NEXT GENERATION ELECTRICAL AND OPTICAL CABLE TERMINATION SYSTEMS FOR THE DRILLING INDUSTRY

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ABSTRACT

The use of deepwater drilling systems has increased dramatically over the last few years and with this so has the need for ultra-high reliability of the control and monitoring systems. The cost of deepwater drilling operations is very high and the time taken to install or retrieve failed equipment has a huge impact on the schedule and hence cost.

The cables and terminations required for subsea control and monitoring systems can be vulnerable to the rigorous operations involved and various operators have seized many initiatives to optimize designs and minimize operational variations of inventory in order to maximize up-time and reduce operational costs for repair.

Drilling in deeper waters pushes the limitations of existing umbilical cable and connectors. The demand for smaller cable connectors that are capable of passing fiber optic communications with very low loss, as well as electrical power and communications, at increased levels of reliability, has driven the development of the next-generation of cable termination systems.

This paper presents an outline of work conducted in optimizing existing field-proven designs by working closely with drilling contractors and drilling controls manufacturers to produce next-generation cable-termination technology suitable for electrical, optical and hybrid cable solutions. It includes connectorization of terminations, use of positive pressure compensation systems, field installable, testable and deployable systems and break-way units. Also included is a universal joint bend restrictor that allows cable bending and strain-relief through restricted-space areas and proper selection of materials.

1 INTRODUCTION

Over the last few years, SEA CON® has worked closely with Transocean Offshore Deepwater Drilling Inc. and other drilling contractors on the design, development, manufacture and testing of the next-generation cable termination systems, with the specific aim of reducing drill-ship downtime. The project has been based primarily in Houston, Texas, in close cooperation with the main SEA CON® Design Center in California. Several technologies were identified as being critical for the next-generation cable terminations.

(a) Connectorization of Terminations: Traditional and older cable terminations were terminated direct onto the host system. Whilst this offered a greater theoretical reliability at lower initial cost by avoiding the use of multiple connector interfaces, the flexibility for operations and maintainability was limited.

(b) Component Separation: In some cases it has been a requirement to create connector systems that are lighter, more manageable and flexible than the conventional connectors that have been used in such applications. The method chosen was to separate the 'connection' component from the 'armor-termination' component, allowing each to be lighter and more manageable than conventional fully integrated terminations. Figure 1 illustrates the main components of a separated system. This system also allows the advantage of separating the load-bearing aspects of the Field Installable Testable Assembly (FITA) directly into the Armor Termination Assembly (ATA).

