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Riser Integrity Monitoring for Offshore Fields

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Abstract

All the structural elements which make up offshore fields are by nature submitted to harsh environmental constraints: seabed to surface liaisons, export lines, mooring systems and all oil & gas operators must keep pace with the technological challenges posed by deeper water depths and increasingly severe weather environments. The top priority is threefold:

- ✓ to mitigate human and technical risks
- ✓ to protect valuable assets and to limit damages
- ✓ to promote safety and sustainable development

A real time surveillance of structural integrity is an absolute necessity in order to keep under control the overall good condition of the field infrastructure. It really allows to improve asset management and to intervene in case of emergency.

The primary objective is to monitor and predict the behavior of the bottom to surface liaison in order to anticipate excessive wear and fatigue as well as overstress, hence the development of original solutions: Asset Integrity is a key trend to optimize lifecycle of fields.

This paper focuses on Riser Integrity Monitoring, and most particularly on reliable and cutting edge technological solutions used to measure the static and dynamic loads imposed to the various kind of Risers to anticipate structural degradation but also to detect structural ruptures. The first is known as a Vibrating Wire Gauge (VWG) for the monitoring of various types of rigid risers. The second technology uses the Acoustic Emission to monitor the armour wires rupture in flexible pipes.

Introduction

Among technologies that are shaping the future of subsea activities, Asset Integrity is a key trend to optimize lifecycle of fields. While Asset Integrity concerns all parts which composed a subsea infrastructure, a particular focus is made on bottom to surface liaisons which are exposed to extreme operational and environmental constraints while they are generally designed to last over the life of a field which is typically 20 years, but can be as long as 40 years in a demanding environment.

Many solutions are proposed, but few of them fully address the following two main concerns.

The first concern is the operability of the monitoring solution. This means limiting installation constraints and costs, avoiding any impact on the monitored structure design, and not generating any additional risks.

Second concern is reliability. Indeed, the idea of a system dedicated to monitor the integrity of structures, designed for decades but failing after few years of service, is not acceptable.

These two main considerations are drivers to define a technological strategy based on non-intrusive solutions and indirect measuring systems (thereby presenting zero risk to the integrity and functionality of the primary component that are monitored) and which demonstrate high reliability (thereby considerably reducing requirements for intervention or replacement over the life of a field).

This strategic axis requires to understand physical phenomena which have to be observed and to find the best way to measure them, preserving both the structure and the sensor.

The first part of this paper focuses on the vibrating wire gauge technology used for the Hybrid Risers and Riser Towers load monitoring system. Its long term accuracy, stability and reliability are presented. In the second part of this paper the monitoring of flexible riser using acoustic emission technology is presented together with the experimental testing program performed and the associated results.

Vibrating Wire Gauge Technology for Rigid Riser Monitoring System

A strain gauge is a device which is fixed firmly to a structure and follows the deformation of that structure throughout its entire service life as it experiences loading and deformation in all directions, i.e. the strain gauge is stretched exactly as the structure is stretched by tensile or other loading. These strains or “stretching” of the gauge are infinitesimal in magnitude, but can be calibrated using the known structural and material properties of the equipment to calculate time varying loads in the structure itself. However, the most optimal solution is to calibrate the sensors directly on the monitored structure (in order to obtain the true transfer function). In this manner, strain gauges can be used in groups to “measure” and record the tensile, compressive or bending moment loading in a structure. Several types of strain gauge are commonly used, but they can generally be grouped in basic categories, namely Mechanical, Optical, Electrical Resistance and Vibrating Wire gauges (VWG). VWG are particularly recognised for their superior performance in geotechnical and structural applications where long term reliability, minimum zero drift (maximum long term signal stability) and signal independence from surrounding electrical noise are all key performance requirements. Technip uses VWG technology for riser monitoring as it is the most robust for subsea applications.

