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Riser Integrity Management for Deepwater Developments

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Abstract

BP's deepwater floating production facilities in the Gulf of Mexico include one tension-leg platform, three spar platforms, and one semi-submersible. In addition, two semi-submersible platforms are in the final stages of construction and commissioning. This total inventory of seven floating platforms in water depths ranging from 3000 to 7000 ft includes a wide range of riser types. In some cases the risers set industry records for design parameter combinations such as depth and diameter. They are thus of particular interest from an integrity management viewpoint.

BP is in the process of implementing a risk-based integrity management program for risers operating on these deepwater producing facilities. This paper explains the process to be applied, drawing on experience from similar processes used for pipeline systems and topside equipment. Some of the risers have instrumentation and monitoring systems which will be of value for long term integrity management, as well as day to day operations monitoring.

Examples of actions arising from an integrity management process are discussed along with challenges in implementation. The paper concludes with a summary of advantages for existing operations and the potential benefit for future riser system design arising from this program.

Introduction

BP's inventory of floating production systems in the deepwater Gulf of Mexico (GoM) has grown rapidly in the past few years. The water depths in which these facilities are installed have increased, with facilities spanning depths of 3000 to 7000ft. The risers on such facilities, like the moorings, are the structural elements of the system most obviously affected by the increased water depth. The fact the risers span the entire water column also exposes them to the strong current environment of the GoM, with the potential for significant fatigue loading from loop currents and eddies through phenomena such as vortex-induced-vibration (VIV). These phenomena are taken into account by the facility designer, and large safety factors are applied. However, the technology stretch required, the uncertainty of some metocean phenomena and the resulting response of the risers have prompted the use of monitoring systems and instrumentation to be incorporated into the integrity management (IM) program.

The floating platforms include a range of riser types: top-tensioned vertical risers (for production, injection, drilling or completion-workover); catenary risers (for production, injection or export); and flexible pipe risers (for production or injection). The IM process is applied to all such riser types..

While IM in its broadest application applies to all stages of design, construction, operation and decommissioning, the riser IM process described here is that being applied in the operations phase.

Integrity Management

Background

The BP Group IM standard applies to all wholly owned and operated BP operations, projects and assets worldwide. The purpose of the standard is to identify and manage risks that could impact the health and safety of personnel or the environment; or be a cause of facility downtime. Features of a typical IM process are shown in Figure 1.

The IM standard includes requirements for accountability, competency, management of change, hazard evaluation, procedures, protective systems, emergency response, as well as, facilities and process integrity. Generally for offshore operations, facility and process integrity refers to all components from the well bore to the export transport. BP's operating facilities in the Deepwater GoM are in the process of developing an overall integrity management program that includes the subea equipment, risers, floating hulls, moorings, topside piping and pipelines.

Some components are highly regulated in the GoM and therefore the IM programs have prescriptive elements. For example a hull and mooring system must be inspected when in production, a minimum of every 2½ years. For other components, such as topside vessels and piping, the requirements are less prescriptive and therefore operators have some flexibility in developing the IM plans and inspection frequencies.

For vessels and piping, BP has used a risk based inspection (RBI) approach as the basis for the IM program, typically following API RP 580 (ref 1). The ultimate goal of RBI is to develop a cost-effective inspection and maintenance program that provides assurance of acceptable mechanical integrity and reliability.

In the UKCS, BP has applied a risk-based approach for integrity management of flexible pipe risers on its floating production systems (ref 2) and on its pipelines. There is also increasing industry interest in riser integrity management, with new initiatives to develop guidance on best practice (ref 3, 4).

Building on the experience from the above, a process has been developed for use on deepwater risers and flowlines for BP's GoM operations, and is described below.

Integrity Management Process

Risk Based Inspection (RBI) assessment techniques are used to perform a risk assessment of the risers, including flowlines where these form part of a continuous production system. This risk assessment leads to focused and detailed inspection and monitoring, targeted at the most critical threats to system integrity.

RBI assessments provide the means by which business, safety and environmental consequences of a loss of integrity of a riser or flowline are regularly assessed against modes of failure and the probability of such a failure mode occurring. This determines the overall risk to integrity, expressed as the Criticality for the system under consideration.

Figure 2 shows the steps taken in the RBI process and how it forms part of the overall IM process.

Key steps in the Criticality and Risk Assessment Process are:

- Define the limits or boundaries of the system being considered
- Identify the primary failure mechanisms and consequences of failure
- Section the riser/flowline system according to applicable threats (similar threats, design, operation etc)
- Assess information from design, operations, inspection and monitoring to determine probability.