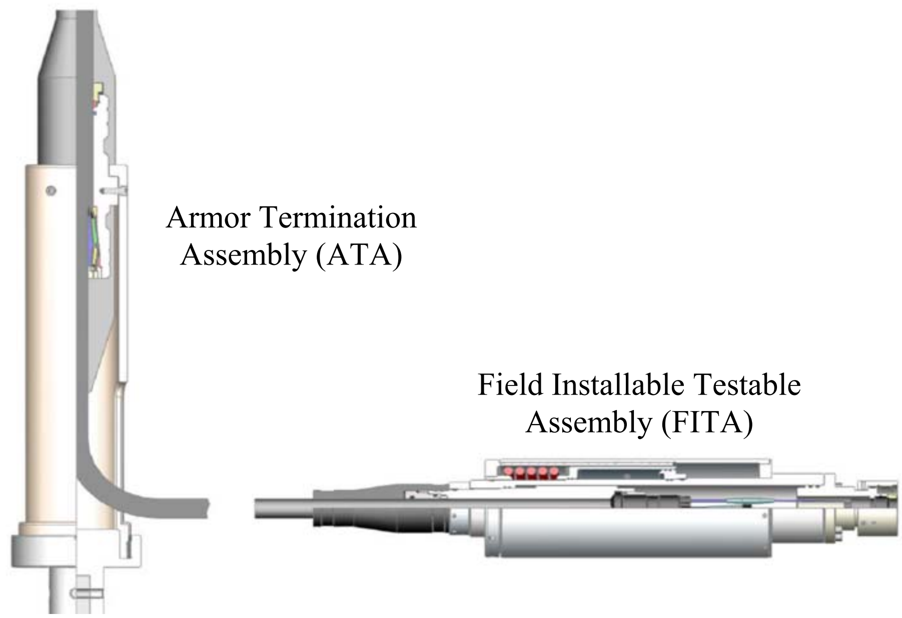

Figure 1 – Separated Cable Termination System

(c) Positive Pressure Compensation Systems: Whilst the use of one-atmosphere connectors and termination systems are acknowledged to be acceptable in many applications, the susceptibility of cable damage in the rough-handling and severe operational environment of deepwater drilling systems, led to a development away from the incorporation of one-atmosphere technology and subsequent pressure-differentials in favour of not only pressure-compensated systems but the use of positive-pressure compensated connectors.

(d) Field Installable, Testable and Deployable Systems: It was paramount that the next-generation cable termination systems be readily installed, tested and deployed in the field as well as being maintainable. The main need for a field installable connector is driven by the ability to replace a connector quickly on-site, keeping downtime to a minimum. The need for a field testable assembly is driven by the fact that conventional pressure testing equipment is not suitable for a connector that is terminated to 5,000 plus feet of cable. Since pressure testing is not feasible, assurance is provided by knowing that the connector will continue to function when water-flooded.

(e) Breakaway Unit: A breakaway unit provides a point of breakaway with an adjustable breaking force. Use of the breakaway unit, in combination with the FITA's low pullout force, allows the cable and termination system to separate from the stack in the event of a major operational failure.

(f) Bend Restrictor: The interface between the cable and termination needs some form of transition to allow cable bending and strain-relief and in some cases this is required within restricted spaces.

(g) Dual Barrier Sealing: All potential water paths should be sealed with dual o-rings for redundancy.

(h) Flooded: The FITA should be designed to function when fully flooded with water.

(i) Leak Detection: The FITA can be tested for water ingress.

(j) Integrated Systems: In some cases certain deck-layouts do not allow for the use of separated systems highlighted in (b) but they will allow the space for fully integrated armor termination and connection systems to be utilized. These are integrated units that contain both the ATA and FITA into the single termination.

2 CONNECTORIZATION

With the susceptibility of deepwater drilling cables to serious degrees of damage during operations, the addition of a connector into the cable termination provides several advantages:

- Flexibility for separate testing of host system and cable system
- Flexibility for separate disconnection of host system and cable system
- Mechanical plug and play

Whilst the addition of the connector compared to a direct penetration termination, is at a greater initial expense and introduces an additional level of complexity, the flexibility it offers during operations and for system diagnostics leads to significant operational cost savings by reducing system downtime.

3 COMPONENT SEPARATION

The two main system components of a ‘ separated’ cable termination are the armor termination, which led to the development of the separate Armor Termination Assembly (ATA) and the cable termination at the connector, which led to the development of the separate Field Installable Testable Assembly (FITA).

3.1 SEPARATE ARMOR TERMINATION ASSEMBLY (ATA)

The **Armor Termination Assembly (ATA)** is designed to take the strain experienced during cable deployment and operations and avoids any of the high forces associated with that being passed onto the connector or cable termination. It also means the armor can be terminated a distance away from the end connection of an umbilical cable. This makes terminated cable handling much more manageable, and provides a point or location for an emergency breakaway point (if required). The ATA is shown in figure 2.