The operating principle of VWG relies on the guitar string principle whereby the natural frequency of a fixed length of wire changes as the wire is stretched (or relaxed). The wire is fixed at both ends to the parent structure which is being monitored (Fig. 1). It is pre-tensioned to a specified level and free to vibrate at its natural frequency along its length. An electromagnetic device permits to set the vibration of the wire at the natural frequency of the wire which changes as the wire and parent structure are subjected to micro-displacements (oscillating frequencies around the kHz). The frequency signal can then be transmitted and displayed by a portable readout or monitored by a data acquisition system. This technology is applicable to rigid riser (no interface between the instrumented structure and the sensors).

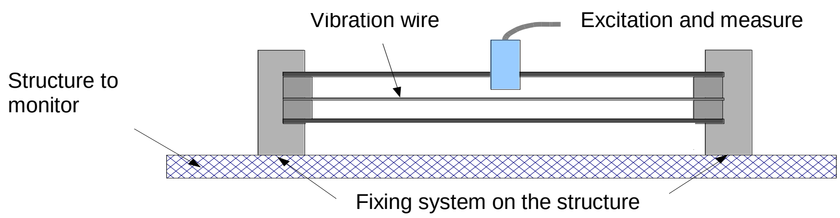

Figure 1: Schematization of a vibrating wire gauge

The fundamental vibration frequency of a wire subjected to elongation is given by the following equation:

$$f = \frac{1}{2l}\sqrt{\frac{E\varepsilon}{\rho}} \qquad (1)$$

Where f is the frequency (Hz), l the wire length (m), E the Young Modulus (Pa) of the wire, ρ the density (kg/m^3) and ϵ the wire strain (m/m). So, the strain can be calculated based on frequency measures :

$$\varepsilon = 4l^2 \frac{\rho}{E} f^2 \qquad (2)$$

Long term accuracy and stability

The long term accuracy and stability of any gauge can be sensitive to many factors such fluctuating temperature and pressure, impact, vibration and drift. “Drift” is the phenomenon whereby every cycle of deformation and load induces an infinitesimal error to the zero setting of the gauges and this error cumulates at each cycle, thereby causing the zero level to “drift” over time. Temperature and pressure variations can be corrected by measuring these parameters independently and auto-correcting the signal to allow for their variations.

A first solution is to use a second gauge (passive gauge or indicator gauge) positioned adjacent to the principal gauges, but placed on the monitored structure at a location which is not subjected to any stress. The measurement given by this gauge is substracted from the values given by the monitoring gauges.

A second solution is to compensate the measured data by knowing the effect of temperature on the VWG.

For example, if the structure monitored and the VWG fixed on it do not have the same coefficient of thermal expansion, a correction like the formula below must be realized by the acquisition system:

$$\varepsilon_{corrected} = \varepsilon_{measured} - (\alpha_s-\alpha_j).(T_1-T_0) \quad (3)$$

where α_s is the linear expansion factor of the testing structure (µm/m/°C), α_j is the linear expansion factor of the VWG (µm/m/°C), T_1 the temperature during acquisition and T_0 the initial temperature (°C).

Technip performed extensive tests within its facilities to check the VWG thermal and pressure stability.

The experimental bench was isolated in a climatic chamber (SAPRATIN -35°C to 150°C), with a temperature regulation of +/- 1°C. Between each temperature change, a 10 hour plateau of constant temperature is enforced to reach temperature uniformity between sensor and support.The results show a maximum error of linearity of 0.016% of sensor full scale (Fig. 2).

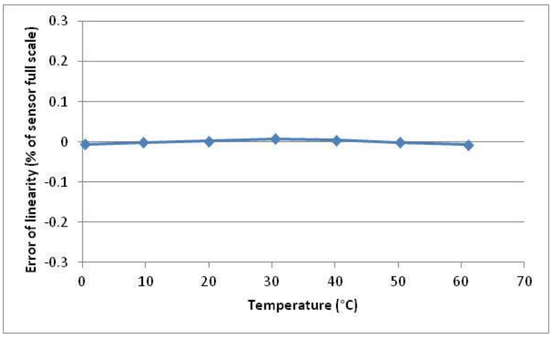

Figure 2: Error of linearity after thermal tests

To check the stability under pressure of VWG, an isothermal hyperbaric chamber (0 to 60 bars) was used (see fig. 3). A thick steel plate was used as a rigid support for the sensor. The temperature didn't change during the pressure increase due to the characteristics of the chamber.

