THE EVOLUTION OF JOINTING TECHNOLOGY - INNOVATION AND SECURING A COMPETITIVE SUPPLY CHAIN

Craig Beech, Stephen Holden (Global Marine Group)
Email: Craig.Beech@globalmarine.co.uk

Global Marine Group, 1 Winsford Way, Chelmsford, Essex, CM2 5PD UK.

Abstract: As submarine cable networks evolve there is an ongoing need to ensure that jointing technology also keeps pace, in particular with respect to designing for evolving fibre technologies and the integration of fibres within power cables; which at the present time are enabling flexible communication grids utilising both telecom and renewable/power cables. The paper will consider the importance of joint design as customer operational requirements change and submarine systems age. It will also consider the ability to secure a competitive supply chain whilst maintaining a fully functioning and competitive market for all submarine jointing piece parts.

1. A SOLUTION SHARED

As you can't have New Orleans without 'Old Man River' or 'Mardi Gras', it's difficult to envisage cable without joints. The first transoceanic telegraph cable installations (Ireland to Newfoundland c1858-66) naturally involved the first unplanned installation repair joints. As telegraph became telephone, the first transoceanic telegraph cable was TAT1[1] c1956 with capacity for 35 telephone conversations and 36 telegraph channels and introduced signal amplifiers 'repeaters' into the cable system, the technology, design and manufacture of cable has developed, and so have jointing technologies with a supporting infrastructure to repair (maintain) them. In a now established approach, cable owners group together to share resources and costs allowing them to keep repair vessels 'on standby' to complete efficient repairs on cable systems. Such as the Atlantic Cable Maintenance Agreement (ACMA) has been in place since 1960 and is an excellent working example of this approach. With a grouping together of system owners into maintenance agreements, there is inevitably a range of cable types and manufacturers to maintain. This has significant implications for management of technologies and readiness to complete effective and efficient repairs.

2. UNIVERSAL JOINTING

Historically, these implications are best illustrated by the issues arising as the copper core coaxial telecommunications cable made way to the first transoceanic fibre optic digital cables with TAT8 in 1988[2]. This system was a collaboration between the three landing countries for the system: France, Great Britain and the United States. Each supplied through its own national telecommunications and cable manufacturing companies: France Telecom with Alcatel, British Telecom with Standard Telephones and Cables (STC) and AT&T with AT & T Bell Laboratories, three different cable types. Each had three different jointing solutions, extensively and independently tested with a unique set of jointing equipment, piece parts and jointing skills (training). This proved expensive and logistically a difficult problem to manage for the ongoing maintenance of the system. The solution was to innovate, in time for TAT9, a consortia of three companies, BT Marine, AT&T in 1989 and then Alcatel in 1990, came together to develop a 'universal' jointing platform. This platform shared a common approach for the fundamentals of the joint but with 'End Specific' terminations to suit the three different cable type structures.

From this the 'Universal Joint Consortium (UJC)' was formed and the 'Universal Joint (UJ)[3][4] product launched for TAT9 (1990) primarily for long haul, repeatered (powered) systems typically less than 12 fibres (6 fibre pairs). KDD-SCS joined in 1992 and these four companies, now called respectively Global Marine, Subcom, Alcatel Submarine Networks and KCS (Kokusai Cable Ship Company) remain the custodians of this 'for the industry' technology. The UJC ruling principles are to advance technology through the sharing of expertise for the mutual benefit of the submarine cable industry, in a cost-effective way and critically, to maintain common technical, manufacturing and engineering information.

Each member contributes key technology, knowhow and innovation to the core 'Universal technology' and with regular reviews sets the standards and looks forward to future developments. For example, Global Marine in 2012 introduced a significant enhancement to the inspection and documentation of repair joints with the introduction of the digital X-ray system (DXr1) [5] to replace 'wet-plate' x-ray analysis. This allows digital collection and inspection of data and reduces overall jointing time and ongoing material costs.