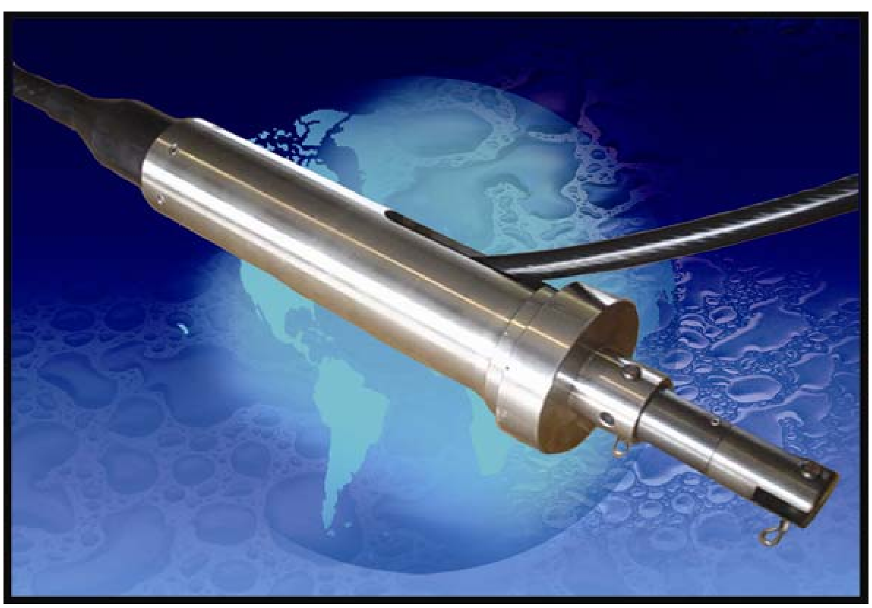

Figure 2 – Armor Termination Assembly (ATA)

The ATA uses epoxy-free dual-cone technology to terminate and anchor contra-helically wound armor. The dual-cone technology assures holding strengths exceeding 75% of the cable breaking strength. The ATA may be located in an easy-access area of the stack's framework, or riser. After affixing the ATA to the cable, it may be latched to the framework in any of four 90-degree rotational positions, thus minimizing cable torsional tension.

The main features of the ATA are:

- Field installable (with no compounds)
- Rated for full ocean depth
- Designed for easy adaptability to cable variations
- Qualification testing breaking strength to 16,900lbs

3.2 SEPARATE FIELD INSTALLABLE TESTABLE ASSEMBLY (FITA)

The **Field Installable Testable Assembly (FITA)** is a positive-pressure compensated vessel that makes electrical and/or optical connection to the host system. The host system may be a Subsea Electronics Module, Subsea Control Module or Transformer Pod. The FITA is designed to continue operating when flooded with water, and may be tested with water before deployment. When mated to a bulkhead receptacle, the interface seal can also be tested. An additional advantage of this style of FITA is that in the event of a breakaway of the main cable it incorporates a system to facilitate the pullout of the cable from the FITA without transferring damage to the host system. The FITA is shown in figure 3, the main features are:

- Field installable (with no compounds) and testable
- Depth rating 10,000 feet
- Electrical, Optical and Electro/Optical (Hybrid)
- Cable pull-out load of 700 lbs

Figure 3 – Field Installable Testable Assembly (FITA)

4 POSITIVE-PRESSURE COMPENSATION TECHNOLOGY

Positive-pressure compensation is based upon two techniques: keeping a minimal differential pressure between the inside of the connector and the outside environment and maintaining a small positive differential pressure inside the connector to deter water ingress in the case of a breeched cable.

The piston method is used for pressure compensation. A toroidal piston operates between the connector body and an outer sleeve. All are dual O-ring sealed. One side of the piston is in contact with the reserve oil volume and a titanium spring and seawater pressure acts upon the other side.

5 LEAK DETECTION

Some design, particularly the RUFF-NEK and FITA are designed to function when flooded with water. In the FITA, a 'Megger Pin' has been included that allows quick testing to detect the presence of water inside the connector before deployment.

6 COMPONENT INTEGRATION

Other models have both the armor termination and field installable elements fully integrated. One of SEA CON®'s highest specification and most rugged configuration, the RUFF-NEK connector exceeded all qualification test expectations, and has been in use in deep-waters off the coast of Brazil for over two years.

The RUFF-NEK has proved to be the most rugged and reliable type of termination designed, installed and used in extremely arduous deepwater drill-ship applications. A cut-away version is shown in figure 4.

