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Steel Tube Umbilicals (STUs) -

Key Issues for Deep Water Dynamic Applications

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Key Issues for Deep Water Dynamic Applications

By Darren Gallagher, Frank Grealish, MCS

Introduction

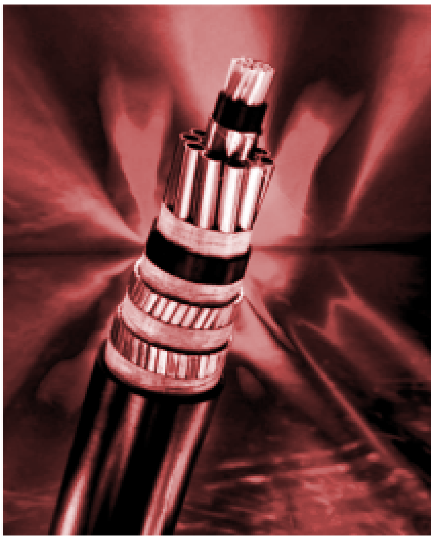

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Fig. 1 Typical STU Cross Section

A key component in the wet tree based development of deep water fields is the umbilical. Failure of the umbilical can result in partial or total loss of production, with resulting severe economic consequences. In many recent deep water projects, steel tubes for control and injection lines have become the preferred solution over traditional thermoplastic hose based designs. This is due to enhanced response times and prevention of permeation of fluids (particularly methanol) from the tube. In general, the preferred material for the steel tubes is super duplex stainless steel. The typical size for the steel tubes is between ½-inch and 1-inch, though some designs are proposed which incorporate a large core tube (e.g. 2-3 inches), which is used for gas lift or methanol injection.

When selecting an STU design there are a number of key issues to be considered. These include material selection and qualification, fabrication procedures, cross-section analysis, design and lay-up, riser configuration selection, installation procedures, risk strategies, dynamic analysis, fatigue life assessment, accumulated plastic strain (APS) and low cycle-high strain plastic loading or low cycle fatigue (LCF).

STU Systems

The free hanging catenary has been the preferred dynamic umbilical riser configuration for many of the deep water TLP and spar developments, due to cost effectiveness and ease of installation. However, for recent projects offshore West Africa and Brazil employing FPSO solutions, dynamic umbilicals must be designed to withstand comparatively large heave motions. This can produce large compressive loads and instability at the touchdown point in addition to significant fatigue damage. As a consequence STU designs are being proposed which include additional weight elements such as steel rods or steel armour wires in either lazy wave or lazy-S configurations in an attempt to counteract this problem. Figure 2 shows a STU in a Lazy-S configuration, where the STU is passed over a subsea arch, which forms part of a riser, tower assembly.

STU and Super Duplex Tubes Suppliers

There are four main suppliers of STUs, namely Nexans, Kvaerner Oil Products (KOP), DUCO and Oceaneering Multiflex (OMUK). Each supplier has different manufacturing techniques and their STU cross section designs will also differ. KOP use PVC profiles to keep the steel tubes separated and the steel tubes have a relatively small helical lay angle, the lay angle being the angle at which the steel tube is wound onto the STU. OMUKs products have tensile armouring and the steel tubes have larger helical lay angles. DUCO and Nexans have similar products in that the steel tubes have a larger lay angle and the cross section designs are very compact. This compact design leads to tube-to-tube interaction. Oversheathing is used on the steel tubes to prevent wear. KOP and OMUK do not require oversheathing however since there is no tube-to-tube interaction. There is a benefit to this as one less pass in the manufacturing process is required hence reducing manufacturing related APS and LCF.

Sandvik produce most of the super duplex tubing used in STUs. Other super duplex tube manufacturers are Sumitomo and DMV. Differences between tube manufacturers should also be considered when selecting a STU design.

Key Issues in Selecting an STU

There are a number of key issues to be considered when selecting an STU for a particular application.

Qualification of the manufacturing process for the steel tubes is critical. Sigma phase is an intermetallic phase which can occur during steel tube fabrication and which reduces the super duplex's corrosion resistance and toughness. The steel tube supplier should have sigma phase control measures in place so as to detect if the sigma phase of the super duplex steel is above the allowable value. Eddy current tests and microscopic examinations are among the tests performed by the suppliers as sigma phase control measures.