Figure 3: Isothermal hyperbaric chamber

The results show a maximum error of linearity of 0,018% of sensor full scale (Fig. 4).

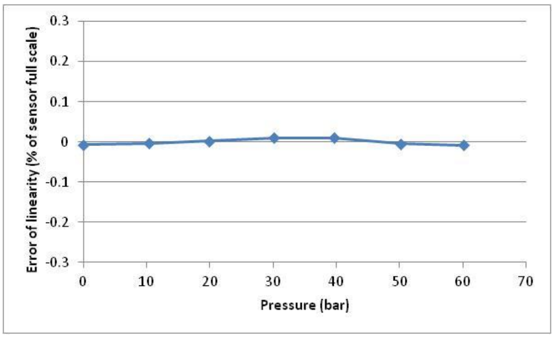

Figure 4: Error of linearity after pressure tests

[1] shows readings during one year from a VWG which have been corrected for temperature and pressure variations confirming that the transducer remains within 0.5% of the full scale accuracy of the sensor.

Stress in the vibrating wire is limited to 10% of its tensile strength such that relaxation and fatigue processes are insignificant.

Figure 5 shows the response of the VWG to mechanical testing used to characterise the strain sensitivity and repeatability of the gauge. The linearity of the response following numerous iterations with different sensors over short and long time periods confirms the repeatability of the results and behaviour.

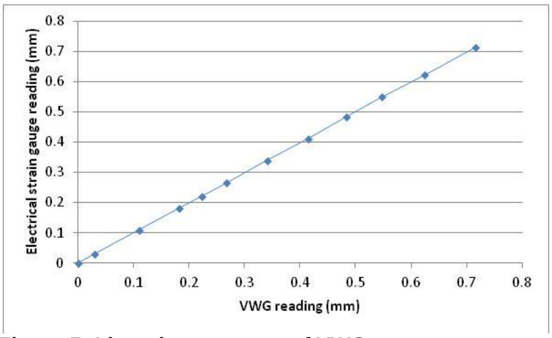

Figure 5: Linearity response of VWG

Qualification tests were performed in laboratory on several vibrating wire sensors to check their temporal stability, the absence of hysteresis and the non-evolution of data during on/off cycles of the excitation systems (conditionners).

The conditioners used to process the data were developed in-house. The acquisition frequency of this product is 4 Hz, with decimation filter. With this, it is possible to measure phenomena such as vortex induced vibration.

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RTMS "Riser Tension Monitoring System"

The Riser Tension Monitoring System (RTMS- fig. 6) consists of at least a group of 3 vibrating strings (2 groups of 3 vibrating strings for the case of nominal/redundant measurements). Each string in the pair is diametrically opposite to the other string. The vibrating strings can be fixed to the riser in different ways (welded supports, assembled supports and ROVable system).

These load sensors are used to measure: tensile load, axial tension, bending moment, direction of the bending moment.

It is also combined with:

- A subsea unit (including the conditioners which excite the sensors) collects measurements to send to the surface unit via cables and ATEX surface function boxes. It can be equipped with wireless connections (acoustic modem) and batteries. It is designed to be deployed by ROV or divers.
- A topside or surface unit with acquisition, processing and visualisation software linked to the platform's supervision system.