Image 1: Digital X-Ray Camera (DXr1)

Although collaborative in setting the common standards each member, wholly independently of the other, competes in the delivery of the supply chain elements of 'qualification' of new cables and cable variants, the provision of jointing kits, equipment and tooling and jointer training & certification.

Image 2: Jointer Training

The benefits of this, cooperative approach to the industry was recognised in2018 by the Pacific Telecommunications Council (PTC) at their 40th anniversary awards, when Global Marine was announced as runner up in the Lifetime Innovation Award Category for its contribution to Universal Joint (UJ) and Universal Quick Joint (UQJ) technological developments.

In 1996 Universal 'Quick' Joint (UQJ) was developed alongside the 'UJ' to address the development of shorter length, coastal festoon, type unrepeatered cables. As repeaters were not required they would utilise more than 12 fibres and with no 'power' requirement there is less emphasis on the high voltage capabilities of the insulation reinstatement methodology.

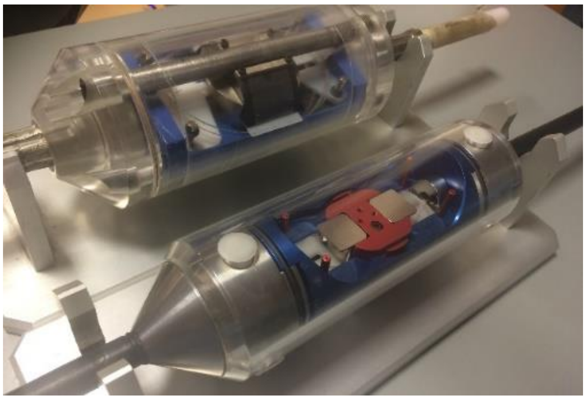

Image 3: UJ (top) UQJ (bottom) ***display models***

These unrepeatered cables are often smaller in diameter without a central strength member in the 'Lightweight' (LW) core being offered in only 'armoured' variants. Hence a smaller joint was developed to accommodate up to 48 fibres, which is better suited to these cable types and does not require moulding and post mould X-ray inspection equipment. Consequently, the tooling and equipment inventory for 'UQJ' is smaller than 'UJ'. [6][7]

3. TAKING AWAY THE STRESS

In early fibre optic cables, the fibres were of a 'tight buffer' arrangement where, over a central 'kingwire' the fibres are in-bedded in an elastomer package and then encased in a welded, sealed, often copper, pressure tube. This type of cable construction from a jointing perspective, requires careful tooling and jointer expertise to remove the elastomer material without damaging the fibre coating or indeed the fibre.

Around the mid 1990's this 'tight buffer' design gave way to the typical loose tube construction we have now (see below).

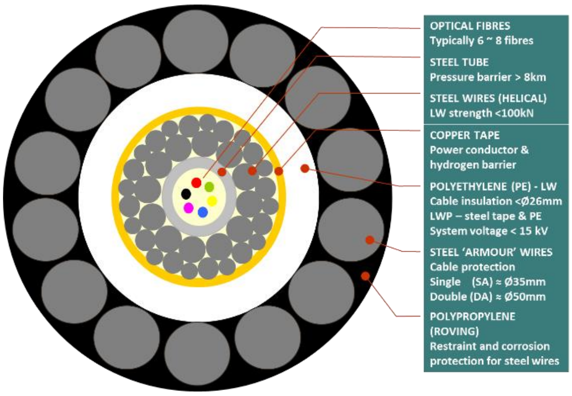

Figure 1: Typical repeatered Cable

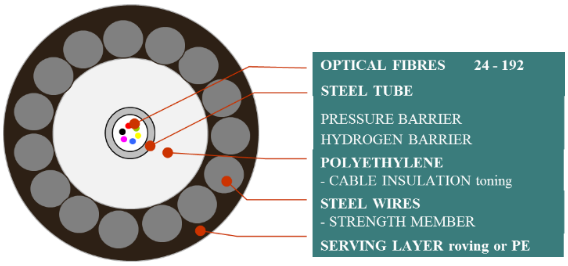

Figure 2: Typical unrepeatered cable

The fibres are cabled unrestrained in a sealed, often stainless-steel tube and the tube filed ideally with a hydrogen scavenging, water blocking (non-hydroscopic) material that is also thixotropic (initially resits strain asserted onto it).

