 5** is a typical attenuation curve for a 1N32PP monoconductor that also uses 15 AWG for its copper conductor. The reader should note that attenuation is measured for 25,000 ft of wireline. Actual attenuation levels are proportional to depth.

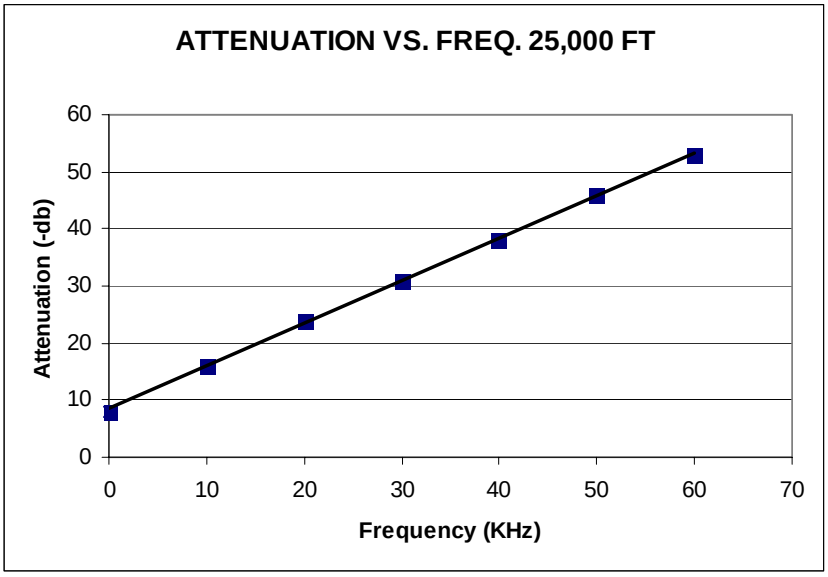

Figure 5 Attenuation vs. Frequency for Monoconductor Wireline

Temperature rating of the electrical conductor is based on the type of plastic used in the insulation. Maximum temperatures for typical well logging cables are listed below:

Plastic Type	Maximum Temperature
Polypropylene	300°F/149°C
Polymethylpentene	420°F/204°C
Teflon®	500°F/260°C
PFA®	550°F/288°C
TFA®	600°F/316°C

It is recommended that an insulation having a temperature rating of 204°C be used. This will assure it can operate at or above the maximum temperature ratings of state-of-the-art MWD/LWD tools.

The majority of MWD/LWD applications can be satisfied at DC power levels below 200 W. Some typical power draws of MWD/LWD equipment are: 1) positive mud pulsers (18–30 W), 2) directional/gamma-ray sensors (<5 W), 3) dual frequency resistivity (24–30 W); 4) rotary steerable (24–75 W).

In recent project activities, MTI's efforts have been focused on analyzing relative advantages/disadvantages of various wire types for the CDP. Specifically, flat conductors versus round conductors were evaluated, as well as twisted pair versus coaxial cable.

Flat Conductors versus Round Conductors

Flat conductors exhibit several advantages over round conductors:

1. Flat conductors have better thermal dissipation than round conductors, which allows use of smaller conductors.

2. Flat conductors are lighter than round.
3. Composite flat cable construction is mechanically strong. Therefore, it is not necessary to have large conductors for strength. The copper cross section can be reduced to carry the current load required.
4. Flat conductors are very flexible.
5. Tensile loads in flat conductors are equally shared by all conductors and insulation together thus providing enhanced strength.
6. Because flat conductor spacing is fixed and geometry of the cable is constant, electrical characteristics (impedance, capacitance, inductance, cross talk, time delay and attenuation) are consistent.
7. Flat conductors are terminated with the entire group of conductors as a unit and therefore more efficient than working with individual conductors.
8. Flat conductor architecture allows mass termination of the conductors to high-density connectors by the insulation displacement contact (IDC) process.
9. Flat conductors are compatible with ZIF/LIF connectors for termination.
10. Flat conductors have greater surface-to-volume ratio than round. This provides a higher efficiency in dissipating heat and allows a higher current level for a given temperature rise and conductor cross-section.