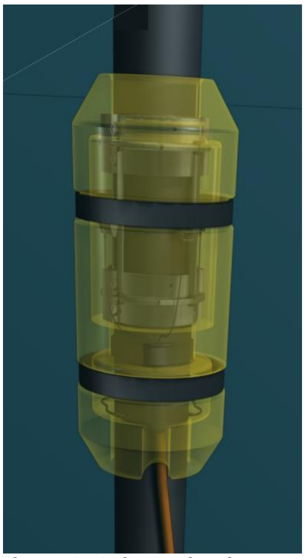

Figure 6: Cybernetix Riser Tension Monitoring System

The technology of the vibrating wire is also used for monitoring mooring leg loads.

Long term reliability of Vibrating wire technology

Vibrating wire strain gauge is a long-term measurement technology. A scientific publication presents results concerning the stability and reliability of vibrating wire sensors that have continuously vibrated for 27 years [2]. The figure 7 below presents the stability of measurement from the vibrating sensor during 27 years.

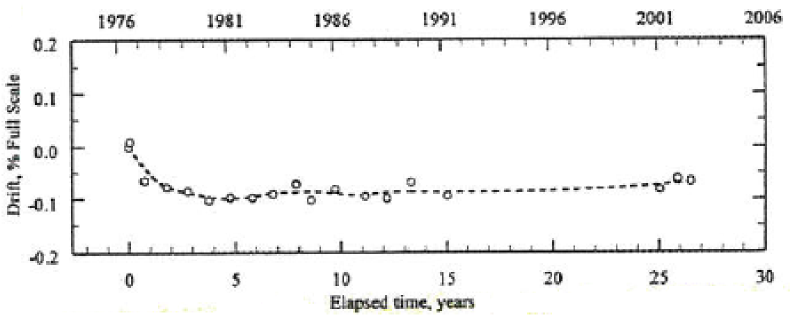

Figure 7: stability of VWG measurement during 27 years [2]

Feedbacks from the use of vibrating wire sensors by EDF are also presented [3]. On 3346 vibrating wire strain gauges used for the control of dams, 5% became unusable during the first year (due to installation defaults), and after 30 years, only 18% of them were out of service.

An other publication [4] also shows the high durability of the VWG by claiming that 80% of the 263 vibrating wire sensors implanted on a dam in Kariba in 1958 were still operational in 2012.

Table 1 [1] shows the variation of the calibration factor after 5 years and the maximum non linearity error in percentage of full scale. The variation of the calibration factor for the 3 sensors is between 0.09% and 0.11% which is within the specified criteria.

Table 1: Recalibration after five years in field [1]

	Sensor	Original Calibration	Calibration 5 years later
CF	A	0.11999	0.11987
	B	0.06616	0.06610
	C	0.07122	0.07114
%F.S.	A	0.15	0.17
	B	0.08	0.04
	C	0.03	0.06

Where CF is the calibration factor in psi/linear unit and %F.S. the maximum error of non-linearity

Vibrating Wire Advantages

As previously highlighted when selecting technology and instruments, the most important criteria is reliability and stability over the lifespan of the structure. Regarding strain measurements in offshore environment, vibrating wire technology comes with the following advantages:

- Resistance against corrosion: The sensor frame is made of stainless steel and sealed to protect the vibrating wire against moisture and/or water ingress.
- Ease of use with long cable: Frequency output is easier to transmit over long cables.
- Long-Term Stability: The long-term stability of vibrating wire sensors is well proven, far exceeding the best of bonded foil type strain gages and equaling or exceeding that of the unbounded (Carlson) type sensors [5].
- No electronic in the sensor itself: the conditioner is external to the sensor and distant from the measurement zone.
- Indirect measurements of loads.
- Marinized sensor in order to be resistant to water penetration (barriers of gaskets).

Flexible Riser Integrity Monitoring System using Acoustic Emission Technology

This section describes the implementation of Acoustic Emission technology for continuous monitoring of tensile armour rupture in flexible risers. This technology is based on the use of non-intrusive clamps installed on new or in-service flexible risers. The fundamental principle of Acoustic Emission is that any damage mechanism has an “acoustic signature” which is unique.

