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Challenges Associated with Electrical and Optical Cable Terminations and Connector Systems for the Drilling Industry

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Abstract

The challenges associated with the design, manufacturing and testing of underwater electrical and optical cable termination and connector systems for the Drilling Industry are vast and far-reaching. No longer are connectors only being supplied, but also complete systems, such as fully terminated umbilicals. For connectors that need to be installed in the field, sometimes in extremely arduous conditions, designs need to overcome the effects of pressure and temperature at ultra-deep sea-depths and to be strong enough to withstand the rough handling topside and rough environmental stress of being within close proximity to drilling systems activity. To meet the challenges and enable continuous improvements, connector companies cannot focus solely on connectors, they must see the future of cable terminations and connectors and their synergetic relationship to the umbilicals and cables.

Introduction

The Drilling Industry uses Umbilical Systems to provide electrical power subsea and facilitate bi-directional high-speed communications to interface between Topside equipment and their underwater or seabed equipment. At the subsea end of these umbilicals are terminations and connections that interface into the subsea equipment. The reliability required is very high as these umbilical systems become the eyes and ears as to what is happening at the deployed depths.

Availability

The challenges that are needed to be overcome are for one purpose only, and that is to produce reliable products with a high degree of "Availability" or "Uptime". The word "Availability" actually has a specific meaning in the world of Reliability; it means the ability to be Available for use when needed. Availability can be calculated by two reliability parameters: MTBF; Mean Time Between Failures and MTTR; Mean Time To Repair.

$$A = \frac{MTBF}{MTBF + MTTR}$$

Example	MTBF	MTTR	Availability	Translation
1	½ Year = 4,380 Hours	2 Days = 48 Hours	98.92%	Connector System will be Available for 361 Days over the course of a Year. 96 Hours Downtime.
Decrease Repair Time				
2	½ Year = 4,380 Hours	½ Day = 12 Hours	99.73%	Connector System will be Available for 364 Days over the course of a Year. 24 Hours Downtime.
Increase Product Reliability				
3	5 Year = 43,800 Hours	2 Days = 48 Hours	99.89%	Connector System will be Available for 364.6 Days over the course of a Year. 9.6 Hours Downtime.
Decrease Repair Time				
4	5 Year = 43,800 Hours	½ Day = 12 Hours	99.97%	Connector System will be Available for 364.9 Days over the course of a Year. 2.4 Hours Downtime.

Table 1 – MTBF versus MTTR and Availability

Therefore there are two mechanisms to increase Availability:

- Increase Product Reliability to increase MTBF
- Shorten Repair Time to decrease MTTR

The two mechanisms will be discussed in this paper.

Connectors

There are two main types of electrical and optical cable termination and connector systems for the drilling industry; the Integrated Connector and Cable Termination and; the Separated Connector and Cable Termination. Selection of either is usually a combination of customer choice and specification combined with availability of deck space. Both of these connector systems are field installable and testable.

Integrated Connectors and Cable Terminations

This type of connector has the armored cable terminated direct into the rear of the connector via a positively-pressurized cable termination chamber. The rear chamber is maintained at a pressure higher than that of the outside ambient seawater pressure by a spring loaded piston and ensures that there is no sea water ingress into the cable termination. The connector termination area is similarly positively-pressurized and ensures the connector termination area is also maintained at a pressure higher than that of the outside ambient seawater pressure, ensuring there is no seawater-ingress into the back-end of the connector itself.