Disadvantages of flat conductors include:

1. Soldering is not used in practice with FC. The FC is wide and fragile and not compatible with contacts where it needs to be soldered.
2. Cost of terminating the flat conductors in a form factor suitable for use with the composite drill pipe termination to go from flat to round will require a special design which will entail the requisite non-recurring engineering costs.
3. The connector will have to be proofed for its durability under shock, vibration and thermal loading whereas this information is well established for round solder connections used in downhole tool service.

Based on this analysis, MTI recommends working with a specialty flat-wire connector manufacturer to produce a prototype design for evaluation while still pursuing the round wire option.

Twisted Pair versus Coaxial Cable

Attenuation of signal with distance and with signal frequency were compared for twisted pair and coaxial cable. Signal loss with wire length is similar for the two wire types (**Figure 6**). However, coaxial cable has much greater channel capacity than twisted pair.

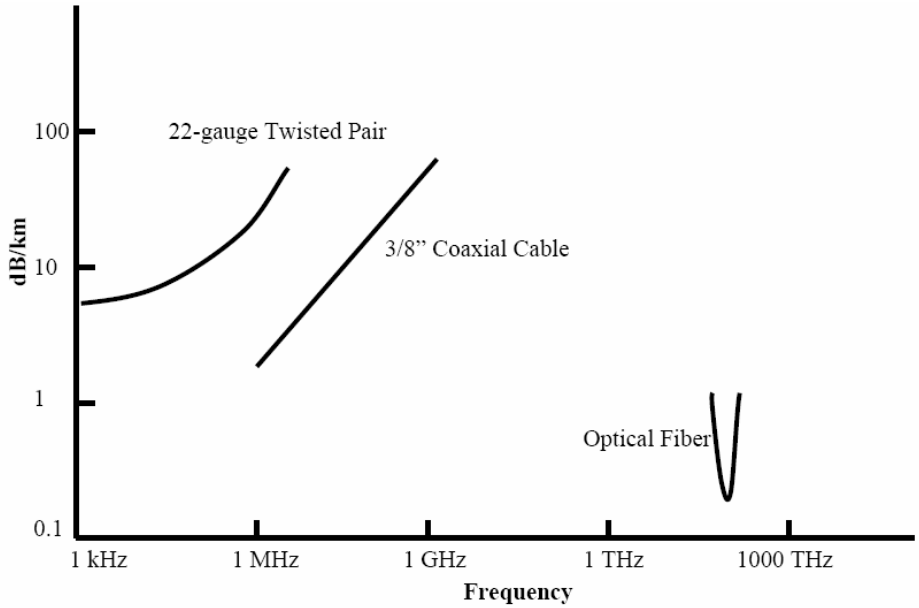

Figure 6 Signal Loss for Twisted Pair and Coaxial Cable

The team's past experience indicates that transmission rates may be as great as 1 to 2 MBits per second, which translates to transmission frequencies between 200 kHz and 800 kHz. This is within the range of both twisted pair and coaxial cable (**Figure 7**).

