Essential Design And Risk Management For A Next Generation Ocean Dry Mate Connector

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***Abstract*— Dry mate connectors perform essential power and communications interconnect functions. An equally critical function for subsea connectors is to protect the cable and sensitive electronics from flooding, thereby minimizing risk for large, capital intensive projects. This paper will address the technology needed to reduce risk, leap forward in design, and incorporate the very latest design attributes, while demonstrating compliance to evolving industry standards, such as ISO and API.**

This paper will broadly review the industry's current dry mate connector options, with a focus on reliability and functionality. A Failure Mode and Criticality Analysis (FMECA) will be presented, which will be used to examine typical dry mate connector failure modes. An analysis of these failure modes will be presented, with a focus on the attributes that can be improved on, from the current design state. The paper will then introduce a next generation dry mate connector, which addresses the current design issues, promising to take the next leap in high reliability, interconnect technology for ocean dry mate connectors. Starting with a fresh, ground up look at the requirements from industry, this paper will begin with a blank slate design, and then develop the desired interconnect attributes after a close look at both mil-spec as well as commercial requirements, and the products that are currently on the market. Designed to be a dry mate connector that is ISO/API compliant, the AMETEK SCP dry mate connector is designed to be fully modular. This modularity allows the incorporation of interchangeable electrical or optical circuits, with exceptionally high performance. This modular design then takes a step further, and makes possible the use of a standard approach for either hard cable termination designs, as well as pressure balanced oil filled designs.

This new product leaps forward from current industry offerings, and makes a number of improvements and enhancements that reset the bar. Modularity for electrical and optical contacts is one improvement, as is the incorporation of an option for a higher performing fiber optic connection, which incorporates angled polished contacts. These higher performing contacts afford greatly enhanced optical performance, specifically with improved back reflection. This enhancement will help satisfy an increasing industry demand for distributed sensing systems. These types of systems are coming online now as a part of Intelligent Well System designs, and other emerging, distributed acoustic and temperature monitoring systems.

Poised to enter both Defense and Oil Gas markets, and improve the status quo, this new product offering takes stock of where the industry is, considers risk elements, and provides a fully up to date design, with options that actually fit industry needs, while reducing risk. This paper will review existing technology, and then introduce this new product, while pointing out improvements over existing designs, explaining the incorporated design attributes, clearly a leap forward in technology.

I. Introduction

There are fundamentally two different types of connectors available in the underwater arena for physical connections. These are basically Wet Mateable connectors, and Dry Mateable connectors (normally called Wet mate connectors, or WMC's, and Dry mate connectors, or DMC's). Wet mateable connectors are of a type that can be connected while underwater. Dry mateable, or Dry Mate connectors, on the other hand, are connected (mated) above the waterline, and then the connector and cable assembly, and it's related equipment, are taken into the ocean environment. This paper presents the design approach for an innovative Dry mate connector, focusing on Technology Gap Assessment, Requirements Analysis and Flowdown, and Risk Management. Much like a new product is developed for a specific industry application, the development of a new line of dry mate connectors would logically proceed from a thorough analysis of industry requirements.

Accordingly, a thorough review of Industry Specifications that drive the design of Dry Mate connections was undertaken, to ensure that a product is developed that is consistent with these specifications. This innovative new connector also introduces a number of attributes that allow this design to leap forward in technology. The key references are noted below in Section III.

II. Brief History of Dry Mate Connectors

A. Brief History

Underwater cables and connections have been in existence since the first successful transatlantic cable laying, which occurred in 1858. Underwater connectors appeared in the 1950's, driven by the post war submarine technology needs, as well as the needs of an emerging offshore oil industry. Simple dry mate designs were first devised, these were designed to be mated above water, and then taken subsea. These initial designs were of two general types: rubber molded interference fit types, and rigid shell designs with mating parts that sealed with o-rings. Both of these designs are still in general use today.

