INNOVATIVE ESSENTIALS IN UNDERSEA JOINTING: EMPOWERING COST EFFECTIVE IMPROVEMENTS

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Abstract: As undersea transmission technology progresses to meet greater capacity demands; cable jointing remains critical to the success of the totality of all undersea networks. Although often overlooked, engineers are hard at work reliably improving jointing to meet these continually broadening performance requirements.

Major drivers include ever-changing cable/system designs targeting cost-per-bit efficiencies, higher fiber-count cables, interoperability/interconnections between suppliers/cable types (installation, maintenance/repair), cost pressures, large-effective area (LEA) bend-sensitive fibers, space division multiplexing (SDM), system performance management (loss, tilt, shape, and L-band) for ultra-long-haul digital line segments (DLS), higher system voltages, and so forth. Customers and end-users alike can be confident that suppliers are continuously innovating and striving to make—and are implementing—improvements on multiple jointing fronts.

This paper reports on jointing development areas being expedited to meet future system needs and maximum performance. These include computer-aided engineering, finite element analyses, new materials, additive manufacturing, splicing, molding, and so forth. Advances are being mined and cultivated in the following areas: Performance Capabilities, Design Processes, Manufacturing Processes, Specifications, Materials, Innovation, Industry Needs, Cost, Hardware, Tools, Testing, and so forth. In combination with qualification testing results from both land and sea trials, these developments have a high probability of success in achieving their functional requirements.

Furthermore, this paper outlines both the evolution and constraints on some technologies due to specific industry needs and maintenance requirements. We also delve into recent development approaches that improve performance and contain costs, all the while supporting legacy equipment and commitments. [1]

1. FUNDAMENTAL TO THE SUCCESS OF UNDERSEA SYSTEMS

Key Component of Undersea Networks

Undersea jointing including cable-to-cable, cable-to-repeater, gain equalization (tilt and shape compensation), and various end treatments (e.g. end seals or end caps), cable sea grounds (anodic/cathodic), keep a low profile. For the most part, they are treated as commodities, givens, and taken for granted. Not that joints need the focus but rather we need to be aware of the complexities, demands, and constraints placed upon them. These devices are enablers that support system design, assembly, installation, repair, and performance. See Figure 1. They are critical for the longevity of a given system as they are single point of failures in any deployed system. Hence, their reliability is of utmost importance to the jointing community.

Success of System Performance

Without quality jointing, long-haul transmission would be more difficult. System designers rely on jointing with repeatable and predictable splice loss as input to their design models and simulations. Their designs are built on projected populations of splice types based on rigorous splice qualification of specific fiber combinations. Additionally, predictable performance of joints and their associated splices are necessary for ensuring system margins for error-free transmission. Repeatable, reliable jointing with consistent splice loss is critical for meeting the performance parameters projected during system design.

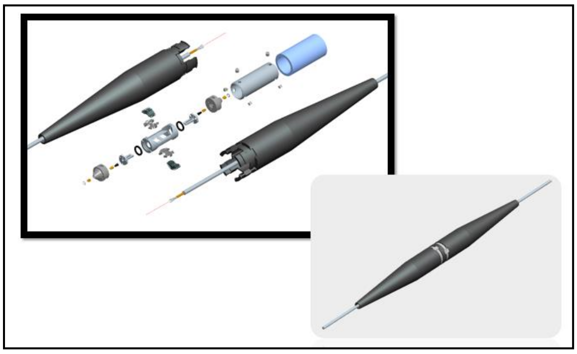

Figure 1: Armorless cable-to-cable joint

Gain tilt and shape compensation are often performed late in the system build to correct for measured differences in as-built to modelled design parameters. Although compensation can be added to amplifiers, having the flexibility to implement these corrections via a joint platform permits late-stage or even field installable tweaks to optimize the system performance. This jointing-based method saves production lead-time and adds to the flexibility of where compensation can be added.