Acoustic emission (AE) is the phenomenon of energy release in the form of elastic transitory waves resulting from internal local micro-displacements within a stressed material. The acoustic waves are detected by sensors coupled on the external sheath of a flexible pipe. These signals, detected by the AE Clamp developed by Technip are conditioned and processed in order to identify and locate an “event” in the flexible riser. When an armour wire rupture occurs inside the riser, it generates its own unique AE signature which can be correlated to a pre-populated Technip AE database. This database relies on a 15-year experience acquired over many flexible risers full scale tests as well as laboratory tests, thus providing a high diagnostic reliability.

Some previous publications can be referenced, dealing with the topic of the development of flexible riser monitoring using acoustic emission [6, 7, 8, 9].

Establishement of armour wire rupture acoustic emission signature database

First, the typical signature of wire rupture needed to be identified: static and fatigue mechanical test on armour wires similar to those used in a flexible riser (taken from armour rolls before flexible pipe manufacturing) have been instrumented with AE sensors. During these tests, a focus was made on rupture phenomenon. Thanks to this monitoring, typical and characteristic signals of rupture were registered (Fig. 8) and identified with the following parameters: peak amplitude, RMS, time, count number, energy, rise time, centroïde frequency, cascade parameters. These parameters can be identified by the names “Conventional Parameters”, “Statistic Parameters [10]” or “Frequency Parameters” according to [11, 12].

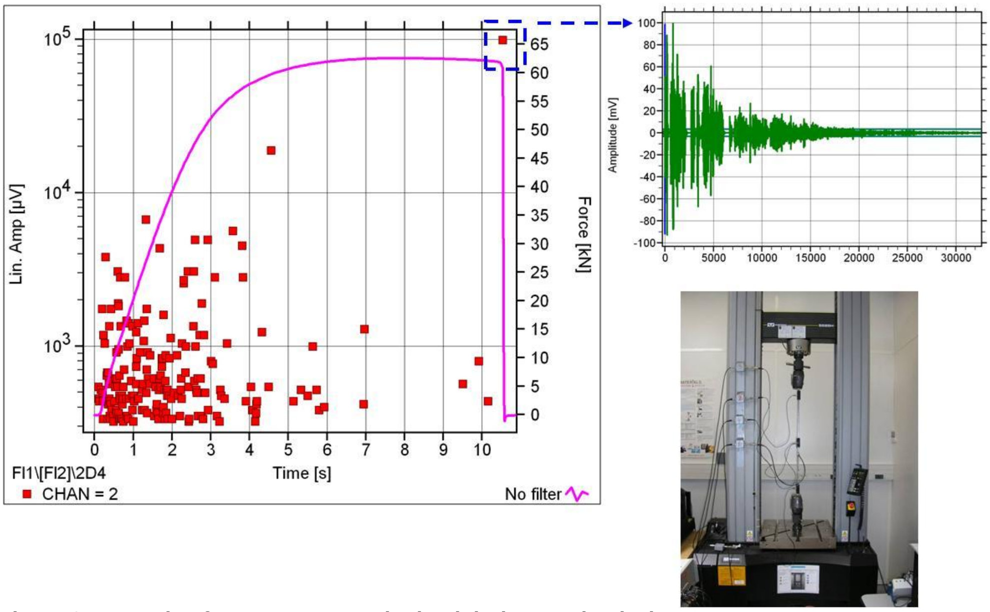

Figure 8: Example of AE parameters obtained during mechanical test

The different layers of the flexible have some effects on the AE signal wave propagation and waveform: During laboratory tests, transfer functions of the different configurations of flexibles were established and measurement of propagation was carried out on the flexible pipe length as well as the end-fittings part to check the accuracy of this monitoring method (Fig. 9).