System designers of ocean equipment have a fair degree of flexibility in the choice of hardware today, with many manufacturers of both wet and dry mateable connectors available. While the number of wet mateable connectors is somewhat limited, the number of dry mate connectors is greater, with several manufacturers providing dry mate connectors, based generally on these historic designs.

B. Today's Technology

The dry mate connectors offered today are much the same in configuration as the first connectors offered in the post war arena. Since that time, much has been learned about dry mate applications. Although the original designs tended to be attached to system cables with an overmolding process, more recent designs have been adapted to pressure balanced, oil filled systems (PBOF). In fact, one of the more widely used specifications for connectors and cabling systems for the Oil Gas arena (Statoil TR2390) requires the use of PBOF cabling. One might logically ask why the Energy community would specify pressure balanced oil filled hoses instead of hard cable for its subsea connectivity hardware. The rationale for this is that the Oil-gas community believes that overmolded designs are not capable of a 25 year lifetime, as the overmolding process is understood to have a life of not much greater than about 10-12 years. Pressure Balanced Oil Filled (PBOF) cabling systems on the other hand, can be fitted with reliable, purpose built terminations, and are being currently sourced for production control systems which require a 25 year design lifetime.

III. Technology Gap Assessment, Requirements Analysis, and FMECA

A. Technology Gap Assessment

Conducting a formal Technology Gap Assessment before beginning a product development effort is a proven way to ensure that you are indeed embarking on a project that will satisfy an existing market requirement. In the ocean equipment business, like any other business, in order to remain viable, the manufacturer must deliver what the customer asks for, i.e. that which has a market. A "really clever device" will remain just a "really clever device", unless it has a market to sell into. Conducting a Technology Gap Assessment ensures that the new product being considered can "map" to an existing market, and will contribute to the revenue stream of the company.

The standard process for conducting a Technology Gap Assessment includes these general steps:

1. Study the market and determine what is being asked for, and where the product can add real value
2. Identify all areas of technology that are available
3. Identify the gaps between where we are today, and where we would want to be. A commercial ROI (risk, return) analysis would be a part of this step.
4. Encourage / Develop products that close the technology gap, and introduce the desired product.

A Technology Gap Assessment was conducted, with one of the key products resulting from this assessment a dry mate connector that would be compliant with industry specifications and current design needs. Accordingly, a dry mate connector was evaluated for commercial Risk and Return, with the results being favorable at this time, to introduce such a product.

B. Requirements Analysis

As mentioned earlier, the design effort that supports a new product should come from both a Technology Gap Assessment and a Requirements Analysis. Currently available dry mate connectors were found to fall short of full compliance to application specifications. Ametek SCP has developed a dry mate connector that is compliant with these industry standards, and includes a number of enhancements that will be welcome to users of dry mate connectors.

From a requirements point of view, a new dry mate product would logically be designed to accommodate all available existing specifications, if at all possible.

The relevant Industry specifications that were examined included the following:

1. Mil-C-24231 Military Specification: Connectors, Plugs, Receptacles, Adapters, Hull Inserts, and Hull Insert Plugs, Pressure Proof, General Specification For
2. API 16A Specification For Drill Through Equipment
API 16D Specification for Control Systems For Drilling Well Control Equipment and Control Systems for Diverter Equipment
API 17E Specifications for Subsea Umbilicals
3. ISO 13628-6 Petroleum and natural gas industries, Design and operation of subsea production systems, Part 6: Subsea production control systems
4. STATOIL TR2390 Electrical/Optical Connectors and Jumpers for Subsea Control Systems

These specifications were examined, with the relevant sections relating to a Dry Mate connector of commercial usage applied to the design.

C. Failure Mode Effects and Criticality Analysis (FMECA)

An additional activity that is extremely valuable in terms of reliability is to conduct a Failure Mode Effect and Criticality Analysis (FMECA). A thorough FMECA is an essential part of Requirements Analysis. The analysis that was conducted follows the methodology as described in both MIL-STD-1629A and API 17N: Recommended Practice for Subsea

Production System Reliability and Technical Risk Management.