Visibility of Jointing Progress

Quietly—almost clandestinely—advances take place without fanfare or notoriety. Progress can be measured in the categories listed in Table 1:

Jointing development related to these is ongoing to keep pace with an ever-increasing variety of cable types and suppliers. Unless one is involved in a specific system procurement or training, new joint qualifications may not be public. Similarly, specific improvement initiatives are likely to remain internal or proprietary and may not be publicized. As an example, this is the case for cost containment via process improvements and design for manufacturing of the hardware.

Table 1: Progress Categories

- Functionality
- Manufacturing
- Kitting
- Equipment
- Performance Capabilities
- Design Processes
- Assembly
- Specifications / Requirements
- Evolution of Technologies

System Owners & Maintenance Authorities

System owners, maintenance authorities, and joiners have different information needs and interests. System owners want to make sure that the system they are buying is fully qualified and will perform flawlessly. They are likely to focus on "new" changes or designs that are classified as "first office applications" (FOA). They are discerning as to taking on inadvertent risks. Generally, they are not purchasing jointing kits or jointer training. Most—if not all—system contracts require one form of universal jointing or another (e.g. MJ, UQJ, and/or UJ). See Figure 2.

Whereas maintenance authorities are interested in jointing kit supply as well as training and certification. Typically, a system price includes the factory jointing and installation but does not address training and parts kits for maintenance and operational spares. Insight into changes to jointing and kits may be most apparent through bulletins sent out by the cable joint platform provider or, if Universal Jointing (UJ), the Universal Jointing Consortium. Maintenance authorities are saddled with keeping up on legacy equipment and service requirements. As time passes and newer systems are installed, there is a greater chance of having manufacture discontinued hardware and training situations. However, none of these are aimed at tracing or following supplier improvement initiatives.

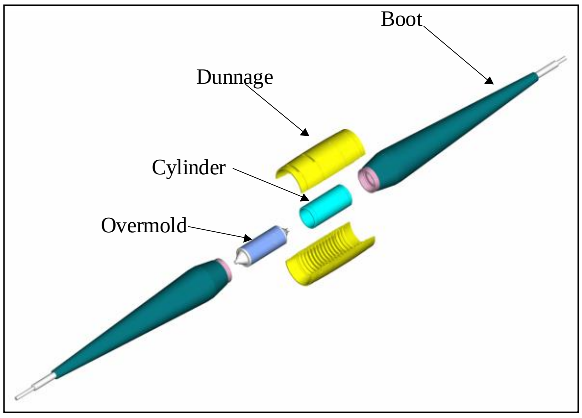

Figure 2: Example universal Armorless Joint

Industry Constraints

A few other areas that are indirectly hidden are the requirements explicit and implicit that affect system suppliers and maintenance/repair. There is a plethora of jointer training, inventory kits in depots around the world, and wide-spread deployment of suites of repair equipment. Due to the "commodity" nature of jointing, system owners are loath to invest heavily in wholesale changes as it goes against using a semi-common approach to field jointing. Although system owners may want their systems up and running, they contract with maintenance authorities that are operating repair ships to do the jointing.

Major Jointing Drivers

Of course, industry needs are fundamental to driving jointing progress or lack of progress. System capacity demands in transmission rates, band width, and fiber count influence jointing design. To increase capacity, system designers are using

- Fiber Types Including Large-Effective Area (LEA) Bend-Sensitive Fibers,
- Higher Fiber Counts,
- Space Division Multiplexing (SDM), and
- Higher System Voltages.

Except for SDM, competition translates to greater cost pressures. The increase in fiber counts adds significant time to the fiber-to-fiber splicing interval. With an increase in the rate of cable purchase and deployment, efficiencies (especially in the factory environment) are more important than ever. To the extent that jointing must fit the system design budget, optical performance and spectral shape are heavily emphasized to manage:

- Loss (optical signal degradation)
- Tilt (spectral slope)
- Shape (spectral band undulations)
- L-Band use (in addition to C-Band)
- Ultra-Long-Haul Digital Line Segments (DLS)

2. JOINTING PROGRESS

Recent Developments

As reported in previous papers, jointing continues to evolve. Generally, this has been incremental rather than wholesale. The infrastructure cost for a complete platform change is prohibitive. Individual system purchasers and maintenance organizations have chosen not to invest their resources. Primarily, this due to the structure of the long-haul undersea cable market and the "commodity" perception of jointing.