In the traditional tight buffer design, strain is experienced as load is applied as the ends are restrained, in loose tube designs the fibres are 'overfilled' into the tube (fibre excess) so that the fibres remain unstrained for much of tensile range of the cable, only becoming stressed once cable strain matches the overfill length of the fibre. Over very short timescales, such as the cable moving over the sheave during deployment or recovery, the thixotropic gel will inhibit the movement of the fibre. For jointing a loose tube design is much more straightforward to prepare, as the fibre tube just needs to be carefully cut and then removed to expose the fibres for splicing. In tight buffer design, the cable fibre tube often needs gentle heat applied to soften the water blocking to allow removal of the fibre tube in manageable lengths. A hot air gun stripping tool is then used to remove the elastomer matrix material from around the fibres. If not done carefully, this can create 'fibre windows', sections where the coating of the fibre is removed to expose the cladding and/or breakage of the fibre.

As mentioned in tight buffer designs, the kingwire and/or the buffer package is restrained (clamped) at the joint to prevent movement of the package out of, or into the joint. For loose tube cable, the fibres can either be restrained or drawn out of the excess pre-wrap into the joint. For fibre restraint additional preparation time is needed to ensure consistent bond to the fibre coating over sufficient length of all the fibres in the bundle to prevent slippage, unrestrained sufficient fibre must be wrapped to allow for movement above the threshold tension above the cables overfill limit. This is normally a LW cable consideration for recovery from very deep water.

4. BIGGER, FASTER, STRONGER

The evolution drivers for the established cable design are, now more than ever, the 'cost per bit' over the working life of the system, including ongoing maintenance repair, upgrade and eventual recovery on decommission.

This has many aspects but in relation to jointing this can have issues of legacy management. Some cable manufacturers have gone out of business during the typical 25 year service life, meaning spare cable is not easily obtained and an alternative supplier must be commissioned to provide new cable stock. For the 'Universal Joint' this is easily managed, as many cross cable qualifications have already been completed. UJ and UQJ, manage some 40 different cable types, from 20 current and historic cable suppliers, across the range of cable type variations: LW, LWS, LWP, SAL, SA, SAM, SAH, DAL, DA, DAM, DAH, RA, etc. New qualification, interconnections can be completed. Which, where possible will be generic, non-system specific to the design limits of the cables so that once qualified, other customers can benefit from the interconnection. Occasionally these are system specific, if some feature of the cable or qualification is non-transferable to other systems.

There have also been examples where systems have been retired from service, recovered from their original route and re-deployed, [8] hence access to an ongoing industry supported jointing platform is essential for the provisioning of spares.

To reduce the cost per bit' repeatered cables have been steadily moving towards a higher fibre count as repeater technology develops. The trend from the first repeaters has been 4, 8, 12 fibre pairs and now 16 (32 fibres) and potentially 24 (48 fibres). This progression has resulted in larger and heavier repeaters, unless countered [9], this could change the requirements on the LW cable, especially in deep water. The tensile strength of the LW core and its operating tension (NTTS, NOTS)[10] are also following the trend and increasing. A longer repeater generally means a greater leverage of tension (magnification factor) as the rigid repeater body crests the sheave of the cable vessel (maximum loads to be seen on recovery operation) Hence increased repeater weight with increased length means there is, for the same maximum design depth, a requirement to review and increase the cable's design NTTS and this potentially narrows the gap between the maximum working tension of the cable (NTTS) nearer to the Ultimate Tensile Strength (UTS) of the cable. For the joint, this means attention to change of material properties (such as a harder wire as the cost driver is to maintain or reduce metal content) and ensuring the safety factor between NTTS and UTS is not compromised by the joint termination. Similarly, the size and grade of the armouring wires needs to be followed for an effective and safe termination.

