

Innovative Connector Technology

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Introduction

Imagine connecting 8-way fiber-optic cable segments on the murky deep-sea floor. Sound impossible? Well, it's not. Over the last three years, connectorized seafloor fiber-optic networks have been laid in various ocean environments including the North Sea and the abyssal Pacific. The technology is here, and it works. It enables an operational flexibility that would greatly reduce the cost of installing and maintaining seafloor telecommunication systems.

It allows, for instance, connectorized branching units, repeaters and universal splices. Telecommunications cables can now be deployed with dormant branching points. Later, ROV's (remotely operated vehicles) or AUV's (autonomously operated vehicles), can simply plug-in extensions as they are needed. All this without the usual recovery of the parent cable or a dormant pigtail cable.

The wet-mateable connectors are rugged... tough enough to support launching through cable engines to full ocean depths, including direct burial. Subsea telecommunications cables, which heretofore have been deployed as continuous strings of segments joined by costly, time-consuming shipboard splices, can now be

connectorized in advance and simply plugged together sequentially as they are launched, greatly reducing ship time. Also, with connectorized systems, damaged cable segments, repeaters and branching units can be replaced at the seafloor by unplugging them and plugging in new ones.

History

At this point, you may be wondering why such connectors have not been available sooner. Certainly the use of optical cables subsea is now quite mature, with the first transatlantic telecommunications cable (TAT-8) deployed in the late 1980's. Well, quite simply, successfully mating optics underwater is a remarkably difficult thing to achieve. It is worth knowing a little history in this field; the first subsea wet-mate optical connectors were offered commercially a little over a decade ago. These connectors passed only one optical circuit, and at best, were temperamental. Some used expanded-beam lenses, but the more successful designs had fiber-to-fiber physical contact junctions. To protect the optical interfaces, both the plug and receptacle contacts were housed in oil-filled chambers that were pressure balanced to the environment. The concept was good, but sealing and cleanliness were not adequate to provide complete reliability.

A second type of subsea-mateable optical connector to be marketed consisted basically of dry-mate style connectors, that is connectors that must be mated prior to being deployed in

water. These connectors were modified by adding some optical index-matching gel between the contact interfaces. The excess gel was then expelled when mating these connectors underwater. There was no attempt to exclude sand or silt from the interfaces, and the resulting performance was left to chance.

Even though these first optical connectors do not meet all modern needs, until recently, nothing better had been offered, and they are still on the market.

This more-or-less briefly summarizes highlights of optical subsea connector evolution from its beginning until the present, except for the latest step - the mid-1996 introduction of multi-circuit all optic or opto/electric "hybrid" wet-mates.

Hybrid Wet-Mates

These unique, patented connectors have taken the best elements of previous technology, such as oil-filled and pressure-balanced plug and receptacle housings, and combined them with novel means for sealing and maintaining cleanliness of the optical interfaces. Within the internal oil chambers on both the plug and receptacle, groups of contact junctions are aligned behind cylindrical rubber face-seals. When mated, opposed plug and receptacle seals first press against each other like the wringers of an old-fashioned washing machine, forcing the water out from between them. As the mating sequence continues, the opposed plug and receptacle seals, like the wringers, roll in unison and transport any debris trapped between them off to the

side. The action simultaneously causes clean, sealed, oil-filled passages to open between opposed plug and receptacle contact junctions. Continuing the mating process, plug pins advance through the sealed passages to contact sockets within the receptacle. Demating is just the reverse sequence. These connectors are also available with electrical contacts in place of optical ones, hence the hybrid description. They work in a similar way to the optical circuits, except each mated pin/socket junction is contained in an individual, secondary, sealed oil-chamber within the common oil volume, providing a desirable additional barrier for electrical isolation. None of the contacts are ever exposed to the outside environment before, during or after mating. Sounds complicated! But, it's really quite simple and results in an assembly of relatively few components. The schematic illustrated in Figure 1 shows a step-by-step diagrammatic representation of the connector mating sequence.

Performance

Of course, the performance of the connectors must be good enough to allow their use without significant optical penalty. For that reason, the connector uses fiber-to-fiber physical contact junctions that give an insertion loss of less than 0.5 dB. To put that into perspective, it equates to a loss equivalent to approximately 2.5 kilometers of fiber. Additionally, the connector has to be capable of repeating this

performance after many wet matings, and so has been designed to maintain its original performance for over 100 mating cycles, under pressure and in arduous turbid conditions. More of the connector's operational specifications are provided in Table 1.

Qualification

The wet-mate connector has also had to demonstrate its operational capability through a significant number of challenging qualification tests, both internally as well as by outside, independent test houses. Apart from the more conventional performance tests, these connectors have been through thermal cycling & shock tests, mechanical shock & vibration tests, and mate/demate testing in turbid seawater at an ambient pressure of 10,000psi, all while monitoring performance. This last test in particular would be a challenge for any subsea connector to pass, let alone one containing optical junctions. A summary of these qualification tests is given in Table 2.