Using Computer-Aided Engineering, Finite Element Analyses, New Materials, and Additive Manufacturing, developments have been quicker because of reduced trial and error of form, fit, and function. Furthermore, through periodic feedback from customers, factory operators, trainers, field jointers, and supply chain personnel, improvements and accelerated developments have been achieved in many—if not all—of the following areas:

- ✓ Fixtures
- ✓ Innovation
- ✓ Kitting
- ✓ Manuals
- ✓ Materials

- ✓ Molding
- ✓ Qualification
- ✓ Splicing
- ✓ Tooling
- ✓ Training

Improvements

Contributing to the invisible nature of many advances is that they may be in areas o that are process, function, or capability not observable by most people. Examples of these are in the areas of

- Functionality
- Manufacturing
- Performance Capabilities
- Design Processes
- Manufacturing Processes
- Specifications / Functional Requirements
- Training

In addition, improvements or changes to equipment, kitting, construction manuals, record keeping, extended applications, interconnectivity, and the like are only experienced by those involved with operations. Unless there is an issue, advances are likely to go unnoticed by all but jointing-related personnel as there is no specific need to reveal these unseen improvements.

As improvements are made and pressures are placed on cost controls, an important caveat emerges: high-quality high-reliability materials must not be replaced with lower-cost inferior materials and low-quality components. After qualifications are completed, the drive for cost competitiveness makes it difficult to manage and prevent inferior supplies from making their way into the field. The industry has paid dearly for using cheap (poorly-made) jointing parts and/or tooling.

Owing to the nature of incremental development and qualification, it is quite easy to lose sight of how far jointing has come. Reviewing the growth of jointing to match new cable introductions is very instructive as to the substantial changes made in the industry. With respect to investment and reliability, improvements tend to have diminished returns over time [2] as the more worthwhile initiatives are pursued earlier on as represented in Figure 3.

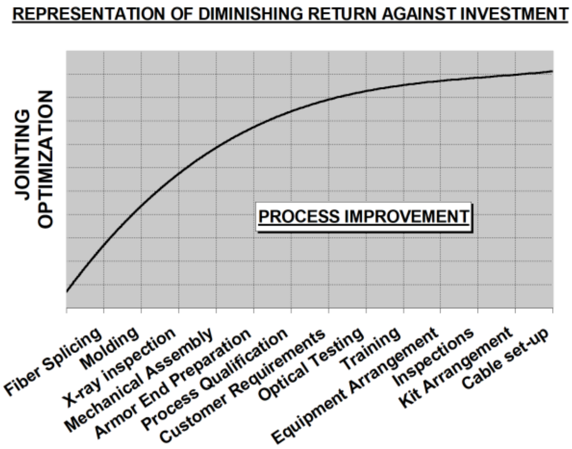

Figure 3: Jointing Optimization Over Time

Technology Challenges

With the growing demand for ever higher capacity systems, customers are seeking not only the lowest cost-per-bit but also higher fiber-count cables. Although high-fiber count is a relative term, here it is taken to mean 24-fibers or more. Given system design and implementation considerations, the maximum number of fibers is likely to be about 48 fibers. Couple this with large mode-field diameter fiber (i.e. inherently more bend sensitive) and potential issues become clear.

Higher Fiber Count (HFC) Cables

Let us explore the effects of higher fiber counts on jointing. Processes that involve fiber will be, at a minimum, scaled up proportionally (See Table 2). For example, fiber cleaning, coating inspection, splicing time (fiber staging, cleaving, fusing, splinting, proof-testing, fiber management) will increase.

More fiber stripped from cable means more bare fiber expose to potential damage. Since the fibers are connected to the parent cable, they have a denser arrangement in the splicing area making them more susceptible to inadvertent damage. Basically, fiber vulnerability goes up while splicing times increase and handling risk becomes greater.

At a minimum, one can expect that a 48-fiber joint will take six times as long as an 8-fiber joint in the specific fiber processing areas. This is a very optimistic view. The reality is likely to be that the complexity goes up with the number of fibers in a non-linear way.