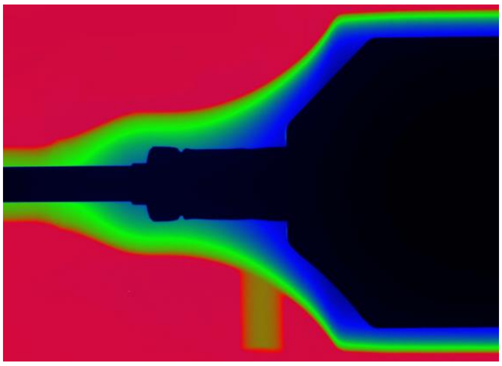

Image 4: Coloured contouring of wall thickness of an X-rayed moulded joint

As the number of fibres has increased, so has the power requirement for the repeater regeneration/amplification and so the maximum High Voltage rating of transoceanic systems has steadily increased from 10, 12 to 15kV. It is anticipated that these may increase again to 20kV and possibly beyond. For jointing, using current moulding methods this should not lead to any change in design but additional, requalification for lifetime testing would be needed.

5. WINDING IT UP

The effective area of the fibres used has also increased as fibre selection moves from within the G652 [11] (8.6 to 9.5 μm Mode Field Diameter at 1310nm) grouping to, for example, G654 [12] criteria. These 80 μm^2 to 150 μm^2 effective area (9.5 to 15 μm mode field diameter at 1550nm) ultra-low loss fibres have a larger radius at which significant macro bend wrapping loss is induced. This may be exacerbated for systems operating in wavelength to C+L wavelengths.

For G.652 type fibres reference to G.657 [13] illustrates the increase in macro bend loss per turn around various mandrel diameters for 1550nm and 1625nm. A very simple extrapolation of the charts indicates, for purposes of illustration only, the loss diminishing for radii above approximately 17.5 for 1550nm and 25mm for 1625nm for G.652. In jointing, there is normally a need to stow (wrap)[14] enough fibre to allow reach to the splicing equipment, an excess for an anticipated maximum number of splicing attempts and, if required, some movement of the fibre within a loose tube design if the fibres are not restrained within the joint. This normally represents approximately 2 to 3 metres of fibre loosely wrapped, elliptically within a fibre trackway, the minor diameter which is typically greater than 60mm, for four to ten turns. The fibres are not tightly wrapped against the central bend limiter mandrel (mandrel). For reference G654 measures macro bending limits of 100 turns around a Ø60mm mandrel when measured at 1625nm (L Band) to be less than 0.5dB for 654.A, B, C, 0.1dB for G654.E and 2.0dB for G654.D, it is not specified for 1550nm. For comparison G.652 B & D macro-bend limit is <0.1db at 1625nm for 100 turns around a Ø60mm mandrel.

Depending on acceptable power budget limits for jointing operations, some 654.D and E fibre and other groups under the L band may influence the minimum bend radius of the joint and could require a shift to a larger jointing cavity. This may also make the overall joint shell larger. This in part is also dependant on the number of fibres to be wrapped. This point needs consideration when selecting fibres in system design or allowance made for short fibre lengths wrapped in joints.

For fibre splicing it is often important to fully understand the details of the fibre manufacturer and fibre type above its grading with the G.652, 653, etc. classification (i.e. Corning EX1000, EX2000 & EX3000 are all grouped under G654 but with different characteristics and subcategories: C. B & D respectively[15]). This allows for optimisation of the splicing parameters to minimise splicing loss and maintain tensile strength and system life reliability. In order to allow cabling of Ultra Low loss, large core fibres, there may be some careful selection of the fibre core with its outer coating to reduce micro-bending in order to preserve the low loss attributes of the fibre core and keeping within the system requirements of loss/km. The coupling of coatings with fibre type may have implication for the effective clamping of restrained fibres and so the fibre core and outer coating may need to be known for effective splicing and restraint.

