Using the Reliability Process to Develop Next Generation Fiber Optic Connector for Subsea Use

Richard T. Jones, Gregory Eskridge, Jeremy Lucas (Teledyne Oil & Gas)
Email: Richard.Jones@Teledyne.com

Teledyne Oil & Gas, 1026 N. Williamson Blvd., Daytona Beach, FL 32114

Abstract: Subsea communications networks historically have not utilized wet-mate fiber optic connectors in their architecture due to the impact to the overall reliability budget. Now with many years of performance data collected from thousands of deployed fiber optic connectors, (over 15 years' worth from Teledyne alone) excellent reliability is now established for these components and the comfort level for inclusion of fiber optic connectors is growing amongst subsea communications equipment suppliers. Though a crucial technology for cabled ocean observatories, offshore platform networks, seismic monitoring arrays, and subsea production controls, wet-mate fiber optic connectors have seen relatively minor upgrades since the first oceanographic applications of the early 1990's.

This paper will explore the reliability metrics associated with the current generation of wet-mate fiber optic connectors offered by Teledyne and how input from this historical reliability data has been utilized in the design of a next generation fiber optic connector. Specifically, improvements to ROV mating have been included as well as fundamental changes to actuation used in the connector.

Typical mechanical and optical performance of the next generation fiber optic connector are discussed. In response to continued performance enhancement needs in the industry, data from high optical power testing (2.5 W) are also presented.

1. RELIABILITY OF CURRENT GENERATION OPTICAL WET-MATE CONNECTOR

Teledyne's first wet-mate fiber optic connectors were deployed in 1995. Since the first shipments, over 5,900 connectors have been supplied to customers, with the number of shipments per year shown in Table 1. When taking into account the number of field issues seen with these connectors, the reliability of the wet-mate fiber optic connector can be calculated to be 99.16% for a 25 year design life.

Every connector that has been returned from the field due to loss of functionality undergoes a root cause analysis investigation. For any issues that have been determined to have been caused by Teledyne design or manufacturing processes corrective actions are put in place to prevent re-occurrence on future products. Additionally, products that have been returned due to causes that were outside of Teledyne's control are used to determine potential areas for enhancement. Historical enhancements have included improved user interface components for easier operation and increases in robustness to withstand harsher operating conditions, among many others. In this way, the wet-mate fiber optic line has evolved over time to increase overall reliability.

Beyond the reactive investigation of products that have been returned from the field, Teledyne's reliability program also takes a proactive approach to product development and improvement through the use of various reliability tools. One such tool used by Teledyne is the Failure Modes Effects and Criticality Analysis (FMECA). Through Design FMECAs, Teledyne has examined each part in its wet-mate fiber optic connector to determine likely failure modes and understand how each failure mode will affect the functionality of the connector. Similarly, the Process FMECA examines each step in the manufacturing process to look for potential process errors and their effects. By ranking the severity, likelihood of occurrence, and detectability of each failure mode and then combining these rankings, the highest risk items in the design and manufacturing of the wet-mate fiber optic connector have been identified, and preventative actions taken to ensure that these failure modes are mitigated. Continuous revisiting of the FMECAs during yearly reviews of field data forms a feedback loop of continuous improvement that has led to the ever increasing reliability of these connectors, and has now led to the design enhancements inherent in the Next Generation Fiber Optic Connector.

Year	Wet-Mate Optical Connectors Shipped
1995	20
1996	15
1997	68
1998	185
1999	262
2000	335
2001	317
2002	171
2003	224
2004	130
2005	216
2006	215
2007	623
2008	642
2009	367
2010	497
2011	846
2012	690
Total	**5,943**

Table 1: Connector Shipments By Year

2. RELIABILITY IMPROVEMENTS THAT DRIVE DESIGN CHANGES

In addition to the Design and Process FMECAs, an Operational FMECA has been performed on the Wet-Mate Fiber Optic Connector. The Operational FMECA focuses not on issues due to design or process errors, but on issues due to customer errors during use. Due to the focus of the Operational FMECA, these are done in conjunction with customers and end users to provide the best knowledge of field conditions. Through the use of this tool, it became apparent that one of the higher risks in the field involved the user of ROVs during mating. As a result of this analysis, Teledyne began the development of a connector alignment system that would make the optical connectors more robust in the event that ROV handling was outside of the guidelines established by Teledyne.