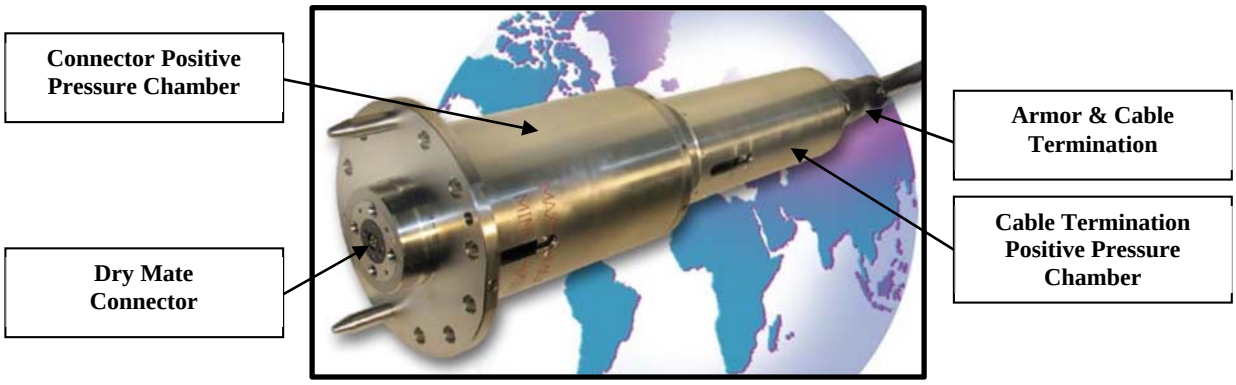

Figure 1 – Integrated Connector and Cable Termination System

Separated Connectors and Cable Terminations

The separated systems utilize a separate Armor Termination Assembly (ATA) that terminates the armor at a distance from the connector, providing armor strength and security at that separate location. The cable that comes out of the ATA is an un-armored cable which has a greater range of flexibility and ability to handle the cable easier, but is more prone to damage without the armor. The connector termination area is similarly positively-pressurized and ensures that the connector termination area is maintained at a pressure higher than that of the outside ambient seawater pressure, ensuring that there is no seawater-ingress into the back-end of the connector itself.

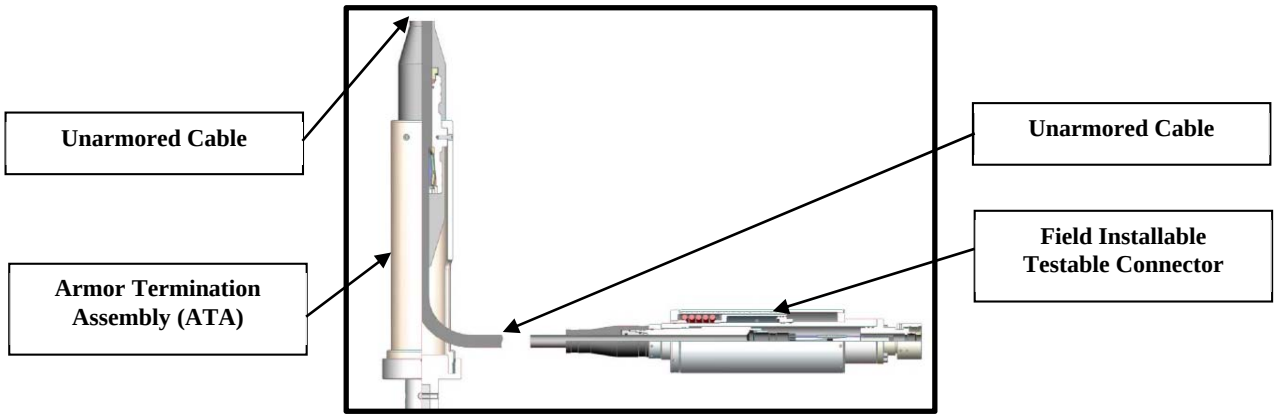

Figure 2 – Separated Cable Termination System

Challenges

There are four main challenges associated with the electrical and optical cable termination and connector systems for the Drilling Industry:

- Water Depth / Pressure
- Robustness / Durability
- Working in Challenging Environments
- Urgent Logistical Coordination

Water Depth / Pressure

Making a robust underwater connector that can withstand the crushing effects of deep-water drilling locations can prove difficult. There are several deepwater connectors being used today all over the world. Various optical, electrical/optical and electrical connectors are qualified to various ratings as high as 15,000 feet (455bar, 6,600psi) water depth and qualification tested up to 19,100 feet (579Bar, 8,400psi) water depth.

Robustness / Durability

When designing a connector and cable termination, for a combination of topside and subsea operations, various factors must be taken into account including ensuring the connector, termination and cable systems can handle the in-service treatment. It is a harsh environment topside and subsea especially during rig operations to get equipment ready, installed, deployed and operational.

Topside it is common to see the following:

1. Unmating connectors using the cables instead of gripping from the connector body
2. Connectors being dragged behind them from their hoses or cables on the deck floor
3. Connectors being dropped
4. Lack of maintenanance, or not being maintained correctly
5. Forklifts seem to have a right to run over the cables!