Failure Modes / Threats

For dynamic deepwater riser & flowline systems, some unique threats apply. Although internal threats (erosion, corrosion) are very similar to those found in other environments, external threats are revised to take account of the dynamic nature of the components in question, as well as the effects of the deepwater environment. The external threats include the following: impacts, external corrosion, structural overstress, structural fatigue, structural wear, material degradation, mechanical degradation, and fire/explosion (applied to above-water sections of the system).

Consequence

The consequence of loss of integrity in a riser or flowline system is estimated by assessing impact on health and safety, environment and operations/business in turn. A consequence level is assigned according to defined criteria.

Probability

The probability of a loss of integrity is a measure of the probability of a particular damage mechanism or threat occurring, leading to equipment failure. The probability is assessed by ranking of a component's susceptibility to degradation via a particular failure mode.

Criticality

The consequence and probability levels are then combined in a Boston Square matrix and expressed as a Criticality. The format used is shown in Figure 3.

Confidence

The Confidence Rating is a measure of the predictability of the failure threat and of the reliability of the inspection or monitoring techniques in detecting and controlling the threat. The confidence rating is based on factors such as: how well the failure mode is understood; whether a previous inspection has been performed and the results; whether pertinent operating parameters are measured or monitoring relevant to the particular failure mode. An Interval Inspection Factor is calculated by combining the Criticality with the Confidence rating; this is used to arrive at an inspection interval as a percentage of the service/design life.

Peer Review

The peer review is a key step in developing an IM plan. The review confirms the accuracy of assumptions and data used in assessing the criticality and inspection intervals, and considers any operational changes which could affect the assessment. A fundamental aspect of the Peer Review is the involvement of personnel from Operations and Project & Engineering teams, in order to access the best and most recent knowledge of the systems.

The Peer Review is performed by a combined team including project and operations personnel, and riser and IM specialists from BP and support contractors:

- Specialists are jointly responsible for reviewing design data and inspection history, assessing corrosion threats and mitigation methods, assessing business and safety criticality, assessing confidence grades and remnant life.
- Personnel from integrity, operations, maintenance, HSE and other disciplines participate as necessary to ensure that the criticalities can be fully evaluated.

Integrity Management Plan

The main deliverable, following the Peer review, is an Integrity Management Plan (IMP). This holds a record of the Risk Assessment and maintains an auditable trail of the RBI assessment process. It collates the recommended inspection and monitoring activities as applied to key threats. This is a live document and is intended to be revised annually based on changes to operating parameters and the results of on-going inspections and monitoring.

Annual Review and Reporting
This completes the Integrity Management cycle shown in Figure 2, by feedback of operational results via the Annual Integrity Review. This involves an update of the Risk Assessment and IMP to incorporate the past year's activities and results from inspection, monitoring and operations. This is summarised in an annual health statement for each riser system.

Offshore Monitoring

Instrumentation to measure structural response of a riser provides key information for integrity management. The type of monitoring varies by riser type. Some examples are discussed below.

Riser Instrumentation
BP's deepwater facilities include many steel catenary risers (SCR); these include large diameter (24-inch) export lines and some high pressure / high temperature production lines. Three deepwater SCRs are extensively instrumented with on-line structural integrity monitoring systems to track the calculated fatigue damage at crtical locations on the riser, specifically the touch down and the hang-off locations. A typical arrangement is shown in Figure 4. These systems also monitor flex-joint rotations to allow flex-joint integrity to be assessed in conjuction with internal fluid temperature and pressure data. The structural monitoring systems mainly comprise of directly bonded strain gauge stations either of the conventional electrical foil type or fiber optic type.

Direct strain measurements are generally not used on the top tensioned riser strings in spars. Installation of these risers through the hull of a spar does not easily permit instrumentation to be pre-installed on the riser string without risk of damage during riser installation. Instead, ROV-installed motion monitoring devices have been deployed along the riser string after the risers have been installed to record data off-line. At the riser and spar interface, top tensioned riser systems supported by aircan buoyancy modules have instrumentation to monitor riser tension and stroke, and on some risers surface wellhead bending moment and aircan guide lateral loads.

Fibre optic strain measurement mats have been installed on selective risers. The strain mat has embedded fiber optic strain gauges within a composite mat structure and measures the change in curvature of the riser joint. On drilling and workover risers the monitoring system may be hardwired into the BOP control system to allow strain data to be communicated to the vessel and fatigue damage rates and accumulation processed in real-time.