The most beneficial features from this development included:

- Guidance of the flying connector half during mating aligning both of the connector halves prior to the faces of the connectors making contact
- High visibility buttons which pop out of the connector's side to indicate successful mate completion.

Figure 1 below shows the GAF/ELI system installed on the current generation optical connector set.

Figure 1: Gross Alignment Funnel (GAF) and Enhanced Latch Indicator (ELI) mounted on current generation optical connector

As a result, the reliability of the end product was improved and as an added benefit, the time taken for mating optical connectors was significantly reduced from 30 – 45 minutes down to 5 – 10 minutes due to the robust nature provided by the new kit.

3. DESIGN ENHANCEMENTS IN THE NEXT GENERATION OPTICAL CONNECTOR

Another example of periodic FMECA evaluations used to guide product development and improvements is related to the actuation of the rolling seals on the flying connector. After the Operational FMECA was used to mitigate the risks due to ROV mating issues, the design was again evaluated using the FMECA process to search for other possible areas of improvement. One area that remained with a higher risk was the center actuator, which became the next focus for mitigation.

In the current 8-way Rolling Seal connector as well as the Next Generation optical wet-mate, both connector halves contain two rolling seals each. The current design utilizes a total of three actuators to rotate the seals including one "center" actuator used to rotate both flying connector seals and individual actuators to rotate each fixed connector seal. All of these actuators are mounted in the fixed connector half. These actuators are long straight pins with features that interact with paddles on each rolling seal to roll them open during mating and closed during de-mating. Teledyne reliability and design engineers examined many aspects of the actuation design from mate speeds to material selection and were able to perform FEA and DVT testing to determine design changes that would improve the operating margins. The current optical wet-mate design, utilizing a single, "center" actuator to rotate both seals in the flying connector is shown in Figure 2. While the individual actuator design concept is shown in Figure 3.

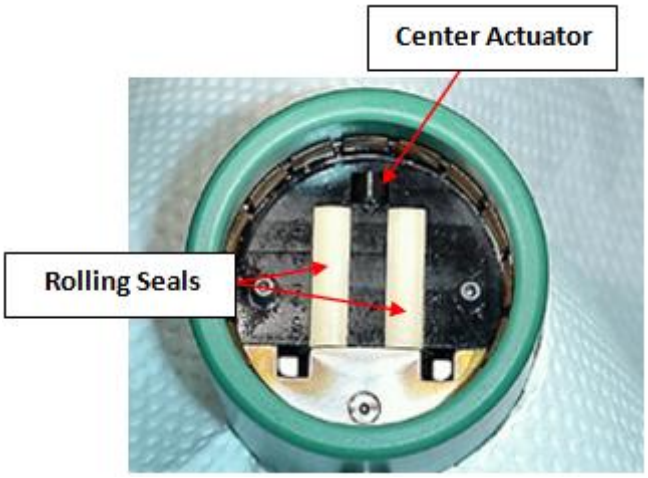

Figure 2: The current optical wet-mate design, which comprises three actuators, one for each Rolling Seal in the fixed connector and one for both seals in the flying connector

Figure 3: The Next Generation optical wet-mate design, which comprises four individual actuators, one for each Rolling Seal

In addition to the use of individual actuators, component level testing has driven a slight modification in the actuator profile. To ensure that the actuator comes into contact with the paddle long before the actuation takes place, the lead-in surface for the paddle was lengthened. This design change was tested to verify that the flying connector seals fully return upon de-mate.

4. PRESSURE TESTING

Incorporating the changes described above, prototype units were assembled as a proof-of-concept. The rolling seals and interfacing components were similar to the current Teledyne optical wet-mate connector; however, individual actuators were used with the improved lead-in. At a pressure of 9000 psi, more than 800 mate/de-mate cycles were successfully performed. As the legacy optical wet-mate connector is currently rated for 100 mates before refurbishment, this test was performed as a life evaluation test.