During Deployment or Subsea it is less common but does occur:

1. Umbilicals caught in vessel propeller
2. Cables get kinked by rope that is caught in riser pipe
3. Connectors/cables hit by ROV
4. Cables snagged

In all cases a common solution is to make the connectors and cables:

1. More durable by understanding the core group of users
2. Common operational and maintenance themes
3. Stringent cable deployment procedures to ensure cable whereabouts and tension on cable
4. Standardization of parts

Working in Challenging Environments

Several Factors must be considered when installing in the field:

1. Limited space availability and work area
2. A highly robust connector is required
3. Non-familiarity with rig-personnel for assistance
4. Local environmental conditions (equatorial, arctic, humidity, rainfall etc)
5. Cleanliness of local worksite (especially crucial when working with fiber optics)
6. Need for a temporary shelter to keep dust and contaminants free during delicate fiber work

When installing an umbilical in the field:

1. Care must be taken not to exceed maximum termination strain of termination interface
2. Training rig personnel on the importance of cable maintenance (in addition to connector mainentance training)
3. The Minimum Bend Radius of the umbilical must not be violated

Urgent Logistical Coordination

A large part of the challenge of any successful Field Service and Repair Department is getting correctly trained staff mobilized as soon as possible with their correct tool-kits, repair kits, test equipment, etc. This requires all personnel to be ready on a standby rotation. Technicians must have Rig Safety Training, Immunizations, proper travel documents, and Global Entry Requirements all sorted well in advance of needing them. A successful operation requires a highly trained staff of Logistical Coordinators, On-Call 24 Hours a Day, 7 Days a Week, 52 Weeks a Year.

Electrical and Optical Cable and Connector Termination System Details

There are many specific challenges to the assembly and testing of the Cable and Connector Termination Systems while being performed in the field. These are discussed in this section.

Field Service and Support Technicians

The process for the technician, once on board, assuming all pre-requisites are met is very detailed and at times, lengthy.

Prior to any work beginning the technician must know some basic facts:

- If possible, he will need to verify the cable to ensure it tests out electrically, and optically
- Will need to ensure the size of the cable is within specification for the connector being used, as all connectors are designed to fit specific cables
- Will need to perform a diagnosis on the connector to ensure that the assumed problem is the actual problem, unless something obvious is the culprit like cable damage

During the connector termination build, the technician will:

- Test the cable/connector three separate times during each major phase of build to ensure that no signal has been lost
- Photograph every step of his work so that there is a visible history of his work to accompany the field report

When the connector is built and final testing has been successfully completed, the technician reviews the rig's inventory to ensure they have the required spares on hand. All notes, actions and details are recorded in the field report which is provided to rig personnel along with the Factory Acceptance Test (FAT) Results.

Armor Termination

The Armor is the load-bearing portion of the cable. It is terminated in an armor termination device either; within the connector, or at the Armor Termination Assembly (ATA). The connector terminations are modular and designed to fit many different cable types. Therefore the design has been made to properly capture the armor within the connector body to take a design force that the main customers find acceptable.

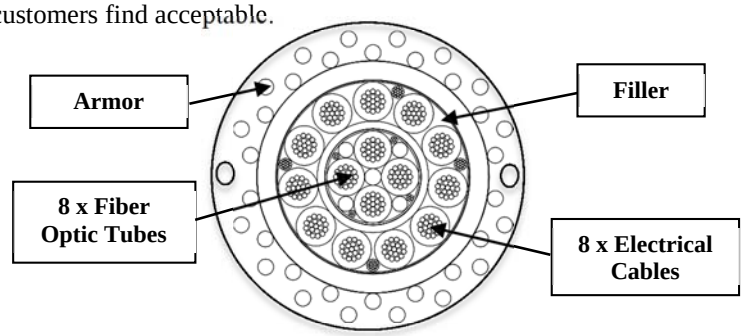

Figure 3 – Umbilical Cross Sectional Area

The design and construction must also take into account side-loads, especially when man-handling of the cable/connector assembly by individuals pulling the cable and not the connector body. Pulling by the cable can create enormous strains at the termination interface point especially when being pulled by 90 degrees off-axis.