Floating System Instrumentation
Instrumentation of relevance to riser IM is also mounted on the floating systems. Acoustic Doppler current profile (ADCP) meters are installed on all of BP's GoM platforms giving the current speed and directional profile over the water column. Other platform instrumentation may include: wave radars to measure wave height; six degree- of-freedom motion monitoring systems; and differential global positioning systems (DGPS) for platform position. These enable measurement of both wave frequency and slow drift motion. The environmental and vessel measurements provide additional data to qualify high response events indicated by the riser structural monitoring systems and can be subsequently used to calibrate riser design models to measured response.

Data handling from on-line systems
On-line monitoring systems provide easily accessible data to operations personnel who require key parameters to be monitored on a regular basis such as internal fluid temperature and pressure, environmental data and vessel position. In addition, today's capacity to transfer large quanties of measured data between remote servers using the internet allows this data to be uploaded on a daily basis for regular assessment against design thresholds and to give a general overview of the system performance.

However, riser response data can be difficult to interpret even with direct strain measurements at discrete locations on the riser. The as-installed configuration and complex riser structural response behavior from phenomena such as VIV require that riser measurements are used with finite element models to fully capture the global behavior of the system and determine critically loaded regions that cannot be directly instrumented. A large quantity of data is produced from an on-line riser monitoring system comprising of instruments to measure vessel, environmental and riser response and can generate in the order of 10-15 GB of data a day. Transmission of this data from offshore is through either satellite link or fiber optic lines where it can be stored at a central server on shore.

Data handling from off-line systems and Operating records
Off-line riser monitoring systems require periodic offshore retrieval of instruments and/or download of data. Compared with on-line systems, off-line monitoring has advantages and disadvantages. An advantage of the off-line approach on permanently installed risers is the ability to more easily repair or replace instruments. The installation of the monitoring devices outside of critical path riser installation activities is also possible. However, off-line systems do not give real-time information and are better suited to more long-term monitoring objectives such as those related to fatigue integrity and design model calibration.

Riser operating records are also relevant for integrity management. Information on fluid contents, as-built stack up, operating tensions, temperatures and pressures are essential for the effective interpretation of measured riser structural response data. This is especially important if measured riser motions are being processed to determine riser stresses and fatigue. Other operating records from chemical injection, corrosion coupons and process fluid composistion are required to check internal threats to the system.

A key requirement for successful data interpretation is the efficient management of data from these various sources such that all the necessary information is available in a timely manner so that on-shore data analysis can commence.

Using the data – KPIs

The measured vessel, environmental and riser response are periodically condensed into key performance indicators (KPIs) in order to demonstrate that loads on the riser and the riser response itself are within design thresholds. This approach is used for long-term fatigue assessment by compiling annual current speed occurrence, annual wave height occurrence and spot fatigue rates at strain gage locations. In addition, short term extreme events like hurricanes can be assessed by extracting maximum magnitides of vessel motions, current speed, wave height, riser strain and flex-joint rotation.

Amber and red limits set for these KPIs define the urgency of action required if a parameter exceeds one of these limits. For example, amber limits may be set for vessel offset and significant wave height that result in riser stresses reaching 0.8 of yield, and may trigger an early inspection focused on a particular system threat. Red limits may be set for events where riser normal operating limits have been exceeded, e.g. for unusually large storms where extreme responses have been observed.

Example KPIs for an SCR are given in Figures 5 and 6 for flex-joint temperature and pressure respectively. KPIs may also be set for internal threats such as excessive process fluid temperature, pressure, CO_2 and water cut.

Integrity Management Actions

The development of an IMP and its annual review in light of operating and inspection information can lead to a range of actions. Examples of actions which can apply to deepwater risers are:

i) A focus on corrosion protection. Some subsea lines may not have subsea corrosion monitoring, and intelligent pigging may be difficult. This requires review of data on actual operating conditions (temperature, pressure) and fluid properties (CO_2, H_2S, water cut, SRBs, sand, corrosion inhibitor) to permit a review of likely corrosion rates.
ii) External visual and CP surveys – to confirm satisfactory coating and anode performance. Unusually high anode wastage or protective coating damage has on occasion been observed, and typically require further investigation, monitoring or corrective action.
iii) A focus on components of known sensitivity to certain operating parameters, such as temperature for riser components containing elastomers. There have been some recent industry examples of flexjoint failure, requiring replacement. Visual inspections provide a valuable early indicator.
iv) Inspection of VIV suppression devices to confirm they are still in place. Missing suppression may need replacing. Excessive marine fouling will require removal, e.g. by ROV water-jetting. We have observed both outcomes and taken corrective action.
v) Adjustment of vessel mean position to distribute SCR fatigue damage by extending the effective riser touch-down zone.
vi) Annulus vacuum testing of the interstitial space in a flexible riser – to confirm no breach of the external sheath, which has the potential for corrosion-fatigue of the reinforcement wires.
vii) In extreme cases, monitoring of actual riser response may lead to system modification or design corrections by offshore retrofit. In recent years the industry has seen a number of such examples for top-tensioned riser systems in spars – to correct clearance and centralization problems.
viii) For removable risers such as for drilling and workover, the IMP and response measurements may enable planned joint rotation to prevent fatigue concentration.

The above actions included examples of where in-service non-conformances have been discovered. The value of inspection and monitoring in their identification and evaluation is clear. The results of such activity are then fed back via the IM process into subsequent reviews of system criticality and updated inspection and monitoring plans.

Challenges in Implementation

This paper has described the procedure for IM but the ease with which it can be implemented depends on a number of factors. For a new facility, it is best to perform the risk assessment and develop the IMP during the project design and construction phase – when the designer's input and information on construction-led design changes can be obtained directly and easily incorporated. For older facilities, the task may be more difficult.

In all cases the process runs more smoothly if the following points are addressed:
i) Design records, readily available.
ii) As-built records and survey information from the initial installation, readily available.
iii) Operating records and process information, readily available.
iv) Personnel with the appropriate knowledge and experience to participate in the risk assessment and IMP development. Offshore staff can provide valuable insight.
v) Survey information from underwater inspections. The surveys can be focused on areas of particular concern with information from the IMP.
vi) Reliable monitoring systems. Often for deepwater risers, the instrument technology is a development in itself. Reliability may be compromised with new technology, and repair may be difficult.
vii) Data handling capacity. The ability to process, condense and interpret a large quantity of measured riser structural response data that exhibits complex behavior requires a significant initial effort to understand the limitations of the monitoring system, identify the cause of high response events and automate the process with appropriate filters and screens.
viii) Interfaces. Riser systems may have interfaces with many other disciplines: drilling and wells, subsea, topsides process,

hull systems, export pipeline. Care must be taken to ensure that the IM for components at the interfaces is owned by at least one group.

ix) Interdependencies. Riser system integrity is complex, and the loss of integrity in one section of a riser and flowline system may well impact the integrity of another area, e.g. loss of strakes from the top of the riser will increase fatigue damage in the touch down section.

Conclusions

A formal process for integrity management of a large and varied portfolio of deepwater risers has been described. The process is based on established practice used elsewhere and adapted for deepwater risers.

The IM process and the actions deriving from it lead to reduced risk, increased uptime and opportunities for improved design of future platforms, through outcomes such as the following:

- Definition of a program of inspection and monitoring.
- Increased likelihood of early discovery of any critical issues through targeted, risk-based inspection.
- Response measurement, confirming actual system response in severe metocean events.
- Use of response data to calibrate and improve the riser design process on future systems.

Acknowledgements

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Figures

Figure 1: Integrity Management Process

Nomenclature

ADCP	acoustic Doppler current profiler
BOP	blow-out-preventer
DGPS	differential global positioning system
GB	gigabyte
GoM	Gulf of Mexico
IM	integrity management
IMP	integrity management plan
KPI	key performance indicator
RBI	risk-based inspection
ROV	remotely operated vehicle
SCR	steel catenary riser
SRB	sulphate reducing bateria
UKCS	United Kingdom Continental Shelf
VIV	vortex-induced vibration

References

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2) OTC14064 "Managing the Integrity of Flexible Pipe Field Systems: Industry Guidelines and their Application to BP's West of Shetland Assets", Picksley, JW et al. 6th- 9th May 2002.

3) MCS SCRIM JIP – Steel Catenary Riser Integrity Management. Joint Industry Project. Commenced 2004.

4) DnV RP F-206. Riser Integrity Management. Draft 0.