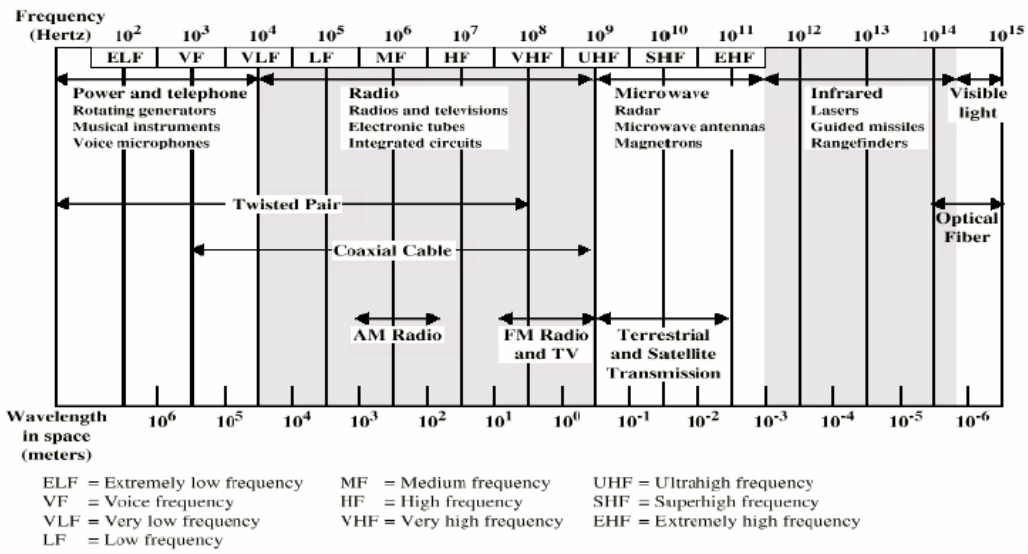

Figure 7 Range of Transmission Frequencies for Twisted Pair and Coaxial Cable

In **Table 3**, performance advantages of twisted pair (unshielded/shielded) versus coaxial cable are compared.

Table 3. Comparison of Twisted Pair and Coaxial Cable

Unshielded Twisted Pair	
–	Low bandwidth and data rate (limited high frequency performance)
–	More susceptible to noise but good design can give better interference rejection.
+	Does not depend on proper grounding to block interference and is easy to terminate.
+	Less likely to fail and easy to install.
–	Shorter cable lengths.
+	Less expensive and more durable.
Shielded Twisted Pair	
–	Low bandwidth and data rate.
+	Less susceptible to noise if well grounded.
–	Discontinuity in shield or asymmetry between current in shield may be interpreted as noise. To be effective and block noise interference, the entire link (end-to-end) needs to be shielded and properly grounded.
–	Length of ground conductor can be a problem and therefore needs optimum grounding.
–	Shorter cable lengths.
Coaxial Cable	
+	High bandwidth and better high frequency performance.
+	Less susceptible to noise interference.
+	Shielded.
+	Greater cable length than twisted pair.
–	Most expensive and less durable than twisted pair.

With respect to data communication and specifically for the data encoding schemes referred to above (FSK, PSK, & PWM), twisted pair and coaxial cable will both be able to support frequencies that cover the range indicated. Of the two, twisted pair is the easiest to work with in the CDP application.

If ACPT is primarily interested in data communication, then 22 AWG conductor sizing will suffice. If the capability to supply DC power from the surface to downhole MWD/LWD equipment is desired, 15 AWG size is recommended.

8.1.3. Task 2 – 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 8**. 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.

