Mooring lines – Integrity Management
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Abstract
The Floating Product Systems (FPS) fleet has increased steadily over the last 2 decades and is expected to continue to grow with developments in the world’s deepwater basins. One of the issues with floating installation is that they are moored to the seabed and therefore subject to the forces exerted during stormy conditions. These exceptional forces can cause deterioration of the mooring lines and in some circumstances result in mooring line breaks. This has obvious implications for personnel, asset and environmental safety.

Being able to monitor the tension experienced by the mooring lines enables FPS operational personnel to proactively take the required measures to maintain mooring line integrity. This paper details the design and installation of a new mooring line monitoring system allowing such mooring integrity monitoring on a Floating Production Storage Offloading (FPSO) vessel operating offshore Brazil.

Introduction
SBM supplied the FPSO for deployment in Brazilian waters. The vessel is moored using 9 mooring lines bundled in 3 sets of 3 lines at 120° from each other around the turret chaintable.

A new mooring line monitoring system was specified for this project. The purpose of the system was not only to notify the operations team in the event of a line break but also to record the line tension experienced over time so the mooring line performance could be evaluated. The project specification also called for the system to have the capability to identify progressive degradation such as line creep and quantify the need for line retensioning.

Technical Challenges
Many of the systems used in the past to monitor anchor leg load have offered limited reliability. Load cells need to be mounted in the load path which leads to difficulties when maintaining them. Shear pins require modifications to the chain which can affect chain integrity. Strain gauges have issues with water leakage. Moreover the cables required to connect these sensors to the data collection system could become trapped and severed during a subsea intervention like riser pull-in.

When developing the system reliability and robustness was foremost in the specification. Therefore Pulse decided to use inclinometers in the development of the system. An inclinometer was attached to the chain hawse of each leg. This meant that the sensor was outside the load path, enabling straightforward maintenance of the sensor. Furthermore, each anchor leg chain can be pulled through the chain hawse to re-tension the chain without affecting the operation of the inclinometer.

In order to avoid the problems associated with cables connecting the system, Pulse used acoustic communication to relay the measured data to the control room. Figure 1 shows the type of acoustic receiver used.

Figure 1 – Example of acoustic receivers
Equipment
The main components of the MOORASSURE system are Pulse’s INTEGRIpod loggers. These loggers have proven themselves in various environments and deployment types around the world.

INTEGRIpods
On this deployment, 9 INTEGRIpod-AF loggers (pictured in Figure 2) were used to monitor each of the 9 mooring lines. Each INTEGRIpod contains a tri-axial inclination sensor with a battery pack which has an operational life of 5 years. The INTEGRIpods can communicate acoustically with each of the 3 acoustic receivers installed underneath the turret chaintable.

Figure 2 – The 9 INTEGRIpod – AF loggers at Pulse’s facility in the UK

The INTEGRIpods are mounted on to the chain hawse of each anchor leg using a robust metal holder. The holders (shown in figure 3) have a special coating which resists marine growth and allows easy removal of the logger during its operational lifetime.

Figure 3 – Logger holders ready for installation

Each of the 9 INTEGRIpod loggers can communicate with each of 3 acoustic receivers. Having 3 receivers ensures that communication can be achieved with the INTEGRIpods regardless of the turret orientation and position.

Acoustic Receivers
The 3 acoustic receivers are mounted on the chain table using holders (shown in Figure 4) similar to the ones used for the INTEGRIpods. The holders are coated in the same marine growth resistant paint and allow easy installation and removal of the receiver. The cables connecting the receivers to the control room are armoured plated and are routed through the Electro-Optical swivel.

The holder for the receivers and loggers were internally protected by a dummy PVC insert until final installation.
Software

MOORASSURE

The data from the receivers is sent to a standard PC in the control room running the MOORASSURE monitoring software. The software allows the control room operators to configure each of the data loggers through the acoustic receivers.

Each data logger stores the chainconnector angle data locally and this data is downloaded every 24 hours to the system PC in the control room. The angle data is converted into tensions using a software model of each of the mooring lines. The conversion of the angles to tension is completed using lookup tables developed during the installation of the system. The lookup tables take into account the as-built mooring line configuration and conditions. The software presents to the user a set of angle to tension curves for each mooring line over the vessel draft range, as shown in figure 5.

The software can be used to present historical tension and angle data which enables operations to make informed conclusions about how the mooring lines are performing.
The INTEGRIpods are also capable of reporting by exception and raising an alarm on the PC in the control room if the measured angle goes outside a certain range. The user can also get data on demand from the system, as shown in Figure 6.

**Figure 6 – On demand data**

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<th>Legs</th>
<th>ISA</th>
<th>Sensor</th>
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<th>Angle [°]</th>
<th>Vertical Distance (m)</th>
<th>Horizontal Distance (m)</th>
<th>Draft (m)</th>
<th>Tension (kN)</th>
<th>Changed Polyester Length (m)</th>
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**Polyester line creep**

An additional client requirement for the installation was the addition of a facility which enables polyester line creep to be evaluated with the software.

The process for evaluating the polyester creep is similar to that of the angle to tension conversion. The turret and relative anchor positions are taken into account. All parameters of the as-built configuration are entered into the software during installation. The software can calculate an angle excursion curve for a selected range of drafts and vessel offsets. This data is then compared with the current angle and position readings while taking into account inaccuracies due to positioning errors and installation inaccuracy using an iterative process. The process feeds the relative horizontal distance between the FPSO and the anchor, and the measured angle. The software then adjusts the length parameter of the mooring line model until the measured angle aligns with the experienced horizontal distance, thus determining the change in polyester length. Figure 7 shows the software interface which reports the angle excursion curve.

**Figure 7 – Angle excursion curve**

**Testing**

The system was rigorously tested in Pulse’s Woking workshop before deployment; Figure 8 shows the function test of the system. This ensured that offshore testing could be minimised when the system was deployed. The INTEGRIpods were pressure tested to 150 bar to ensure their integrity at the operational depth of 30m. The acoustic communications link between
the devices was tested in a local swimming pool.

**Figure 8 – System function testing**

**Deployment**
The system deployment was completed in 3 stages. As part of stage one the logger holders were installed at the shipyard in Singapore. The topside equipment and cabling was completed as part of stage 2. Stage 3 was completed offshore; this involved the diver installation of the loggers and the system commissioning. Figure 9 shows the loggers installed in their holders. The system has been operating since May 2009.

**Figure 9 – INTEGRIpod AF installed in holder on chain hawse**

**Conclusion**
The installed system allows the FPSO operating team to monitor the tension experienced by the mooring lines and thus make informed decisions about mooring line performance and integrity. The polyester creep assessment enables the operations team to determine the need for re-tensioning the mooring lines. The information gathered by the system aids integrity management of the operating vessel and can also be used in the future to improve the design of mooring systems.
A significant benefit of this system is its ease of maintainability as the sensors are not in the load path and have a 5 year battery life. To increase the ease of installation of the system Pulse has been working on a ROV deployable version.