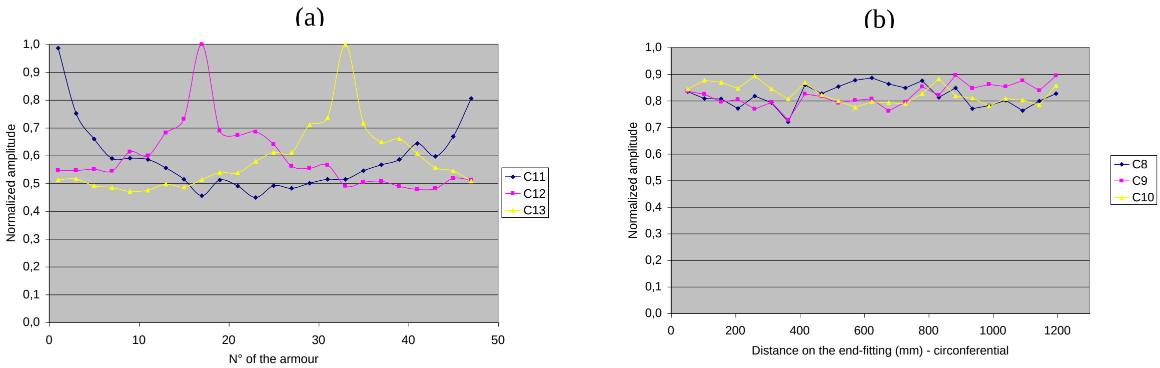

Figure 9: Propagation measurement on armours (a) and end-fittings (b)

The results show a stable profile on the end-fitting (homogeneous structure) and an irregular profile on the armour (complex propagation ways). All these results were implemented in the monitoring software to optimize the armour wire rupture detection.

After laboratory tests on armours, fatigue, static and burst tests on full scale flexible pipes were monitored on specific test benches. Different conditions of tests were applied: tensile/tensile tests, tensile/flexure tests, tensile/flexure combined with pressure test. The objectives were to test the AE clamp on periods of several months and to detect and register the acoustic signal of armour ruptures in conditions similar to those sustained in service (inter-layer displacement and friction, but without background noise of offshore platform).

The figure 10 below shows two significant events (EV4 and EV5) detected in a time of 6 seconds during a damage phase of a fatigue tensile/flexure test. With the optimized monitoring software (with a system of alarm when an armour breakage is suspected), these two events triggered the detection alarm, they were then dissociated (two different events at two different locations) and associated to armour ruptures.

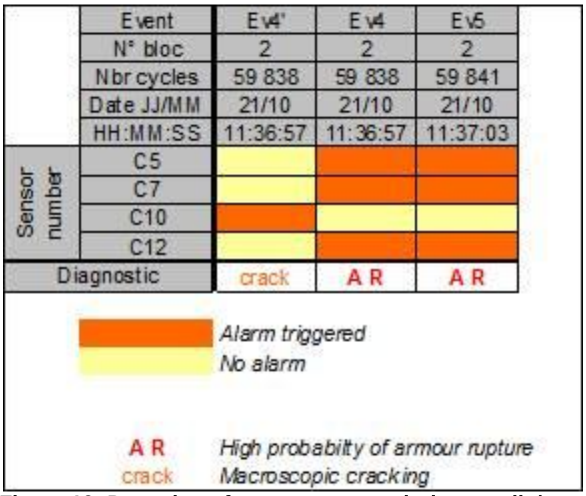

Figure 10: Detection of armour rupture during tensile/tensile tests

Figure 11 shows the correlation between the AE diagnostic and the dissection of the specimen. A diagram also shows the location in terms of armours and so the accuracy of the AE algorithms location (one AE alarm corresponds to a specific area on the structure).