Figure 4 – RUFF-NEK Connector

The RUFF-NEK™ connector is an Electro/Optical/Mechanical termination that applies a constant over-pressure to the end of the cable and termination volumes.

This over-pressure is maintained at a constant pressure and helps to prevent water ingress into the termination volume that may be caused by flooding of the conductor strands (in the event of cable jacket and conductor insulation breech).

The main features of the RUFF-NEK are:

- Field installable (with no compounds)
- Operating tensile load, 6,000 lbs.
- Dual positive-pressure compensated chambers
- Depth rating over 22,000 feet
- Hybrid, electrical and fiber-optics
- Electrical operation even with flooded connector interface
- Test ports for O-rings

7 FIELD INSTALLATION

All components of the connector system are field installable. It is recommended that installation be done by SEA CON® staff, however training can be provided to rig personnel. No epoxies are used, which decreases installation time, as well as eliminating or reducing permit requirements. In addition, the FITA may be water-filled and tested onsite to ensure functionality, then emptied and re-filled with silicone oil.

8 DUAL BARRIER SEALING

All potential water paths are sealed with dual o-rings for redundancy. Where possible, redundant o-rings are not located on the same diameter to reduce the chances of the same debris violating both o-rings.

9 BREAKAWAY UNIT

A Breakaway Unit (BU) connects the ATA to the framework or riser. It utilizes shear pin technology to allow breakaway in the case of stack or BOP being dropped or non-synchronous payout of the cable.

The BU provides a means of reducing the damage to the host system caused under these conditions. The shear pin material uses a low ultimate/yield strength ratio to increase the accuracy of targeted breaking load. The Breakaway Unit is shown in figure 5.

Figure 5 – Breakaway Unit

The main features of the Breakaway Unit are:

- Field installable (with no compounds)
- Rated for full ocean depth
- Overall length of less than 6.5”
- Non-destructive failure mode and replaceable shear pin

A Breakaway Unit allows a destructive parting of the cable from the FITA on the basis that the cable/connector damage is significantly less than any possible corresponding vessel host-system damage. Equally a Breakaway Unit could incorporate a connector to facilitate easy system breakaway and should there be no cable/connector damage after breakaway then it offers easy re-connection of the retrieved cable system.

10 RIGHT-ANGLE FLANGED CONNECTOR RECEPTALE

The Right-Angle Flanged Connector Receptacle (FCR) provides the flexibility to route a connector/cable in a more manageable fashion. The receptacle mounts to existing hole penetrations on subsea modules. The connection side of the receptacle interfaces with SEA CON®’s standard Metal-Shell Series (MSS) dry-mate electrical, optical or electro/optical connectors.

The Right-Angle FCR is shown in figure 6, the main features are:

- Field installable (with no compounds)
- Rated for 20,000psi mated
- Resistant to back-pressure
- Seal tested
- Electrical, Optical and Electro/Optical

Figure 6 – Right-Angle Flanged Connector Receptacle (FCR)

11 BEND RESTRICTOR

Cable Bend Restrictors (BR) principle purpose is to allow cable bending whilst providing an adequate level of strain relief and bend restriction at critical interfaces. Examples are at the end of a cable at the interface to the cable termination. They come in many different styles, shapes and sizes depending on the key details of their specification requirements. The standard and most cost-effective bend restrictor is a rubber-molded boot that fits the cable, allows flexibility at that interface but restricts excessive loading at the critical areas. The rubber–molded boots are shown as standard in the next-generation cable system however through areas where there are space limitations, the Universal Joint Bend Restrictor (UJBR) allows cable bending through restricted-space areas whilst still providing an adequate level of strain relief and bend restriction of the cable system. The Universal Joint Bend Restrictor is shown in figure 7.