Configurations

The connector is currently available with up to 8 circuits, any of which may be utilized as single-mode optical, multi-mode optical or electrical passes. Due to the modular nature of the connector, this configuration is expandable to 16 or more circuits.

The operational "heart" of the connector can be included in a variety of connector styles. To date, the connector has been configured in the following ways:

Diver-mateable (or screw-to-connect), suitable for use in shallower water, where it provides a compact, cost-effective connector;

Stab-plate mounted, where the connector is to be mounted on a larger piece of equipment with its own mating & locking device, or where more than one connector is to be mated simultaneously;

ROV mateable, with one-half fixed to a bulkhead, using tried and proven paddles or T-bar grips for straightforward ROV mating;

Finally, the connector is configured for ROV mating in an in-line format, for applications such as cable-to-cable connections. This example also contains integral fiber management chambers for the storage of excess fiber and splices.

The drawings in Figure 2 and photographs in Figure 3 show several examples of the current connector configurations.

Of course, providing an appropriate termination onto the cable is also very important. Successfully achieving the connector-to-cable interface can make the difference between success and failure in a cable system. It is therefore essential to also have available all the other elements to make this happen, such as fiber & splice management housings and penetrators. The flexible design of these connectors has allowed them to be terminated to a wide variety of different cable

constructions including armored and unarmored cables, composite cables (electro-optical), and oil-filled, pressure balanced cables. Indeed, in the not too distant future, with the ongoing reduction in size of optical amplifiers these too could be incorporated into the connector termination, resulting in a compact simplified repeater or branching unit assembly.

Conclusion

So, what this all means is that the technology to enable successful and reliable optical connections in the harsh subsea environment is already available and proven. It is expected that, with such connectors available, there will be a substantial increase in many areas of subsea optical cabling that have previously been stifled due to the absence of this key enabling connection system. In addition to telecommunications, there are anticipated requirements in oceanography (e.g. use of optical sensors), military (e.g. submarine systems), and oil & gas (e.g. subsea wellhead communications). Although very different fields of work, they all share the same desires of higher bandwidth, lighter weight, noise immunity, and secure data that optical communications provide. And in addition, what they all desire is in-place system upgradeability, reduced maintenance costs, and the many additional advantages gained by underwater connection of their system components. The method exists, and the wait is over.

Operational Specifications	
Property	Specifications
Pressure Rating	10,000 psi
Temperature Rating	-10° to +60°C (tested down to -25°C)
Optical Fiber	125µm single or multi-mode
Typical Insertion Loss	<0.5dB
Typical Return Loss	>30dB (>50dB also available)
Maximum Current	10 amps/circuit
Maximum Voltage	1,000 VDC
Insulation Resistance	>1 gigohm, circuit-to-circuit & circuit-to-ground @ 1,000 VDC
Number of Circuits	Up to 8 (higher circuits counts possible)
Mate/Demate Cycles	>100

Table 1, Listing of the Major Specifications for the Hybrid Wet-mate Connector

Partial List of Qualification Tests		
Test	Duration	Conditions
Mechanical Shock	6 cycles	½ sine @ 18 ms, 30G
Vibration	30 minutes plus	20-80 Hz, 4G, 3 axes; Resonant search plus 2 Hr hold at frequencies.
Hydrostatic Pressure	100 cycles	0-8,000 psi
Mate/Demate Under Pressure @ low Temp	100 cycles	0-8,000 psi, 32°F
Burial	1 cycle	Buried in 1 meter in sand/silt, removal, cleaning, and demating.
Thermal Limits	7 days	-10° to +140°F
Thermal Shock	Plunge	+140° to 32° and -10° to 32°F
Turbid-Tank Mating	200 cycles	0-10,000 psi, 1.5% solids, seawater

Table 2, Listing of the Major Qualification Tests Carried Out on the Hybrid Wet-mate Connector