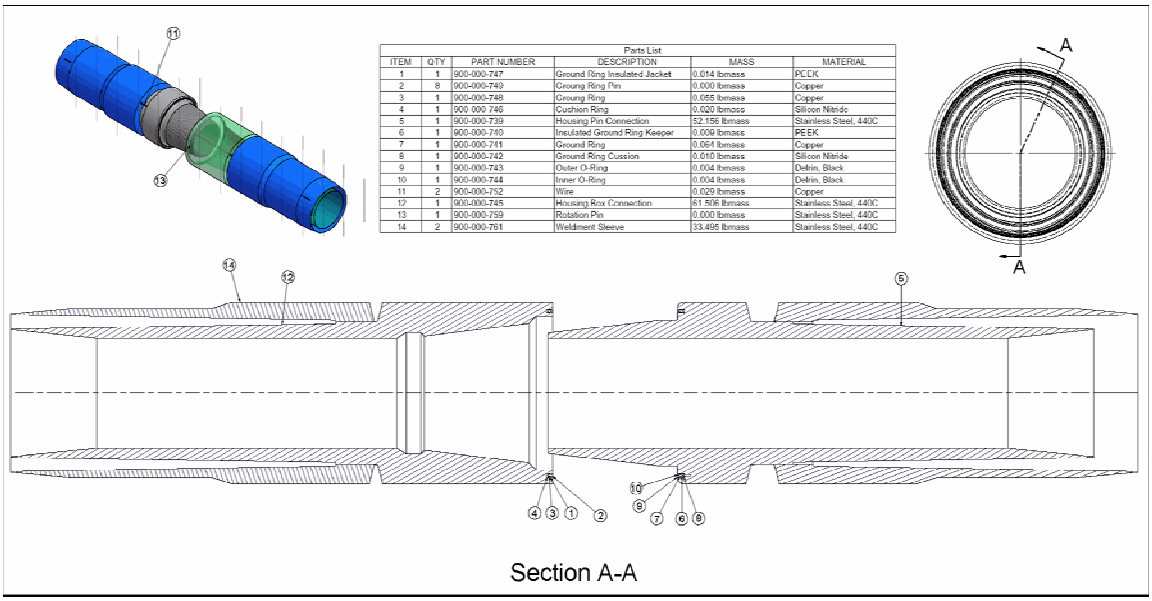

Figure 8 Dual-Ring Electrical Connection for CDP

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 9**. 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.

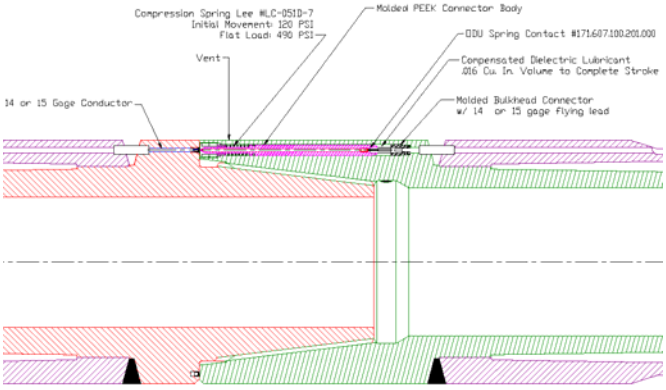

Figure 9 Design of Bayonet-Style Contact Assembly

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.

8.1.4. Work Planned for Next Period

The next goal under Task 1 activities will be to complete the wire design comparison between flat and round conductors within the next two months so a preferred embodiment can be selected by ACPT. This schedule will be dictated by the turn-around time for the flat-to-round conductor termination piece for both 15 and 22 AWG sizes.

Under Task 2, MTI will perform comparative testing between the dual-ring and ring/bayonet direct electrical connection designs using our breakout unit. The tests will entail several joint make and breakout cycles with measurements of continuity and resistance.

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. First Commercial Order for SR-CDP

Following the successful completion of the field tests, Advanced Composite Products & Technology, Inc. (ACPT) began offering the SR-CDP commercially to drilling companies. The first order was placed in January 2004 by Integrated Directional Resources (IDR) of Lafayette, Louisiana. Integrated Directional Resources (IDR) intends to use the pipe for drilling ultra-short-radius (USR) wells in the Gulf Coast. On location at one well in late July, IDR reported problems with steel pipe failing while drilling the lateral section and that IDR was using the composite pipe for all fishing operations, consistently pulling 20,000 to 25,000 pounds. As a result, IDR now plans on using their entire available composite pipe to complete the lateral section.

8.4. Papers, Conferences and Presentations

Leslie, J.C., New Composite Drill Pipe Offers Advantages for Short Radius, Extended Reach/Deep Water, and Deep Trek Operations, GTI Natural Gas Technologies II, Phoenix, Arizona, February 2004.

Covatch, Gary L., Heard, James T., CDP Designed for Short-Radius Wells, American Oil & Gas Reporter, September 2004.

Attended SPE show in Houston and presented an update on the program in DOE'S booth

Leslie, Dr. J.C.; Heard, J.T.; Truong, L; Leslie, J.C. II; 2004 Annual Technical Progress Report "Cost Effective Composite Drill Pipe; DOE/NETL Report No. 40262R25; 1/30/2005

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
3. Leslie, Dr. J.C., Composite Drill Pipe for Extended-Reach and Deep Water Applications, Paper #14266, Offshore Technology Conference, Houston, Texas, May 2002
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.
5. Leslie, Dr. J.C.; Jean, J.R., Heard, J.T.; Truong, L ; Neubert, H ; 2002 Annual Technical Progress Report "Cost Effective Composite Drill Pipe; DOE/NETL Report No. 40262R15; 9/20/2002
6. Leslie, Dr. J.C., Developing a Cost Effective Composite Drill Pipe, "Gas Tips", Hart/IRI Fuels Information Services, Winter 2002, Volume 8, Number 1.
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