The small size of the UJBR, also allows cable termination and connectorization with ease. These types of bend restrictors are usually found associated with small-bore arrays rather than those systems associated with drilling ships. The main features are:

- Less than 2.5” in diameter
- Modular cable terminations, suitable for interface to any type of connectors
- Operating Tensile Load of 60,000 lb
- Dynamic Cyclic Bend Load of 11,000 lb

Figure 7 – Dynamic cyclic bend of Universal Joint Bend Restrictor (UJBR) connector over 0.9m (36”) diameter sheave

12 ELECTRICAL AND OPTICAL CHARACTERISTICS

The fully developed and tested terminations are customer driven in their configurations for electrical, optical or electro/optical requirements. The FITA shown has twelve #16 AWG electrical contacts that are rated for 600 Volts AC at 15 Amps each. Connector insulation resistance is >100 MΩ@500 VDC. These characteristics are quite typical of most applications. Also being developed in the FITA configuration is an electro/optical connector that will employ four #10 AWG and eight fiber-optic contacts. The RUFF-NEK shown has 4 #10 AWG electrical contacts and eight 8 fiber-optic contacts. The fiber-optic contacts are designed for optical attenuation of better than 0.5 dB per mated contact pair.

With a huge range of experience for both electrical and optical SEA CON® can supply configurations of:

- Up to 3,300VAC
- Up to 100Amps
- Single-mode or multi-mode optical systems
- High optical performance

13 COMPLETE SEPARATE SYSTEM

The following system diagram, figure 8 shows an example of a complete cable termination system.

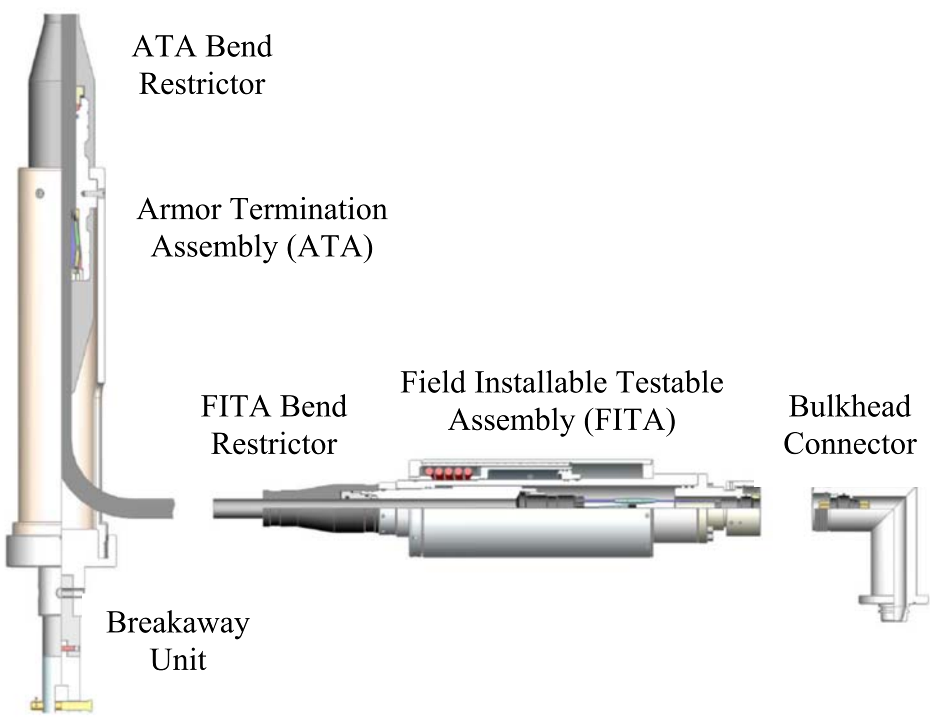

Figure 8 – Complete Cable Termination System

14 TEST RESULTS

Each of the main system components underwent individual and extensive qualification testing. The following does not detail all qualification tests and only lists those items of special interest to the designs.