Figure 2: Riser & Flowline IM Process

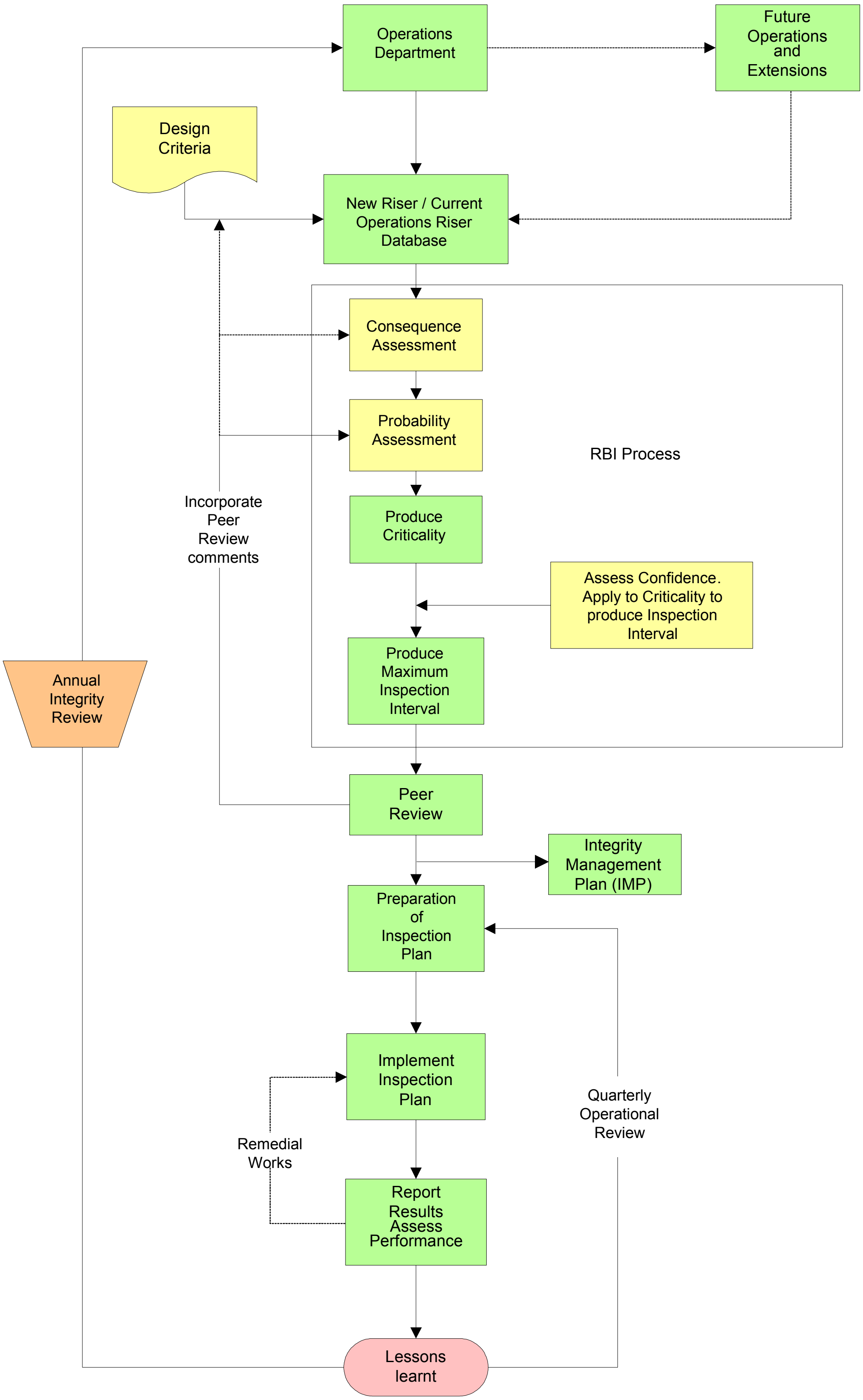

Figure 3: Criticality Matrix

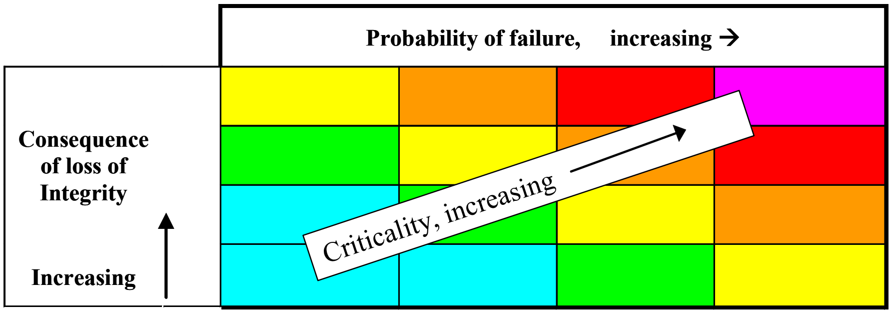

Figure 4: Riser Monitoring on an SCR