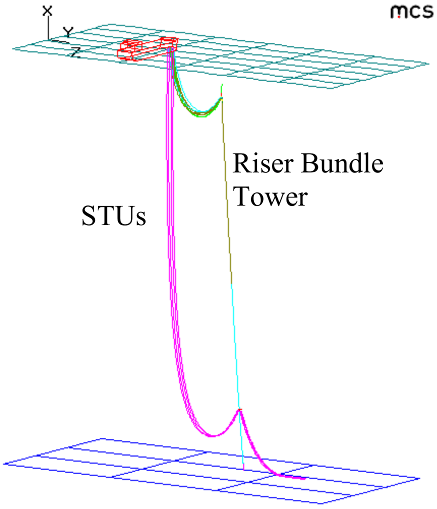

Fig. 2 Lazy-S STU Configuration

Analysing the manufacturing process is very important in STU selection. Consideration should be given to which supplier produces the steel tubes and what welding procedures they use. During manufacture the STU is reeled a number of times onto different carrousels as the multi component cross section is assembled. This procedure can cause the larger steel tubes to plastically deform and this can significantly effect the performance of the steel tubes, particularly in terms of fatigue.

Optimisation of the STU cross section design is required. The advantages of using armouring and weight components should be investigated. Armouring will reduce the stresses experienced in the steel tubes while including weight members means that a required diameter to weight ratio can be achieved.

The validation and qualification of fatigue S-N data is critical in the design process. Factors that impact on the S-N curve qualification include tube size, welding process, number of weld passes, weld versus parent material performance, effect of mean stress and effect of LCF seen in the manufacturing process. Global fatigue analyses of the STUs which are based on tension and bending of the individual tubes, may give acceptable fatigue results. However, including the effects of friction within the STU due to tube-to-tube interactions and tube mean stresses can significantly reduce these fatigue lives. VIV fatigue analysis of an STU is also critical and again should include friction and mean stress effects. The overall structural damping in the STU will have a significant impact on the VIV response characteristics.

An STU should be designed for a number of contingency scenarios during installation. These scenarios include retrieval and reinstallation as well as suspension of the installation procedure, both of which can add to the plastic strain experienced in the tube. Selecting the installation procedure, vertical lay system or overboarding chute, is also a critical design issue.

As well as achieving von Mises stress and fatigue life criterion the integrity of the steel tubes must be considered. All possible failure modes, such as buckle propagation, pipe collapse and pressure containment should be analysed.

Low Cycle – High Strain During Manufacture and Installation

During the manufacture and installation of an STU the steel tubes are subject to the curvatures of the manufacturing bobbins, the STU helical radius, the transport reels and the installation chute as demonstrated in Figure 3. These curvatures induce elastic and plastic strain within the steel tubes. The key issues to be considered when analysing the manufacture and installation of the STUs are accumulated plastic strain (APS) and low cycle fatigue (LCF) and the calculations associated with both of these phenomena are based upon the axial and bending strains experienced.

Accumulated plastic strain (APS) is defined as “the sum of plastic strain increments, irrespective of sign and direction”. The APS level in an STU is calculated by summing all plastic strain increments experienced in the manufacturing and installation procedures of a particular STU. Hence, when calculating the APS of an STU an accurate knowledge of the manufacturing and installation procedures for the particular STU is required.

The APS must remain within a certain limit to avoid unstable fracture or plastic collapse for a given tube material and weld procedure. There is some uncertainty between the different STU manufacturers as to what is an acceptable level of APS. The selection of a limiting APS level is critical and must be established and agreed upon by suppliers and contractors. If installation has to be suspended due to weather the steel tubes within the STU can quickly reach unacceptable levels of APS at the installation chute. Therefore it is important that the section of the STU in contact with the installation chute is varied by intermittently letting out additional STU when installation is suspended thus avoiding localised high levels of APS. A sufficiently large chute radius should be chosen so as to minimise the levels of plastic deformation experienced during installation.