	Dissection		Monitoring by Acoustic Emission	
	Broken Armour	Cracked Armour	Probability of armour rupture	Macroscopic cracking
Defects found	12	2	12	3
Total number of found defects	14		15	

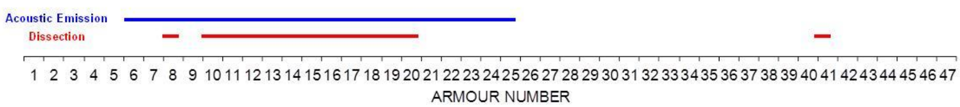

Figure 11: Correlation between dissection and AE monitoring. Location in terms of armours

To complete and implement the AE monitoring software, tests in riser environment were also carried out in order to measure the acoustic emission generated by the flow, the surrounding noise so as to be able to separate the acoustic signal of the armour rupture (tests performed on an Offshore Platform). The environment noise is identifiable with specific characteristics (acoustic emission parameters, for example waveform, Fast Fourrier Transform…) different from those measured during armour rupture.

In order to evaluate the influence of the background noise on the reliability of the armour breakage alarm, the recorded data on the offshore platform were processed with the algorithm used in the fatigue lab tests. During 35 hours of measurement, a total of 124 509 hits were recorded. Among these hits, zero (0) reached the criteria of the armour breakage algorithm (fig. 12). These results show a good robustness of the algorithm against the noise environment.

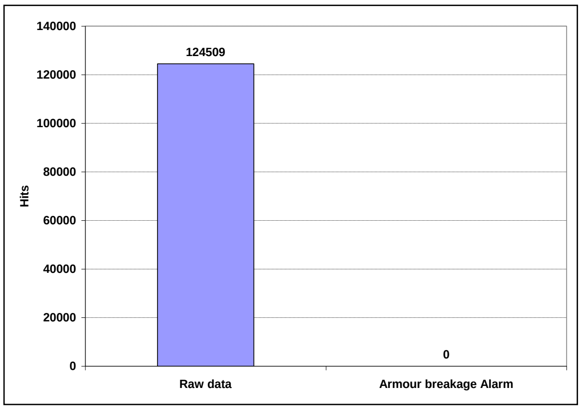

Figure 12. Statistics of the hits during offshore measurements.

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15-year experience acquired over several R&D programms and all the testing previously presented performed on full-scale flexible risers have provided a highly reliable armour rupture monitoring system packaged in a clamp adapted to flexible riser. The figure 13 shows the principle of the overall AE clamp flexible riser monitoring system.

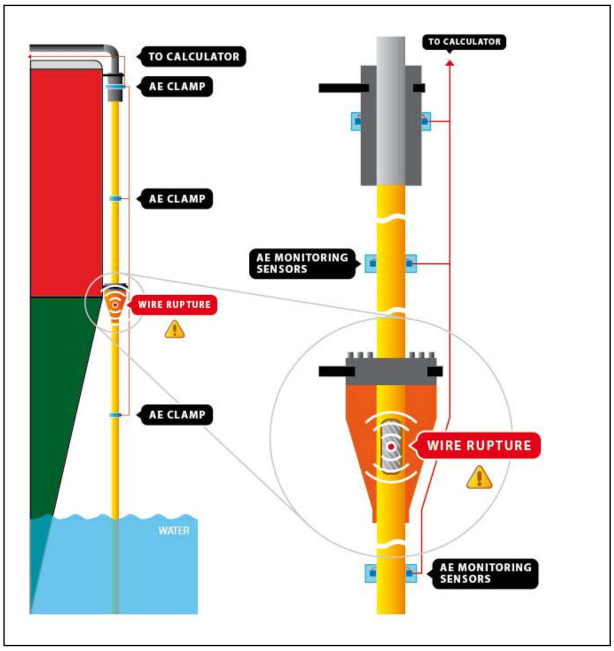

Figure 13: Monitoring of riser by acoustic emission using specific AE clamp

The resulting monitoring solution consists in a real-time armour wire rupture detection evaluation by an expert algorithm, which sends an alarm message to the control room of the platform and to any other destination of preference (Fig. 14).

This solution is an expert system capable to trigger this alarm autonomously and to communicate it to an onshore engineering or analysis centre where it can be immediately assessed by Technip experts. It is an ATEX system compatible with the offshore environment. It is compatible with different monitoring systems of offshore companies (with possibility to adapt output signals to the needs of operators).