Field jointing times are typically 8-12 hours for lightweight cables and 12-18 hours for armored cables. If the splicing portion of jointing increases by about 6x as is expected, 24 fiber splices may take 3 hours while 48 fibers could be as long as 6 hours. Note that these times assume a single splicer. Splicing will very likely become a very significant part of the overall jointing time and come under greater scrutiny—as ship time is valuable.

Table 2: Jointing Steps Affected by Higher Fiber Counts

- Fiber Cleaning
- Fiber Inspection
- Fiber management
- Fiber Termination
- Splicing Time
  + fiber staging,
  + cleaving,
  + fusing,
  + splinting,
  + proof-testing,
  + temporary fiber placement
- Fiber Coiling and Splice Storage
- Optical Testing (if required)

As a possible mitigation to increased splicing times, jointing developers may consider methods other than single splicing. See Figure 4. Using multiple splices would reduce the time but still involve issues of fiber handling and management.

Another possibility is to use mass-fusion splicing or array splicing. Mass-fusion splicing may involve splicing 4 to 12 fibers simultaneously. Mass fusion splicing requires greater tolerances on the spread of acceptable splice loss (to avoid low process yield). These splices are a case of one for all and all for one. Generally, if one fiber's loss is too high, the other fibers in the array splice must be remade.

Two more important considerations are related to (a) re-work and (b) overall performance. Obviously, replacing a joint or having to extract individual splices becomes a lengthier process and involves the same vulnerabilities mentioned earlier. Rework becomes more time-consuming and expensive.

Figure 4: Example improved splicer with improved performance at a reduced cost

With respect to mass-fusion splicing, variation in splice loss is not desirable. In mass-fusion splicing, there are more chances for variation and the fibers are more difficult to uniformly position as compared to single-fiber splicing. This may mean greater tolerances on acceptable splice loss in a mass-fusion splice to allow acceptable yield rates. This is a fundamental shift in performance expectation and a challenge, as all fiber paths are normally expected to be equivalent for a typical mass-fusion holder or splint. See Figure 5.

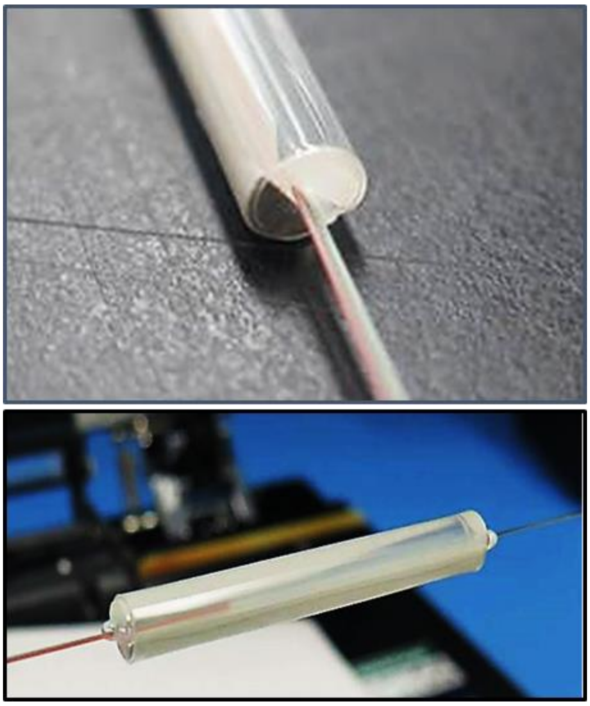

Figure 5: Example mass-fusion splice and splint

Jointing stakeholders and their customers can expect that HFC systems will require substantially more jointing time while adding additional pressure on shipboard operations.

3. ADDITIONAL CHALLENGES

Expectations

To the casual observer, jointing has not changed much. Without peeling layers both figuratively and literally, the basic size and process are substantially the same as in legacy platforms. Generally, this is dictated by various constraints—explicit and implicit. For example, previously we mentioned that the structure of the industry has divided the objectives and resources of the various stakeholders. This, combined with the "commodity" view, makes investment in totally new approaches difficult and unlikely. The exception to this as reported previously [4] is incremental improvement.