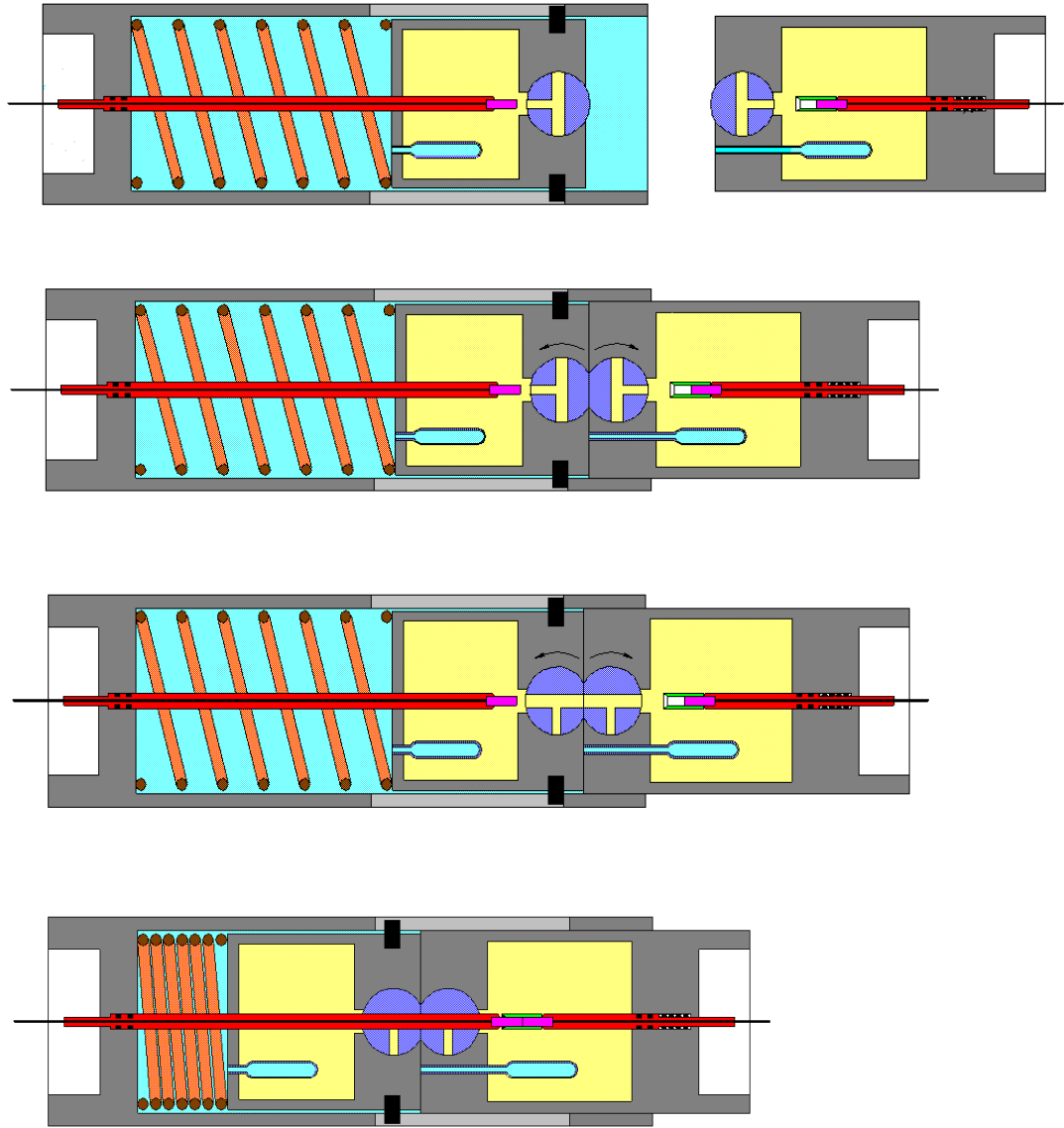
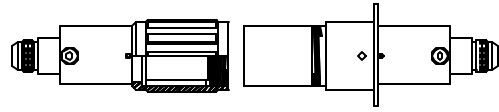
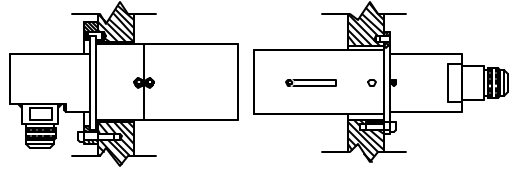


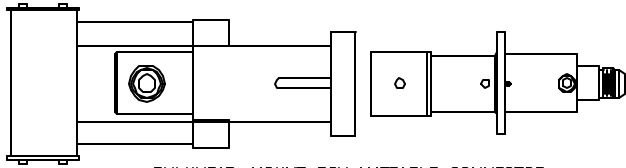
Figure 1, Schematic of Connector Step-by Step Mating Sequence



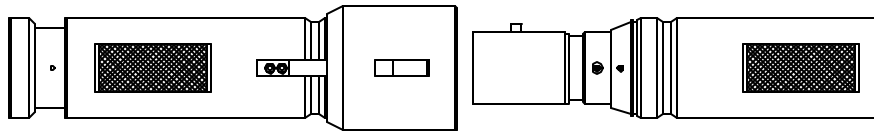
DIVER MATEABLE CONNECTOR



STAB PLATE CONNECTOR



BULKHEAD-MOUNT ROV MATEABLE CONNECTOR



IN-LINE ROV MATEABLE CONNECTOR WITH FIBER MANAGEMENT HOUSINGS

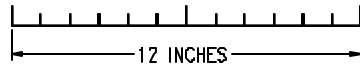


Figure 2, Typical Configurations of Connectors

Cable-end Connectors showing
End seals



In-Line ROV
Mateable
Connectors,
shown both mated
and unmated.



Stab-Plate Connectors

High-Strength Shore-End Fiber-
Optic Cable Termination with
Connector Breakout



Figure 3, Photographs of Connectors