6. Cu -> Al

The conductor used for powering repeater cable has, for time immemorial, been copper and is often varied to change the resistance per km to suit the system application. At the 2019 PTC annual conference, Alcatel in conjunction with Facebook challenged this status Quo, and announced the use of aluminium into their long-haul telecoms cable portfolio to reduce cost and increase material. Already widely used in the power cable market, the implication will be that the cross-sectional area of aluminium for the same resistance per km will be slightly larger than copper. This could have some consideration for ensuring electrical continuity through the joint at the termination and in cable preparation tooling.

7. KNOWLEDGE IS POWER

There is also a general transfer of experience and knowledge from ‘Telecommunications’ to the offshore renewables energy sector market where the optic fibre cable, used for data transmission, is bundled between the power cores of the power cables. Here, the lessons of planned maintenance (repair) scenarios and the benefits of group maintenance agreements are being seen For example the financial benefits of minimising a total repair time from fault to reinstatement are readily recognised. Often a telecoms fibre optic joint is used within the larger power joint due to its proved track record and availability of jointing piece parts, tolling and trained jointers. In a power joint repair, there is no requirement to take any significant tensile load, but there is still the need to provide a compact joint housing that replicates and continues the functions of the cable elements and the fibre count is often high (48 fibres). The need for earthing of the cable is paramount to negate any effects of induced voltage from its close proximity to the power cable.

Indeed, there have been suggestions that the ideal fibre optic cable would have no metallic element at all. In such an application, without an effective hydrogen barrier the reliance on hydrogen scavenging gels may be pushed to the limit or the saturation level of hydrogen attenuation factored in over the system life. Jointing a non-metallic cable joint has been demonstrated as feasible with testing completed to 2,000m of a non-metallic joint housing using a variation of the optical power joint[16] presented at the 2016 SubOptic conference in Dubai. The suitability of hermetic (carbon coated fibres) fibres in a non-conducting cable has not been stated, nor the consequences for wrapping and re-instatement, or not, of the hydrogen barrier with this type of fibre. Where power cables are laid in close parallel proximity to telecommunications cables a small induced current from the power cable has been measured. For other unpowered, unrepeated cables, this could have some safety concerns should the telecommunications cable need to be repaired. To negate this, the Protection Grounding technology (PGU) developed for the repair of branched repeatered cables has been modified for lower voltage alarms within a PGULite set of procedures.

8. IT IS NOT THE END

Jointing solutions for optical fibre cables continue to evolve and take advantage of the synergies and challenges of the growing fibre count and the expanding Power market.

9. REFERENCES

[1] A Krotoski, *Hidden Histories of the information age TAT-1*, www.bbc.co.uk/sounds/play/b04m3bcc

[2] S Ash et al ‘*From Elektron to ‘e’ Commerce ISBN0953907805*

[3] E.K. Kordahi et al *Innovative Jointing & Stable Technology*, SubOptic 2007

[4] J Chesnoy *Undersea Fiber Communications Systems* ISBN9780128042694
[5] C Beech D*igital Xray & assessment Developments for subsea Cable Jointing* SubOptic 2013
[6] C Beech *What Next for the Universal Joint* SubOptic 2007
[7] R Stix et al, *The Global Challenges of Comprehensive Undersea Jointing* SubOptic 2016
[8] R Merett, R Laude *Re-use and re-routing of Retiring Systems* SubOptic 2007
[9] P Frost et al, *How Composite Materials Could Make Light Work of Submarine System Construction* SubOptic 2019
[10] ITU-T G.976 *test Methods applicable to Optical Fibre Submarine cable Systems*
[11] ITU-T G.652 *Characteristics of a single-mode optical fibre and cable*
[12] ITU-T G.654 *Characteristics of a cut-off shifted single-mode optical fibre and cable*
[13] ITU-T G.657 *Characteristics of a bending-loss insensitive single-mode optical fibre & cable*
[14] F Palacios et al *Ultra-Large Effective Area Fibre Performances in High Fibre Count Cable and Joint – A New technology Challenge* SubOptic 2016
[15] Corning® Vascade® Optical Fiber Product Information www.corning.com PI1445_3.17.pdf
[16] C Beech *New Subsea Optical Fibre Junction Box for Reduced Tensile Load Applications* SubOptic2016