"The implementation of jointing platforms requires overcoming the inertia associated with the following:

- ✓ Qualified Designs
- ✓ Qualified Jointers
- ✓ Qualified Procedures
- ✓ Documentation
- ✓ Parts Supplies
- ✓ Qualified Tooling
- ✓ Tooling Availability

Improvements and innovation must factor in the customers' needs for current product / system support as well as capital invested in inventory and tooling. For innovation to take place and make it to the field, changes must often be retro-qualified and backward compatible to replace current methods, hardware, tools and the like." [4]

Pragmatically, business cases around new jointing platforms are not lucrative enough to entice investment. Establishing reliable supply chains for new equipment and hardware is extensive and expensive work. Available development resources are tied up with sustaining engineering and cost containment activities. Assuming new approaches are pursued, risk-averse customers are loath to gamble on them. RFQ requirements generally require specific jointing platforms for repair and maintenance.

Developers continually look for opportunities to improve on the current platforms and weight these with the cost-benefits—hoping the predicament has changed. See Table 3. The present approaches serve the industry well. They provide a stable, reliable, cost-effective approach for both factory and field use.

Higher capacity systems with more fiber pairs and longer hauls are power-hungry with more amplifiers to feed. Generally, this leads to higher system voltages that further burden insulation systems and the materials that isolate the system conductors from sea ground. Higher voltage systems will continue to depend heavily on quality joint molding to maintain system conductor isolation from sea ground potential.

Polyethylene insulated products have been used for years with proven success. Molding is still a very critical step to the reliable operation of the system (See Figure 6). Higher voltage systems are evermore dependent on quality molding to isolate the system conductor from sea ground potential. Extensive experience has cultivated a certain comfort and, perhaps, complacency about how easy it seems. This performance record did not come easily, as it is known that molded interfaces can fail at less-than-extreme conditions[1] for what seems to be very subtle reasons. This serves as a reminder of molding's sensitivities and that molding remains as much an "art" as a science.

Table 3: Factors Affecting Innovation

Platform: design, technology, qualification, requirements, commonality, universality, complexity, ergonomics, shipboard environment, capability
Cable: cable conformance, fiber types, cable end preparation, fiber handling
Splicing: strength, fiber handling, process/equipment, available technology
Insulation: voltage, wall thickness, insulation material
Equipment: calibration, maintenance, training
Kits: quality/conformance of components (piece-parts), packaging, storage, inventory
Other factors: product life-cycle, reliability, regulations, customer expectations, backwards compatibility, documentation, performance, stake holders, cost, collaboration, shared responsibilities, shared interests, contracts, sales, marketing

Performance

There is growing demand for both Cost-Per-Bit Efficiencies as well as Higher Fiber-Count Cables. Transmission technology continues to change and has ushered in new fiber designs that are more bend-sensitive than their predecessors. With cable proliferation, interoperability and interconnections are being used more and more and provide greater system design and repair flexibility.

Developers are always looking for ways to improve and innovate while managing risk as carefully as possible. They are tuned to their customers and end-users to provide reliable, cost-effective, jointing that serves their ever-changing needs.

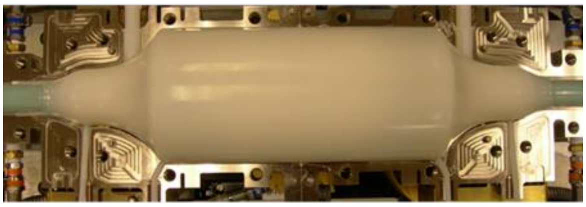

Figure 6: Polyethylene insulation molded over splicebox

The Future

After the silt finally settles and visibility returns, it remains apparent that customers want incredibly reliable systems including a variety of joints that can be used in the factory and aboard ship.

The ability to make system repairs using a variety of ships and jointers is critical to the flexibility for getting undersea systems back in service. Customers are likely to be dissatisfied if any new platform is not at least as good as the previous one. Moving to higher fiber counts (denser cables), higher voltages, more bend-sensitive fiber, suggests that suppliers prudently stick to what they know—at least for the time being.

4. REFERENCES

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