Electrical Cable

The electrical cables within the umbilicals are manufactured by a small range of Cable and Umbilical Manufacturers around the world. Connector suppliers have to work closely with the selected Cable Supplier to ensure that the cable is produced exactly the same way repeatedly. If any part of the cable is out of specification; larger diameter, smaller diameter, softer insulator, then it can, at best, violate the original qualification testing performed on the system and, at worst, result in immediate medium or longer-term system failures. If the cables are undersized, any sealing technology may be compromised to leak. If the cables are oversized then any sealing technology may be at risk of premature damage. Measurement and Testing can of course identify these at that time, but it is too late for any immediate fix. Softer insulation material or material with too many voids can also be problematical by crushing slightly at the type of depths the customers are now drilling at. This can result in reduced diameters and may compromise the sealing systems. Each cable also needs to be fully qualified for the connector and to this end it must be qualified against an actual sample of the real cable and not a datasheet. Qualification must include as a minimum pressure testing to full Ocean Depth. Electrical Cables are typically #14AWG to #20AWG for Signal, #8AWG to #14AWG for Power. Most cables use a thermoplastic polymer called polyethylene as their primary insulation material. This is a superior electrical insulation material for these applications and has excellent long-term use underwater. Speed is one of the requirements for field installations. This dictates a requirement for the use of no bonding materials (unique tooling, curing times, heat etc.). This has ruled out any thermoplastic bonding processes for the primary and secondary sealing, hence other sealing processes are used for these electrical cables.

Optical Cable

The optical cables within the umbilicals are supplied by the same small range of Cable and Umbilical Manufacturers around the world, many of whom manufacture the optical cables themselves. Connector suppliers have to work closely with the selected Cable Supplier to ensure that the optical cable is produced exactly the same repeatedly. Similarly to the electrical cables it is prudent to understand about accurately measuring the cables and ensuring within specification. Each optical cable also needs to be fully qualified for the connector and so it also must be qualified against an actual sample of the real cable and not a datasheet. There are many areas to consider when designing around optical fiber:

- K-Tube or Armor
- Diameter
- Number of optical fibers
- Flexibility
- Tensile strength
- Ease of cutting without damaging fiber
- Protection around fiber
- Fiber buffer diameter

Optical Fiber

The use of fiber optic communication systems allows high-speed communication between topside and subsea. The optical fibers are supplied within the terminated optical cable. Optical fibers used in the drilling industry are typically Multi-Mode (MM) or Single-Mode (SM). The differences are physical and are a requirement of the customer when they order the umbilicals. Optical fibers are fragile and need to be handled with care when assembling the connector, especially in an emergency situation on a rig. They must be terminated with optical ferrules and these must be polished and kept clean to get the required level of repeatable optical performance. Optical fibers and interfaces can also be pressure-dependent and therefore need to be qualified with the connector at full test pressure and the field installation process must also be qualified. Highly skilled staff are required that have the knowledge not only how to terminate, polish and handle, but also about the surrounding work conditions, which are required to be as clean as possible. While on board the rigs these Fiber Optic Technicians can be utilized to provide additional training to rig personnel on the handling of optical fiber.

Positive Pressure

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 environments of deepwater drilling systems, lead to a development away from the incorporation of one-atmosphere technology and subsequent pressure-differentials, in favor of not only pressure-compensated systems but the use of positive-pressure compensated systems. 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. 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. During field installation the springs are set to pressurize the connector to its rating. The integrity of the connector is verified during the assembly and build and the integrity of this positive pressure is expected to be maintained and act against all internal sealing systems. The spring sets it above the external ambient seawater pressure. The positive internal pressure system has many advantages:

- Continually verifies the seals are working (in the correct direction) topside before deployment
- Visual indicator shows a minimum and maximum piston position, which correlates directly to the amount of fluid in the pistons set position and hence the amount of internal pressure. i.e Users, ROV Operators etc. can verify positive pressure integrity immediately by visial means, with no additional special tools
- Positive pressure is considered to provide an “extra barrier" preventing the sea-water from entering the connector and cable termination system via the connector or the cable
- The connector can be set up topside for use in training rig personnel

Boot sealing

Boot sealing technology is a very well known and well tested technology. It uses elastomeric rubber sleeves called boots that are carefully designed to suit the cable that they are sized for. They are installed on a cable and the stretch of the rubber boot is carefully calculated to provide an optimum stretch and seal onto that cable. They seal better under increased pressure. They are sized to suit the minimum and maximum diameter tolerance size of the cable with a calculated stretch that covers that diameter size but retains within an optimum proprietary stretch size. This must include all operating and environmental conditions, which is why extensive qualification testing is required.