Pressure	Number of Mates	Speed (in/sec)	Completely returned paddle?
9 kpsi	800	2.0 (max rating)	Yes
9 kpsi	10	3.0	Yes
9 kpsi	10	3.5	Yes
9 kpsi	10	4.0	Yes

Figure 4: Summary of life evaluation testing at 9000 psi

During the life evaluation testing, no anomalies were found with optical testing including insertion loss, mated return loss and unmated return loss. Testing during the life evaluation test also included successful de-mates at exaggerated speeds up to 4.0 in/sec and atmospheric partial mates with a stroke up to 1.0 in short of the fully mated position. Based on these results, the individual actuator design is expected to exceed the > 99% reliability of the current optical connector, which is rated for speeds up to 2.0 in/sec.

Number of Mates	Pressure	Mating Stroke	Adverse Effects?
10	0 psi	-0.2 in	None
10	0 psi	-0.4 in	None
10	0 psi	-0.6 in	None
10	0 psi	-0.8 in	None
10	0 psi	-1.0 in	None

Figure 5: Summary of partial mate testing of individual actuator concept

5. HIGH OPTICAL POWER TESTING RESULTS

The APC contacts to be used in the Next Generation optical wet-mate connector are currently being qualified for high optical power use. APC contacts were incorporated in the next generation optical design due to a prior effort to evaluate and improve operating margins. The 8-way APC optical wet-mate connector is being used as a test vehicle to determine the limitations of optical power throughput for the system. A set of nine, 8-way APC connectors have been manufactured, and split into three sets of three units each (24 contacts each set). For each set of three, a different optical power will be applied, 2.5 W, 3.0 W and 3.5 W are the values planned. Within each set of three units, one of the units will be in the as manufactured state, one will have been subjected to 100 mates and the third will

be subjected to 20 turbid mates. This will provide a greater insight to the optical power performance of the APC contacts after the connectors have been exposed to different harsh environmental screening. Each connector will be subjected to the high optical power level for a period of 2000 hours, or until significant circuit failures are observed.

Figure 6 below graphically depicts the test plan for high optical power testing.

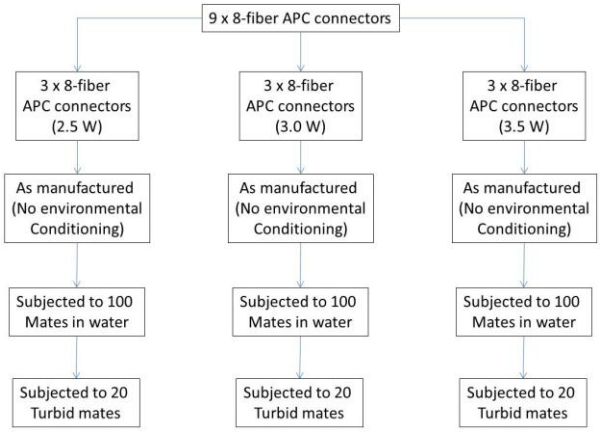

Figure 6: High Optical Power Test Flowchart

To date, the first unit in an "as manufactured" condition has completed 2000 hours at 2.5 W average power. The second and third units have begun the testing at 2.5 W and have logged 300 hours as of writing of this paper. Testing for 2000 hours will be completed on these two connectors by May 1, 2013. For all three connectors, no failures have been reported.

Figure 7 shows the high optical power test setup used for the single connector test. The test setup has been expanded to enable two simultaneous connectors under test.