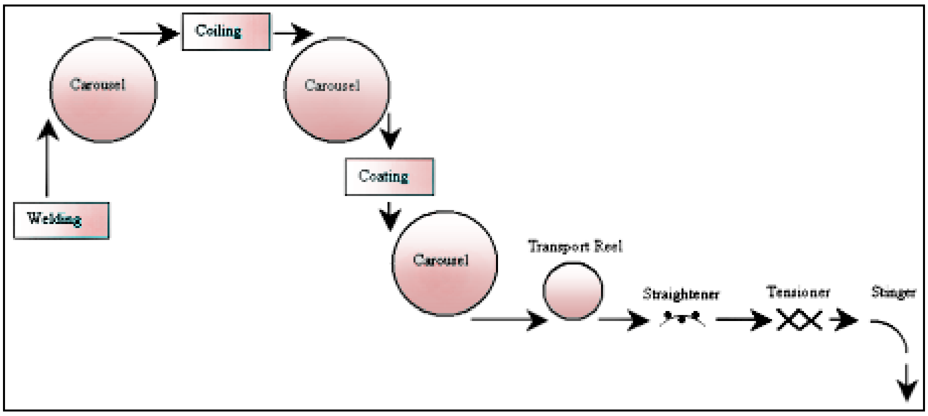

Fig. 3 Schematic of Manufacturing and Installation Process

LCF damage is calculated using a strain-based approach. A schematic of a strain-life fatigue curve (ε-N curve) is shown in Figure 4 on a log-log scale, where 2Nf is the number of reversals to failure. The total strain amplitude has an elastic and plastic strain component. At a given life, Nf, the total strain is the sum of the elastic and plastic strains.

For accurate LCF damage calculations a qualified ε-N curve must be specified for the steel tube material. Allowable levels of LCF damage must also be decided upon.

Recent analyses of STUs have shown that both LCF and APS are critical in the design of an STU for a deepwater application.

In-Place Fatigue Friction and Mean Stress Effects

In dynamic STU applications, friction stresses occur in the STU due to the different tubes within the STU interacting with each other. Traditional in-place fatigue analyses techniques calculate the STU in-place fatigue damage based on the axial and bending stresses which occur in the steel tubes due to the dynamic motions of the STU. These stresses can then be used to calculate the friction stresses within the STU which are then added to the original axial and bending stresses and a new fatigue life can be calculated using these increased values. Including friction stresses can significantly reduce the calculated fatigue life of an STU.

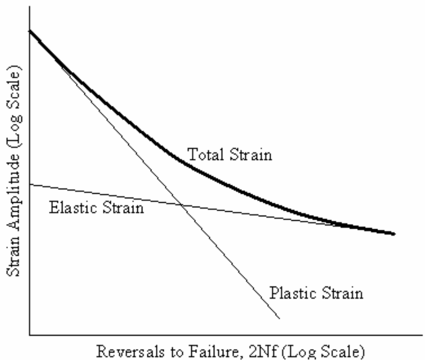

Fig. 4 ε-N for curve Low Cycle Fatigue

STU friction stresses are largely dependent on the lay-up of the STUs particularly the steel tube layer radius, the distance from the centre of the umbilical to the neutral axis of the steel tube, and lay-angle. Analyses have shown that the smaller the lay angle and the larger the layer radius the longer the fatigue life. Careful consideration has to be given to how many tubes are acting on each other and at what angle are the contact forces acting relative to the contact surfaces, all of which make the accurate modelling of friction within the STU a complicated procedure.

Including mean stress effects also reduces the STU fatigue lives. In a specimen where there is an alternating stress the fatigue life is usually calculated based on the amplitude of the alternating stress. In an STU where large tensions exist, i.e. at the hang-off region, it can be argued that the fatigue life of a steel tube is not solely based on the tube stress amplitude but is also a function of the mean stress of the tube. Mean stress effects can be accounted for using a Goodman-Soderberg approach.

Recent analyses have shown that including the effect of both friction and mean stresses can in some cases increase the fatigue damage by up to 140-fold.

Conclusions

STUs represent a complex construction which is subject to significant loads in all stages from initial fabrication through installation to in-place operation. Detailed evaluations are required in the design and verification process, so as to ensure that qualified designs are achieved, particularly for deep water dynamic applications.

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Galway

Galway Technology Park,
Parkmore, Galway,
Ireland

T +353 (0) 91 781010
F +353 (0) 91 781020
E Galway@mcs.com

Aberdeen

Exploration House,
Bridge of Don, Aberdeen
AB23 88GX, Scotland

T +44 (0) 1224 708877
F +44 (0) 1224 708899
E Aberdeen@mcs.com

Houston

16350 Park Ten Place,
Suite 202, Houston,
Texas 77084, USA

T +1 281 646 1071
F +1 281 646 1382
E Houston@mcs.com

www.mcs.com