If the cable diameters are incorrect, then this can result in boot seals that are:

- Too loose (cable undersized) in which case the necessary stretch has not been achieved to optimize the seal
- Too tight (cable oversized) in which case the boots are being over-stretched and may be subject to premature failure

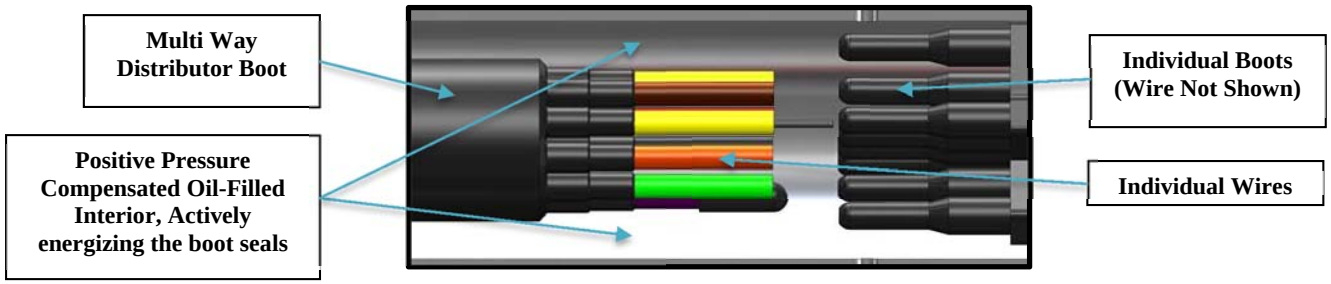

Figure 4 – Boot Seals

Also the surface finish of the cables or wires that the boots are sealing to is critical, it must be smooth and free from any damage so boot seals can seal securely and effectively for the lifetime of the product. The big advantage of boot seals is that they negate the use of compounds such as epoxies, polyurethane or polyethylene, where molding and long curing times subject to temperature-controlled conditions may be required.

Significance of Defective or Damaged Parts

Manufacturing defects or damaged parts are something every company and customer has to deal with. For the drilling industry these need to be identified as early as possible so that the technicians do not discover defective or damaged parts during an emergency situation. Highly trained staff in quality and inspection is crucial, as is ensuring the field technicians have the same knowledge to recognize defective or damaged parts in the field. The “home team” parts department and project coordinator ensures that any sub-par parts are immediately replaced should the need arise. Cables that have a severely damaged surface should be removed in sections until a damage-free area is found for optimum installation. Conductors should be within tolerance. Armor should be wound correctly using correct material, fiber optical cables should be within tolerance and contain the correct fiber.

Testing

Before a connector can be used for a particular application, stringent testing requirements must be met. These requirements increase almost every year as more rigs are drilling in deeper water in significantly different environments around the world. In the field there are no pressure vessels capable of verifying pressure integrity to 15,000 feet after installation of the connector and termination system onto 10,000 feet of cable, therefore other techniques are required during the connector assembly process and by secondary methods:

- Helium or Nitrogen Leak Testing (the connector is filled full of gas and monitored over time)
- Electrical tests
- Optical tests
- Conductive fluid tests (simulates seawater filled testing)
- Positive pressure integrity
- Pressure test ports for mating O-rings

Americal Petroleum Institute (API)

There are several variations of connectors that comply with API Specifications 16D (Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment) and 17E (Specification for Subsea Umbilicals).

Product Standardization

Product standardization is a key element for Customers and has proven to be a huge advantage for inventory control, spares, and reserve level flexibility leading to a larger economy of scale, and associated cost benefits. Lower costs can be passed onto customers on the back of higher volumes of products being manufactured. But critically, stocking more standardized parts on rigs is the key element in successfully overcoming emergency situations.

Modularity

Connectors are designed around the cables they will be installed onto, so only the internal sealing dimensions of various connectors will change for their specific cables. Keeping the external shells, pistons and other costly machined parts as Standard and Modular between Products ("one size fits all") allows for greater reserve parts storage for these long lead time items. Modularity goes hand in hand with product standardization. The advantage of modular connector models is that all parts are standard between all connector versions and customers, with the exception of the internal sealing components. Reducing the number of different components needed for multiple connectors provides the manufacturer a greater stock level to meet higher consumer demand. Modularity of connector parts allows for quicker supply during rig down emergencies, as well as improved lead times on normal orders.

Inventory

With product standardization and the modularity of designs we get the benefit of economy of scale, therefore more stock can be stored than in previous years. This means rigs get what they want faster. Keeping critical inventory set to auto-order when it drops below a certain level also ensures ample stock is on hand for any eventuality, or the ebb and flow of cyclical ordering. Ensuring good stock levels is also critical to keeping the rigs well stocked so that in a downtime situation, they have everything they need so that technicians can rebuild their connector.