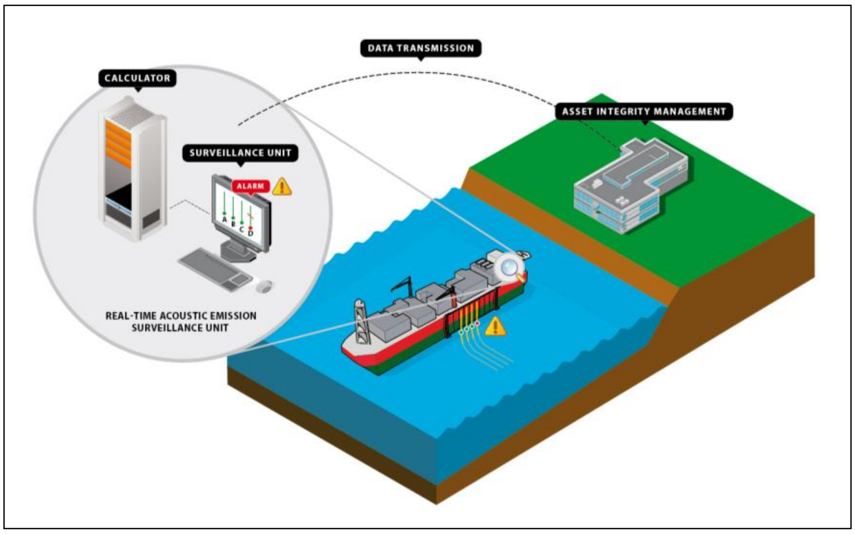

Figure 14: AE surveillance unit

The full qualification of the AE monitoring clamp has now reached its final stage with offshore prototype currently being deployed and tested. The first industrial version will be produced in 2014.

Conclusion

In offshore fields and in particular on the bottom to surface liaisons, the knowledge of the asset integrity is a top priority to keep under control the good conditions of the infrastructure. The solutions presented in this article allow to measure static and dynamic loads imposed on various types of rigid risers and to detect structural rupture in flexible risers.

The technology of vibrating wire sensors used for monitoring rigid riser loads is recognized for its long term accuracy, reliability, and stability. Its resistance to water penetration, resistance against corrosion, and ease of use with long cable show the benefit of such technology in the hostile subsea.
Tests performed to validate internal temperature stability and behavior under pressure of sensor of this type were used to determine the rules to compensate for these effects on measured values and increase the reliability of the systems and results.

For the monitoring of armour rupture in flexible risers by acoustic emission, new approaches have been developed to fully integrate the flexible structure in the signal analysis. This real-time monitoring combined with the database obtained during extensive laboratory tests as well as full scale tests allows to reliably detect and locate armour wire ruptures.
The acoustic emission clamp system can autonomously generate alarms based on the level of probability damage while communicating it in local on the platform or remotely to an onshore enginerering / analysis center. The system includes an interface compatible with softwares customers, with also simple user interfaces.

The above mentioned reliable and cutting edge technologies draw benefits from measuring knowledge and experiences gained over more than 10 years in order to take into account the operational constraints and the customer's requirements to provide technical and innovating solutions. This experience helped to improve the robustness and reliability of our clamps for the subsea hostile environment.

These products have been developed as part of the activities of Technip Asset Integrity Management (AIM) Services. Asset Integrity Management is an emerging focus area for the subsea industry which incorporates technology development for monitoring products, as well as integrated service models for harvesting, processing and reporting of integrity data relating to subsea assets.
Now the associated monitoring products and services are developped and optimized to contribute significantly to increase the efficiency of rigid and flexible riser integrity management for a safe, durable and cost-efficient production in ever more harsh, challenging and demanding environment.

Nomenclature

AE = Acoustic Emission
VWG = Vibrating Wire Gage

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