The Development of a Cable Termination System for Deepwater Applications

By John Theobald, Ocean Design, Inc.

Introduction

As oil and gas production projects move into deeper waters, new key enabling technologies are required to terminate electrical, optical and hybrid subsea cables. Two failure modes have been identified using current commercially available termination technology in deepwater applications; core element collapse into an atmospheric breakout region and wicking of the compensating fluid from the termination into the interstices of the cable elements. Either failure may lead to partial or catastrophic failure of the termination. Each failure mode can be directly linked to the interaction of the cable elements with the pressure-balanced dielectric fluid-filled splice region in the termination.

Both of these failure modes have been encountered in the recent past during the installation phase of ultra-deepwater developments. In each instance, an understanding of the failure mode led to the development of design modifications that were qualified and successfully deployed. The difficult lessons learned from these experiences have resulted in new design considerations and more rigorous qualification procedures during the development of cable specific Field Installable Termination Assemblies (FITAs). These lessons have also been cause to rethink the design philosophy of cable terminations. Ocean Design, Inc. (ODI) has embarked on a design program to eliminate the limitations of the current technology and increase the reliability of their terminations. The result of this effort is the FACT (Field Assembled Cable Termination) system, a modularized termination system that completely isolates the cable's internal elements from all pressurized fluid interfaces.

Conductor Core Collapse

Push-back is caused when a pressure gradient exists between termination modules through which a cable element is passed. The resulting load on the element drives the cable element from the high-pressure module into the low-pressure module if the load exceeds the column strength of the element. This failure mode is typically associated with the conductor elements within the cable as they pass from the atmospheric potted module to the pressure-balanced dielectric fluid-filled splice chamber.

Bird-caging occurs when the individual strands of a helically wound conductor buckle as a result of loads placed on the major element, as in the push-back case. As the individual sub-elements buckle, they radially flare outward from the major element axis, allowing the major element to collapse onto itself. Experiments have shown it possible for the individual strands to pierce the conductor insulation, possibly leading to termination failure. This failure mode will most likely occur in atmospheric regions where loaded conductors have a slip fit with machined components.

In either case, it is difficult to predict the behavior of the composite elements or the individual sub-elements under high differential pressures. In the case of the insulated conductors, column strength of the core elements and sub-elements are functions of many variables including, but not limited to, composite copper diameter, number of copper strands, copper strand diameter, insulation thickness, insulation material, and geometry.

Wicking

Wicking occurs when the dielectric compensating fluid vents from the termination into the interstice filled cable elements. This will happen when one or more sealing elements or cable elements in contact with the pressurized compensating dielectric fluid are compromised. The fluid will migrate from the high-pressure compensated splice chamber into the low-pressure interstices within the cable elements. This loss of fluid in itself may not lead to termination failure, but it can, under the right circumstance, initiate events that can cause partial or catastrophic failure of the termination. All commercially available termination technologies that have internal umbilical elements in contact with the pressure compensating medium contain this "Achilles Heel" by the very nature of their design. Breakout boot seals, boot seals that interface the conductors to connectors and cable splices or the conductors themselves within the pressurized dielectric compensating fluid, all have the potential to void the termination if compromised.

FACT (Field Assembled Cable Termination)

As a result of field and lab experiences, ODI has gained an in-depth understanding of the interactions of the cable elements with the design elements of traditional terminations. The solutions developed to extend the operational depth of the current termination designs themselves do not eliminate the failure modes associated with the interaction of the cable elements with the pressure-balanced splice chamber. It becomes apparent, after examining the failure modes, that the complete isolation of the internal cable elements from the pressurized splice chamber and ambient environment is necessary.

Based on these conclusions, ODI has developed the FACT (Field Assembled Cable Termination) system; a highly reliable, modular, field assembled cable termination. The premise behind the concept is to use field-proven technologies to completely isolate the cable internals from the ambient subsea environment and, most importantly, the pressure-balanced fluid-filled splice chamber, regardless of cable construction.

The FACT assembly consists of a high-pressure penetrator assembly (see figure 1) that completely isolates the

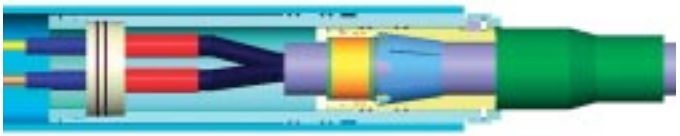

Fig. 1. *Field Assembled Cable Termination (FACT) Penetrator with high-pressure "Web" that isolates the cable from the pressure- balanced splice chamber*

electrical, optical and hybrid cable internals from the subsea environment and pressure-balanced splice chamber. The penetrator assembly consists of an outer elastomeric boot seal as the primary barrier to water ingress. This is followed by either a compression type cable grip or epoxy armor termination for mechanical strength. Depending upon the cable construction, either the outer cable jacket sheath or redundant inner cable jacket sheath is passed through a self- activating bi-directional elastomeric gland seal to further isolate the cable from the subsea environment. This field-proven gland seal/boot seal combination is very robust and reliable in high and low-pressure applications. The individual conductors and optical fibers are broken out and interfaced to a "Web" assembly (high pressure header) using dual redundant solder pot boot seals and/or an optical fiber seal. All interstices within the penetrator assembly are high pressure filled with a rigid non-compressible epoxy compound to reinforce the cable, prevent the cable from pistoning inward and prevent the compressive loading of the conductors and fiber tube.

The "Web" assembly isolates the internal cable elements from the pressure-balanced, dielectric fluid-filled splice chamber using field-proven Nautilus and Fiber Seal technologies. The "Web" assembly has been rigorously qualified at differential pressures greater than 10,000 psi. This and other key enabling design elements have led ODI to file for patent coverage for the FACT system.

The FACT system is ideally suited for a multitude of optical, electric and hybrid umbilical termination applications including production and infield power and signal distribution, drilling controls, remote location controls and sensing. The FACT penetrator assemblies have been designed with modularity in mind and may be used with ancillary accessories to adapt to a wide array of interfaces. The FACT penetrator assemblies may be terminated directly to atmospheric enclosures or pressure-balanced dielectric fluid-filled splice canisters.

Currently, the FACT system is available as either a single entry/exit unit or a multi-entry/exit unit (see figure 2). The multi-entry/exit unit can accommodate any combination of up to six electrical, optical or hybrid FACT penetrators and/or jumper assemblies with wet-mate or dry-mate electrical, optical or hybrid connectors. Additionally, the FACT penetrator assemblies can accommodate a wide range of electrical, optical and hybrid cables, with or without gel fill.

Product Design and Qualification Status

The FACT system is scheduled to complete its full qualification program at the end of October 2003. At the time of submission of this article, ODI has completed prototype design, manufacture and initial qualification testing of many of the FACT system components with great success. As the system is based on field-proven technologies, ODI feels there is little technical risk associated with the product qualification. The assembly is being rigorously qualified in three distinct phases to verify each design element and the system as a whole:

"Web" Qualification:
- Hyperbaric pressure and cycling
- Hyperbaric test to destruction
- High voltage

FACT Penetrator Qualification:
- Hyperbaric pressure and cycling
- Thermal testing

FACT System Qualification:
- Hyperbaric pressure and cycling
- Thermal testing
- Shock and vibration

John Theobald is a Lead Project Engineer for Ocean Design, Inc. John has been with the company for five years and specializes in the design of subsea electro-optic umbilical terminations and distribution equipment.

***Fig. 2**. Multi-entry/exit FACT system*