In its simplest form, the essence of a FMECA is to evaluate all possible failure modes, and consider both the Probability of their occurrence, as well as the Consequence (impact, or effect) of the failure mode, should it occur. The probabilities of failure range from Frequent to Extremely unlikely, and the Effects (Criticality) of the failure event range from Catastrophic to Minor.

In mechanical design, the essence of a FMECA is to examine all failure modes, and to mitigate both their likelihood as well as their impact, should they occur. In the parlance of the MIL-STD-1629A, Probability ranges are as follows:

A. Frequent
B. Reasonably probable
C. Occasional
D. Remote
E. Extremely Unlikely

and the Consequence (Criticality) of each failure event is reckoned in terms of:

I. Catastrophic
II. Critical
III. Marginal
IV. Minor

Note that in a new design, when specific parts configuration or failure data rate are not yet available, a qualitative approach is utilized. Failure modes identified in the FMECA are assessed in terms of grouped categories. Thus, the FMECA Analysis of failure modes for both Plug and Receptacle included the following: Main shell assembly, Coupling ring (plug), Contacts, electrical, and Contacts, optical.

The value of a FMECA during the design phase, is that if this can be done effectively, failure modes can be identified and then mitigated with thoughtful design. Therefore, a more reliable product can be developed and offered to market. All possible failure modes for key components were identified, and then examined for probability of occurrence as well as impact. An example of the value of this analysis is a design choice made, which incorporates 2 seals to each point of seawater entry.

Although many connector manufacturers might claim that in some cases, one seal might be “good enough”, it is also true that o-rings can be damaged during assembly, or fall out of position, or extrude at high pressures. For these reasons, a second seal serves as a backup, and can mitigate the effects of issues with the one seal.

Per MIL-STD-1629A, the goal of the analysis is to develop a Criticality Matrix, a simple example of which is drawn from the MIL-STD-1629A (from Figure 102.2). Figure 1 is a simplified example of a criticality matrix, which represents all of the analysis data points. Each analysis point represents the intersection of a particular Probability and Severity (Consequence), of one failure condition. As can be seen, a failure mode that is both extremely unlikely and whose impact is minor (green on the chart), would be preferred to a failure mode that would be reasonably probable, and catastrophic if it should occur (red on the chart).

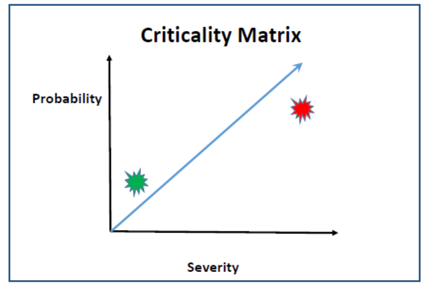

Figure 1

The result of the FMECA Analysis on this new dry mate connector allowed the designer to anticipate trouble areas, and also focus on all of the past failure modes that have been seen.

IV. NEXT GENERATION OCEAN DRY MATE CONNECTOR

The result of the aforementioned analysis has been the development and introduction of a new Dry Mate connector, which complies with the relevant standards, and which also has innovative, up to date features that reset the design bar for underwater dry mate connectors. Ametek SCP has introduced its Elite Series Dry Mate Connector, which includes the following attributes:

- Design Life 25 Years
- ISO/API Compliant Design
- 316SS Standard, Ti Gr 2, 5 Available
- Dual O-ring Seals at All Points of Seawater Entry
- O-rings Captured for Retention
- Fully Modular Design
- 19 Positions for Electrical or Optic Contacts
- Industry Standard Mounting Interface
- APC Contacts Available for Fiber Optic Version Permits Very Low Back Reflection
- Cable Termination or PBOF Designs Available
- Glass Sealed Electrical Version Available
- Open Face Pressure Rated (as well as reverse)

The Elite Series Dry Mate Connector was designed to accommodate all of these attributes, and to be a 25 year lifetime connector. Accordingly, the nominal termination design for this connector is a connection to a PBOF (pressure balanced, oil filled) hose or mechanical Field Installable and Testable Assembly (FITA) type termination. While the technology can certainly be offered in an overmolded backshell design, the user would of course need to be aware of the life considerations consistent with an overmolded design (for example polyurethane overmolding). Examples of the prototype Elite series connectors are shown in Figure 2 below.