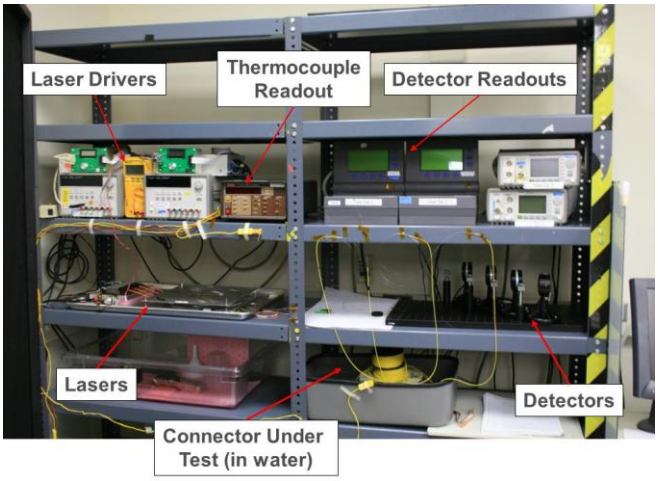

Figure 7: Test setup for single 8-fiber wet-mate connector high optical power test

Results for the 2000 hour test of the APC optical wet-mate connector are shown in Figure 8.

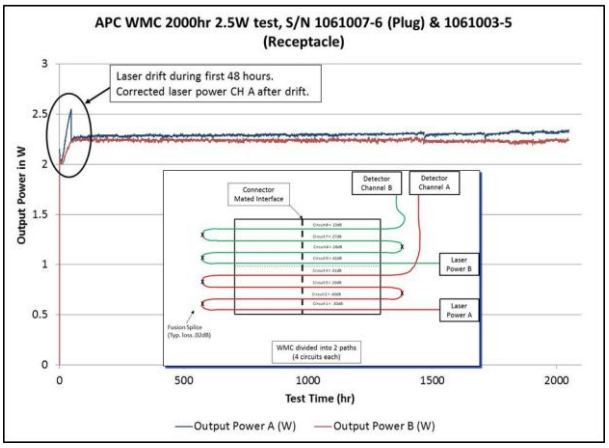

Figure 8: Test data from first 2000 hour high optical power test performed

As seen on the chart, laser drift was experienced during the first 48 hours of the test, but once adjusted, drift did not continue for the balance of the test. The connector was configured with two, four circuit loops, so that each interface in series experienced a slightly lower power level. The ~2.25 W output shown on the chart represents the final power coming out of the last physical interface. Accounting for insertion loss in each circuit, the

average power for each 4-circuit loop was 2.5 W.

Once all the data has been gathered for this test, later in 2013, Teledyne will perform reliability data regression analysis in order to determine a high optical power rating for the APC contacts from the accelerated life data. This methodology is graphically shown in Figure 9.

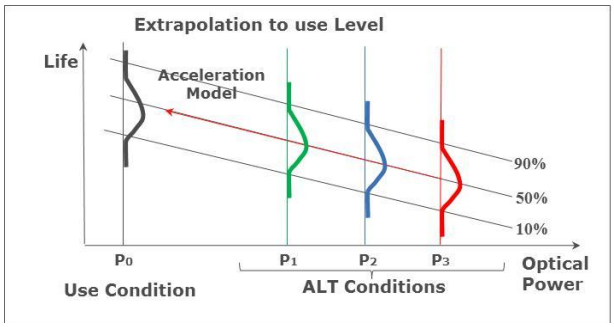

Figure 9: Accelerated Life Testing Methodology

6. FUTURE EFFORTS

Qualification and design margin testing of 12-way Next Generation optical wet-mate assemblies will commence at the start of the third quarter of 2013. These tests will give a complete picture of the performance of the connector and will provide information on the design margins inherent in the Next Generation wet-mate design. A quantity of three units is planned for all qualification tests and the regimen will adhere as closely as possible to the connector-level requirements of Statoil TR2390, recognized as the most stringent industry standard for optical wet-mate connectors. The next generation optical wet-mate is planned to be fully qualified by the end of 2013.

7. SUMMARY

Reliability is the cornerstone of the New Product Development process at Teledyne Oil & Gas. By periodically reviewing FMECAs for the design, process and operation of a product and including field data in the review process, engineers have made informed decisions on design enhancements that have influenced the next generation wet-mate optical connector design. The next generation optical wet-mate connector is expected to have a high optical power rating in excess of 1.0 W and have a 30-year reliability of greater than 99%. This next generation connector will be fully qualified by the end of 2013.