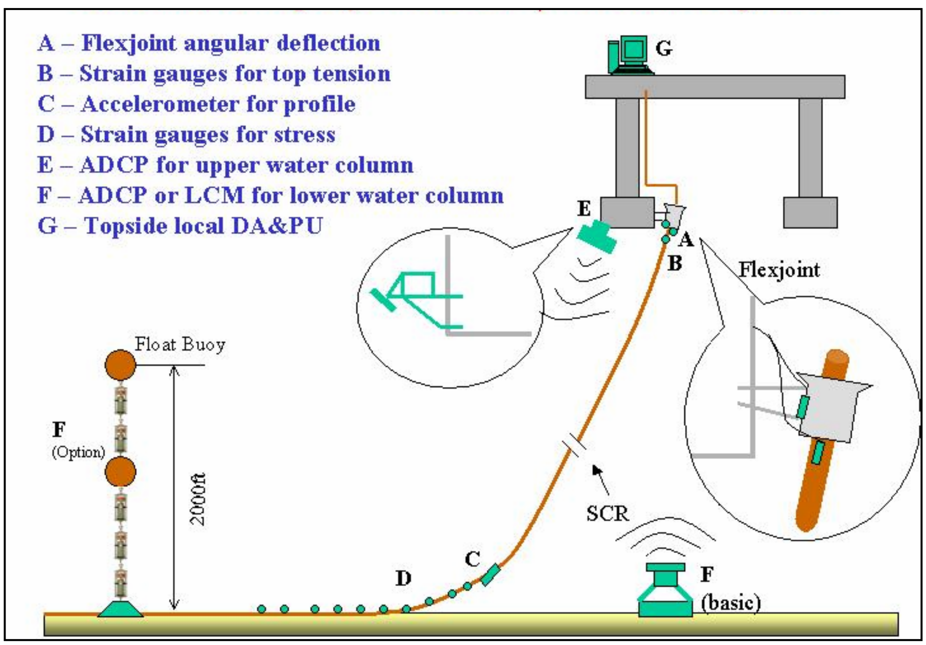

Figure 5: KPI for Riser temperature

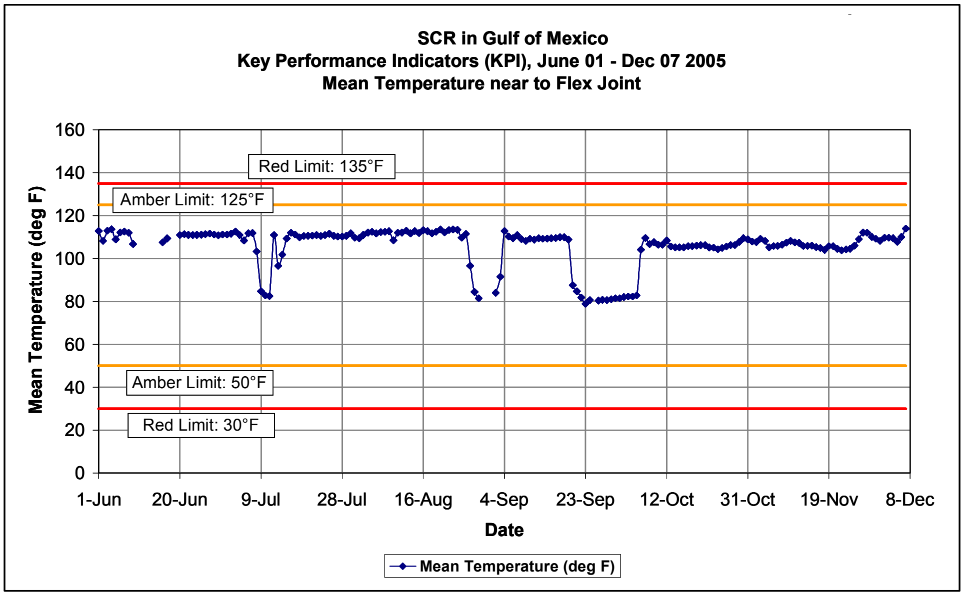

Figure 6: KPI for Riser Pressure Cycles