Figure 2. Elite Dry Mate Connector

The modular design, and the ability to configure the connector quickly with either electrical or optic contacts is a highly desirable attribute. In addition, since the connector is designed from the outset to be compatible with today's Oil&gas PBOF cable systems, today's oil–gas system designers will have a Dry mate connector choice that fits their design needs immediately, with no modification to an older design needed.

Figure 3. Pressure Balanced Oil Filled (PBOF) Fitting

Another desirable attribute that will save precious repair dollars is the ability of the Elite series to be rebuilt. In an overmolded plug design, the backshell of the cable ended plug can in theory be recovered. However, anyone who has done the cost benefit analysis of this repair quickly realizes that the cost of the repair (carving away all of the old polyurethane material and recovering the shell) usually exceeds the cost of a new connector. With the Elite series, the connector can be easily disassembled and rebuilt, as the backshells are designed for industry standard MK2 PBOF hose fittings, as shown in Figure 3.

A quick review of the currently available dry mate connectors in the marketplace will show that a majority are fitted with single seal designs, and are not open faced pressure rated. Also, these are based on a historical design approach, and are generally suited for overmolded terminations. The Elite DMC is the first dry mate connector that has been designed from the ground up as a dual sealed high reliability dry mate connector, suitable for the Oil&Gas, Oceanographic and Defense industries, see Figure 4 below. Because of the modular design of this connector, the backshell design can accommodate any of the popular termination methodologies, including 1. MK2 termination for a pbof hose 2. Gland sealed to a hard cable 3. Overmolded to a hard cable. 4. FITA (Field Installable and Testable Assembly)

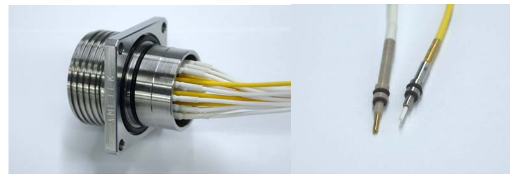

Figure 4. Dual Seals On Both Shell And Contacts

With regard to fiber optics, this new product again leaps forward and resets the bar for dry mate optical performance. With today's distributed sensing systems demanding very low back reflection, the Elite series is offered with both UPC Polished Contacts, as well as Angled Physical Contacts (APC) fiber optic contacts. These contacts offer substantially lower back reflection, and make this dry mate connector a winning product for distributed sensing system designers.

V. Conclusion

This paper has proceeded to outline a design approach for a next generation dry mate connector. The design process reviewed assesses current technology, takes note of current reference specifications, and offers a leap forward technology, with a product that minimizes current failure modes. This exciting new product is poised to enter both Milspec and Oil&Gas markets and improve the status quo. The Elite Series takes stock of where the industry is, considers risk elements, and provides a fully updated design, with options that actually fit industry needs, while reducing risk. This paper has taken stock of existing technology, and introduced a new product, while pointing out improvements over existing designs, explaining the incorporated design attributes, which are clearly a leap forward in dry mate connector technology.

Acknowledgment

The authors would like to express our thanks to the many unsung heroes of ocean connector design, who have provided the improvements in connector design over many years, generally one feature at a time, and in many cases, in response to customer feedback, an RCCA, or lesson learned. While relatively unnoticed, these improvements form the basis for the leap forward technology being presented. While taken individually, each of the improvements and reliability measures designed into the Elite series DMC are not particularly earth shaking in importance, however the aggregate impact of the features in this exciting new technology is significant, and incorporates many quiet years of development, experience and lessons learned. The authors salute these subsea engineers, who rarely are recognized for their accomplishments.

References

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