The FITA was pressure tested in chilled water at 40°F to 7500 psi. The first tests were performed with the connector's ports open, flooded with water inside the test vessel. The lowest insulation resistance measurement was 75,000 MΩ between two adjacent pins. The water was then drained, and replaced with silicone fluid. During three 10-minute pressure cycles and one 1-hour pressure cycle, the lowest insulation resistance measurement was 150,000 MΩ between a pin and the connector shell. After pressure testing, the FITA was disassembled and the cable grips were re-affixed to another piece of cable and pull-tested. The cable began pulling out at a load of 680 lbs. and gave way at 754 lbs. This met design requirements, which intended for the cable to pull out of the connector at a minimal load to avoid damaging subsea vessels.

The ATA was terminated to a sample of embedded, contra-helically wound armor cable and pull tested. The breaking load was 16,620 lbs. The failure mode was armor breakage.

The right angle Flanged Connector Receptacle was capped on both ends, and pressure tested to 7,500 psi however the MSS connectors are rated to 20,000psi in the mated condition.

The Breakaway Unit, which is built around a 17-4 PH SST shear pin, was pull tested with an 8,000 lb. pin installed. All results were within 5% of the theoretical target force calculation based on the size and design of the breakaway force.

The Universal Join Bend Restrictor successfully underwent significant testing including dynamic cycling under tension, over a 36" diameter sheave. The qualification testing of the RUFF-NEK included successful operational testing at pressure with no compensating fluid and in flooded conditions.

15 FIELD RESULTS

The next-generation cable termination systems have been installed on two deepwater drilling rigs in the Gulf on Mexico, and several more installations are scheduled over the next few months. One installation, on the Transocean Offshore Deepwater Drilling Inc. Deepwater Nautilus, has been in operation for several months in 9,000 feet water, which is a record depth for a moored rig. RUFF-NEK connectors have been in use trouble-free in Brazilian waters for two years.

16 CONCLUSIONS

Reliability

This is one of the key issues of underwater electrical / optical connectors. Many companies have suffered high expense as a result of cable and cable termination failures. The main contributing factor being the inadequacy of the designs to suit the extreme operating, cycling and handling conditions associated with repeatable deepwater installation and retrievals of deepwater drilling systems.

SEA CON®'s cable termination systems are designed to be reliable for 20 years. The reliability concept is based on the core feature of positive pressure compensation combined with the ability of the connector to function fully flooded. This means that in the unlikely event that the connector system does become fully flooded, it does not matter to the overall integrity of the system.

The ability to test for water in the connector also provides the operator with additional instant information about the health of the systems.

However it is not only the positive-pressure feature but also a combination of all of the features of the next generation systems that provide the required levels of reliability sought.

Robustness

Separation of system components has allowed each to be built with suitable robustness, without becoming unmanageably heavy or large in size. The Armor Termination Assembly was qualified with the weakest of the cables that were expected to be used with it, indicating that higher breaking points could be expected. A replaceable engaging nut has been incorporated into the FITA, in case the connector is dropped on the nut during routine maintenance / inspection.

Suitability

Not only drilling operations are suitable for this technology. Completion, workover, and production systems may use these connectors. The modularized design allows a user to select key components. The flexibility of the choice of bend restrictor also provides modular flexibility.

Costs

Similar to conventional cable connectors, the SEA CON® systems offer the ability for field installation and testing. However, positive-pressure compensation add additional security against water ingress with the additional advantage of faster installation times than conventional cable connectors, simply by the use of a "no compound" philosophy which eliminates the need for epoxy-cure wait times during the installation period.

The connector system has been designed to allow for easy modification to accommodate different cables types, including fiber optic. To date, the next generation systems have been retrofitted for over six different cables types.

In trading off the full benefits of CAPEX for procurement and installation versus the life-cycle Operating Costs, OPEX, the advantages of the latest generation cable termination technology offers extremely cost-effective solutions for both.

ACKNOWLEDGMENTS

This paper has been based on over 40 years of continuous experience in the field of underwater connectors and cable termination systems. We would like to thank the continued and dedicated SEA CON® teams around the world for their continued efforts in contributing to the knowledge that made this paper possible.

We would particularly like to thank Transocean Offshore Deepwater Drilling Inc. for their partnership in working towards many of the latest generation concepts, developments, testing and installations described herein.

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