Global Field Service, Repair and Support

The Field Service Division of any company must be strong and quick, with the ability to adapt to multiple high stress situations at any one time, working with the common goal of getting the technicians out of the door and to the rig. Several specialty people are required; from those that get the call in the middle of the night, to the logistics and travel coordinator, to the parts person, to the toolkit person and everyone else helping to get him mobilized and gone.

Rapid mobilization

Rapid mobilization from a responsive team and high availability of parts are critical when a rig is losing USD $500,000 a day because their Umbilical was severed. It is imperative that a pool of skilled technicians are available to have a team deployed within hours of receiving the call, with parts in hand (if possible) and ready to fly. Every delay contributes to further delays to the rig getting fully operational. It's also important to have enough technicians to handle the busy times, and keep the shop running at home.

Parts

Sometimes it is not possible to hand-carry parts to certain countries due to newly imposed flight restrictions or importing restrictions. Therefore it is crucially important that rigs carry the correct spares required for rebuild work, and that they are stored securely in their original and sealed state. While on site, technicians regularly perform a review of stock, confirming what is needed, and if any chemicals are out of date from previously purchased rebuild kits. The list is reviewed with senior rig personnel, and also provided to the home team after completion of the job so that those items can be quoted.

Training

The technicians that are sent out in the field are highly skilled fiber optic and electrical connector product specialists, who also provide training on a regular basis. Customers are encouraged to know how to handle and maintain their equipment, to understand how it works and how to troubleshoot it when it doesn't. Training can be provided to as many rig personnel as possible, at any location (rig, warehouse, host facility). Training focusses on handling and mating/de-mating procedures, proper care and maintenance of connectors, fiber optic handling, proper electrical testing of each pin etc.

Customer Liaison

It is very important to form good working relationships with the personnel in the field. A customer liaison on the other side of the line with an understanding tone and friendly voice can calm nerves and ease the stress of a situation. This is an important role that should not be overlooked. It's not just about the sale, or the service after the sale – it's about building a bond with the people who use your products, and understanding how to serve them better for years to come. This is important for many reasons:

- Getting urgent instructions to mobilize at any time of the night or day, anytime of the week
- Making technician travel arrangements to get to rig, local transfers, security
- Ensuring all travel Visa, Passports, Documents are in hand

- Providing copies of all medical and training certificates to Customer
- Ensuring the rig has the correct parts, they are in order or new parts are urgently required
- How to get the parts to the destination (freight forwarder, hand-carry, courier, Hot-Shot etc.)
- Local requirements on rig like Helium or Nitrogen
- Power requirements on rig
- Work area for Technician
- Local Weather, local knowledge, safety and travel warnings

Conclusion

The challenges associated with the design, manufacture and testing of underwater electrical and optical cable termination and connector systems for the Drilling Industry are vast and far-reaching. Having dedicated vendors, devoted staff and life-long customers helps ease these challenges of growth and allows for speed-of-light service and stocking of parts. Collaboration of the highest degree is needed from the critical urgent vendors, through inspection to shipping, to the field service technician who installs the connector, at short notice, anywhere in the world. By understanding the needs of the customers one can be assured of staying ahead of the program. With a renewed push for deeper drilling, an ultra-deepwater connector is on the horizon. Current optic and electric cable terminations and connectors can reach depths of over 12,000' (3,658m) and are being pushed continually deeper every day around the globe. Our records show that these connectors have been used on the sea-floor for over year-long drilling programs with absolutely no maintenance, at depths over 10,400'. Providing world class connectors to the drilling industry has been realized by a single-mindedness built on continual improvement, focusing not only on the cable terminations and connectors, but the entire system and its synergetic relationship to the umbilicals and cables. From its humble beginnings several years ago, to the complex positive-pressurized units being supplied today, reliable underwater cable terminations and connectors keep the drilling community communicating.

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Nomenclature

API	American Petroleum Institute
ATA	Armor Termination Unit
AWG	American Wire Gage
Bar	Non SI Unit of Pressure
FAT	Factory Acceptance Test
K-Tube	Miniature Stainless Steel Tube
MM	Multi Mode
MTBF	Mean Time Between Failure
MTTR	Mean Time To Failure
psi	Unit of Pressure, Pounds per Square Inch
ROV	Remotely Operated Vehicle
SI	International System of Units
SM	Single Mode

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